Comparative Resource and Energy Yield Assessment Procedures (CREYAP) Pt. II
Mike Anderson (on behalf of Niels Mortensen DTU)
Acknowledgements

• The data pack used for the comparison was made available by Renewable Energy Systems Ltd. (RES); thanks to Mike Anderson and Euan George.
• The 60 sets of results were submitted by 56 organisations from 17 countries; thanks to all of the teams for making the comparison and this presentation possible!
History and Evolution of CREYAP

Comparison of Resource and Energy Yield Assessment Procedures

• Onshore
  – Part 2 (Dublin 2013): complex terrain many masts, operational data.
  – Part 3 To be designed.

• Offshore
  – Part 1 (Frankfurt 2013): Large wind farm and neighbour impact.
  – Part 2 In design but likely to include operational data.
Outline

• Purpose and participants

• Case study wind farm
  – Wind farm and turbine data
  – Wind-climatological inputs
  – Topographical inputs

• Comparisons of results & methods
  – The prediction process
  – Long-term wind climate
  – Wind farm energy yields
  – Comparison to observed AEP
  – Mast strategy and site results

• Summary and conclusions
Purpose and participants

CREYAP Pt. II
• 60 teams from 56 organisations in 17 countries submitted results!
  - consultancy (41)
  - developer (7)
  - R&D/university (5)
  - wind turbine manufacturer (3)
  - electricity generator/utility (2)
  - certification body (1)
  - service provider (1)

Reliable energy yield predictions are obtained when the bias and the uncertainty are both low.
Note, that the ‘true value’ is often measured – with some uncertainty...
What’s different compared to CREYAP Pt. I?

**General**
- Complete case study
- Operating wind farm
- Production data available (5y)

**Input data**
- Seven measurement locations
  - One reference, six auxiliary
- Two types of long-term data
  - Ground-based
  - MERRA reanalysis
- Roughness data for site
  - Wind farm site only
- Obstacle data for site

**Modelling**
- Air density correction needed
- Larger terrain effects
- Larger wake effects
These effects are all of order 10%
Case study wind farm

- 22 wind turbines (28.6 MW)
  - Rated power: 1.3 MW
  - Hub height: 47 m
  - Rotor diameter: 62 m
  - Spacing: irregular, 4-5 D between neighbouring WTG
  - Air density: 1.208 kg m$^{-3}$

- Primary site mast – M49
  - Wind speed @ 50 and 40 m
  - Std. deviation @ 50 and 40 m
  - Wind direction @ 48.5 m a.g.l.

- Six 50-m site assessment masts
  - Same levels as primary mast
Wind-climatological inputs – site measured data

M49 site data (5y)
- 2001-10 to 2006-09
- Recovery rate 94%
- Statistics:
  \[ U = 8.3\ \text{ms}^{-1} \]
  \[ P = 649\ \text{Wm}^{-2} \]
  \[ A = 9.4\ \text{ms}^{-1} \]
  \[ k = 2.05 \]
Wind-climatological inputs – reference data

**Ground-based**
- 5 years of hourly mean data
- 16+ years of monthly mean data
- 11-y historic wind data statistic

**MERRA reanalysis**
- 16+ years of hourly mean data
Comparisons of results and methods

1. LT wind @ 50 m (mast) = Measured wind ± [long-term adjustment]
   • comparison of long-term adjustment methods

2. LT wind @ 47 m (hub height) = LT wind @ 50 m + [wind profile effects]
   • comparison of vertical extrapolation methods

3. Gross AEP = Reference AEP ± [terrain effects]
   • comparison of flow models

4. Potential AEP = Gross AEP – [wake losses]
   • comparison of wake models

5. Net AEP ($P_{50}$) = Potential AEP – [technical losses]
   • comparison of technical losses estimates

6. Net AEP ($P_{90}$) = Net AEP ($P_{50}$) – 1.282 × [uncertainty estimate]
   • comparison of uncertainty estimates

7. Comparison to observed AEP – spread and bias
Long-term wind at the meteorological mast

LT wind @ 50 m = Measured wind ± [long-term correlation effect]
Long-term adjustment effect

Data points used = 57 (of 60)
B45, 53 and 58 report no results

Mean long-term effect = 0%
Standard deviation = 2.2%
Coefficient of variation = n/a
Range = −9 to 6.5%
(observed $U_{50}$ of 8.3 ms$^{-1}$ assumed)
Comparison of LT adjustment methods

![Comparison of LT adjustment methods diagram](image-url)
Long-term wind at hub height at the met. mast

LT wind @ 47 m (hub height) = LT wind @ 50 m + [profile effects]
Comparison of vertical extrapolation methods
Gross energy yield of wind farm

Gross AEP = Reference AEP ± [terrain effects]
Comparison of flow models

Topographic effect [%]

-20 -15 -10 -5 0 5

WDSP (30)  CFD (9)  WindSim (6)  Metodyn (3)  OpenWind (4)  Meso/NWP (4)  Misc. (3)  All models
Potential energy yield of wind farm

Potential AEP = Gross AEP − [wake losses]
Comparison of wake models

The diagram illustrates the comparison of wake models with different wind farm wake loss [%]. The models include WASP Park (16), WindPRO Park (8), WindFarmer EV (7), Jensen model (9), OpenWind (5), Ainslie EV (4), Misc. (6), and All models. The box plots show the distribution of the wake loss for each model, with the central line representing the median, the box boundaries showing the interquartile range, and the whiskers indicating the range of the data excluding outliers.
**Net energy yield of wind farm, $P_{50}$**

Net AEP (P50) = Potential AEP − [technical losses]

where [technical losses] = AEP $\times f_1 \times f_2 \times ... \times f_n$

and $f_1$, $f_2$, ..., $f_n$ are the individual loss factors.
• Overall availability given as 96.8% (first 4 columns)

• Electrical loss given as 1.2% (first column)
Net energy yield ($P_{50}$)

Data points used = 58 (of 60)

Mean net yield = **75.7 GWh**
Standard deviation = 4.4 GWh
Coefficient of variation = 5.8%
Range = 64 to 91 GWh
Net energy yield of wind farm, $P_{90}$

Net AEP (P90) = Net AEP (P50) − 1.282 × [uncertainty estimate]
Uncertainty estimates by type
Spread for different steps in the prediction process

- Measurements
- LT wind @ 50 m
- LT wind @ 47 m
- Gross yield
- Potential yield
- Net yield, P50
- Net yield, P90

Steps in the prediction process:

1. Measurements
2. LT wind @ 50 m
3. LT wind @ 47 m
4. Gross yield
5. Potential yield
6. Loss estimation
7. Uncertainty estimation
Comparison to observed AEP – spread and bias

Observed long-term energy yield based on 5 years of production data; corrected for windiness, as well as an overall plant availability of 96.8%. This produces an observed yield of \(76.25 \text{ GWh/year}\).
How do the predictions compare to the observed AEP?

Observed AEP = median of 58 results!
Mast strategy – impact on gross AEP

*What is the consequence of using a single mast (49) vs. multiple masts?*

- For all teams:
  - Single-mast predictions +2% higher than multiple mast do.
  - Single- and multiple-mast predictions are different!

*Try now with one model only to see if pattern persists.*

- Say, for WAsP teams only:
  - Single-mast predictions +2% higher than multiple mast do.
  - Single- and multiple-mast predictions are different!

*Rather clear signal, and significant.*
Mast strategy – impact on net AEP $P_{50}$

*Does mast strategy have an impact on the final estimate of the net AEP?*

- For all teams:
  - Single-mast predictions +1% higher than multiple mast do.
  - Single- and multiple-mast predictions are ‘not different’!
  - Multiple-mast prediction is closer to the observed AEP.

- For WAsP teams only:
  - Single-mast predictions are almost equal to multiple mast.
  - Multiple-mast prediction is closer to the observed AEP.

*Less clear signal, not significant.*
Predicted turbine site mean wind speeds
Predicted turbine site mean wind speeds

- CFD models (18)
- Meso/NWP type models (3)
- Mass-consistent models (4)
Predicted turbine site wake effects
Predicted turbine site \textit{wake} effects

\begin{center}
\begin{tikzpicture}
\begin{axis}[
width=\textwidth,
height=0.8\textwidth,
axis lines=left,
xlabel=WAsP Park model (median) wake effect [%],
ylabel=Modelled (median) wake effect [%],
legend style={at={(0.5,0.95)},anchor=north east}
]
\addplot[red,mark=*]
\addlegendentry{Jensen-type models (20)}
\addplot[cyan,mark=*]
\addlegendentry{Ainslie eddy viscosity (11)}
\addplot[green,mark=*]
coordinates{(5,5)(6,6)(7,7)(8,8)(9,9)(10,10)(11,11)(12,12)(13,13)(14,14)};
\addlegendentry{OpenWind Deep Array (5)}
\end{axis}
\end{tikzpicture}
\end{center}
Turbine AEP contribution – predicted vs. observed

Wind turbine contribution [%]

Predictions
Observation

T1 T2 T3 T4 T5 T6 T7 T8 T9 T10 T11 T12 T13 T14 T15 T16 T17 T18 T19 T20 T21 T22
Turbine energy yields – predicted vs. observed

![Graph showing predicted vs. observed turbine energy yields. The graph includes data for linearised models (32) and CFD-type models (18).](image)
CREYAP II Data Pack – Revisions: Feedback

Following the closing date for submissions (May 2013), comments were fed back from 3TIER and Deutsche WindGuard Consulting regarding the MERRA data supplied within the pack.

Feedback Comments:

• CREYAP II MERRA data record consisted of data merged from two adjacent nodes (see map).
  Note: The node intended for CREYAP II was 56.00N - 2.67E

Results from RES Investigation:

• Human error was responsible for the discrepancy in the MERRA data from January 2002 onwards.
• The ground-based reference data may have a small discontinuity circa 2000.
Average wind speeds before & after Jan 2002

- Ground-based: CREYAP II reference site data increase by 0.07 m/s (1.4 %)
- This is in good agreement with MERRA: CREYAP II

<table>
<thead>
<tr>
<th></th>
<th>Jan 1990 - Dec 2001 (m/s)</th>
<th>Jan 2002 - Sep 2006 (m/s)</th>
<th>% Change in Mean Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERRA: 56.00N -2.67E</td>
<td>7.86</td>
<td>7.40</td>
<td>-5.9 %</td>
</tr>
<tr>
<td>MERRA: CREYAP II</td>
<td>7.86</td>
<td>7.98</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Ground-based: CREYAP II</td>
<td>4.96</td>
<td>5.03</td>
<td>1.4 %</td>
</tr>
</tbody>
</table>
• The ground-based reference data and MERRA: CREYAP II data are in good agreement - however:

  – A system change at the ground-based reference station in the late 1990s produced a change in the data record that, by coincidence, obscures the error in the MERRA data.
  – This results in both sources of reference data producing very similar long-term mean wind speeds.
  – There are insufficient reliable ground-based reference data to verify MERRA at this location prior to 2001.
  – The MERRA: CREYAP II data are likely to have caused an under-prediction in the long-term estimate when using MCP.
  – The production data windiness correction was not affected by the error.
Conclusions

- **CREYAP II Objectives**
  - Promote discussion of the challenges involved in resource assessment
  - Explore the impact of industry standard models and approaches
  - Allow organisations to benchmark themselves against the rest of the industry

- **Although the absolute results are important, value can be taken from analysing the range of assumptions and techniques employed by participants**
  - The discussions surrounding the CREYAP II exercise are an integral part of the exercise
  - While the error may introduce bias into the benchmarking, it does not devalue the objectives of CREYAP II and has proven to be a valuable learning experience
Lessons Learned

• Care must be taken when extracting re-analysis data
  – It is advisable to extract more than one MERRA node for comparison

• Agreement in results does not necessarily mean that all reference data sources are reliable

• Visual and statistical assessment of reference data should always be complemented by thorough checks of meta-data