How Wrong Can the Operational AEP Uncertainty Estimate Be When We Ignore the Correlations Between the Uncertainty Components?

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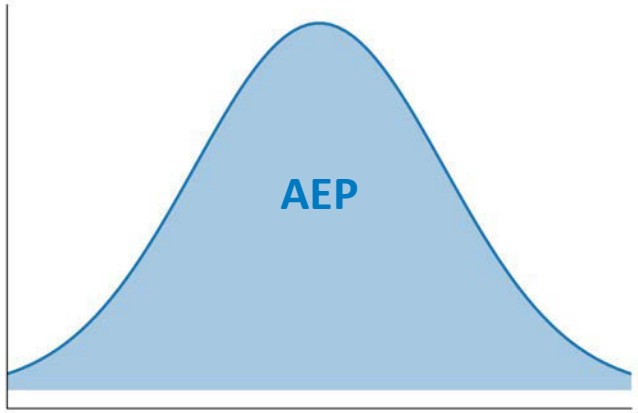
Problem: how to combine uncertainty components for operational AEP?

Operational-based annual energy production (AEP) estimates are affected by several uncertainty components:

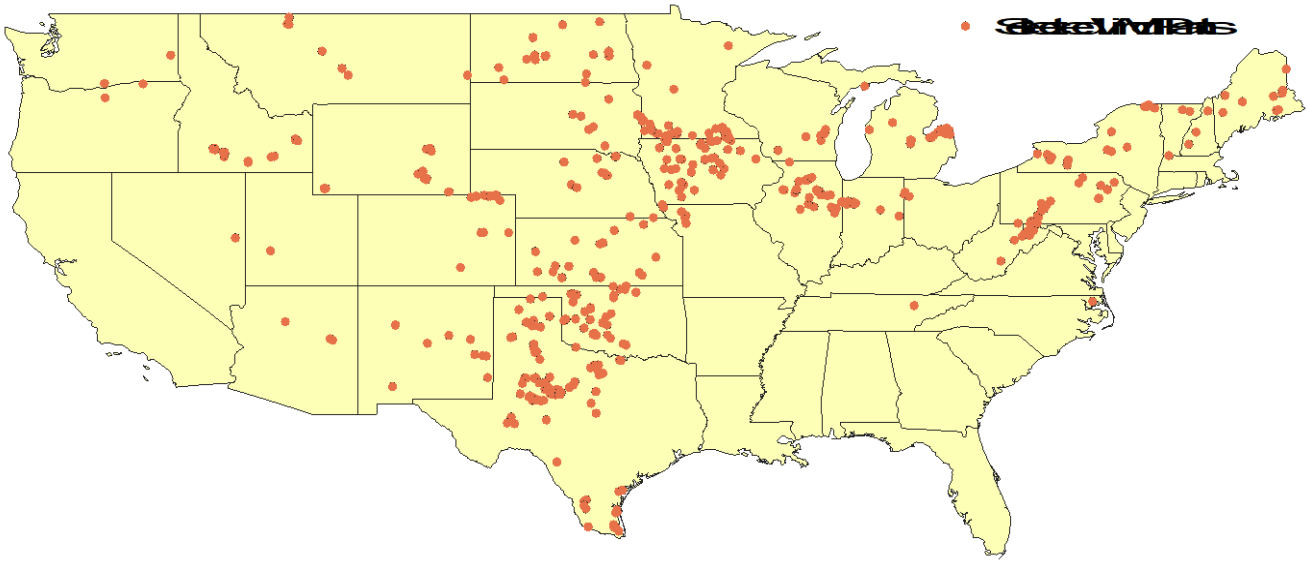
- Revenue meter uncertainty
- Long-term wind measurements uncertainty
- Regression model uncertainty
- Inter-annual variability (IAV)
- Windiness adjustment uncertainty
- …



How to combine the different uncertainty components?

Let's look at a lot of data to learn more!

- Energy data from U.S. EIA-923 data set
- Wind speed data from three reanalysis:
  - MERRA-2
  - NCEP-2
  - ERA-I

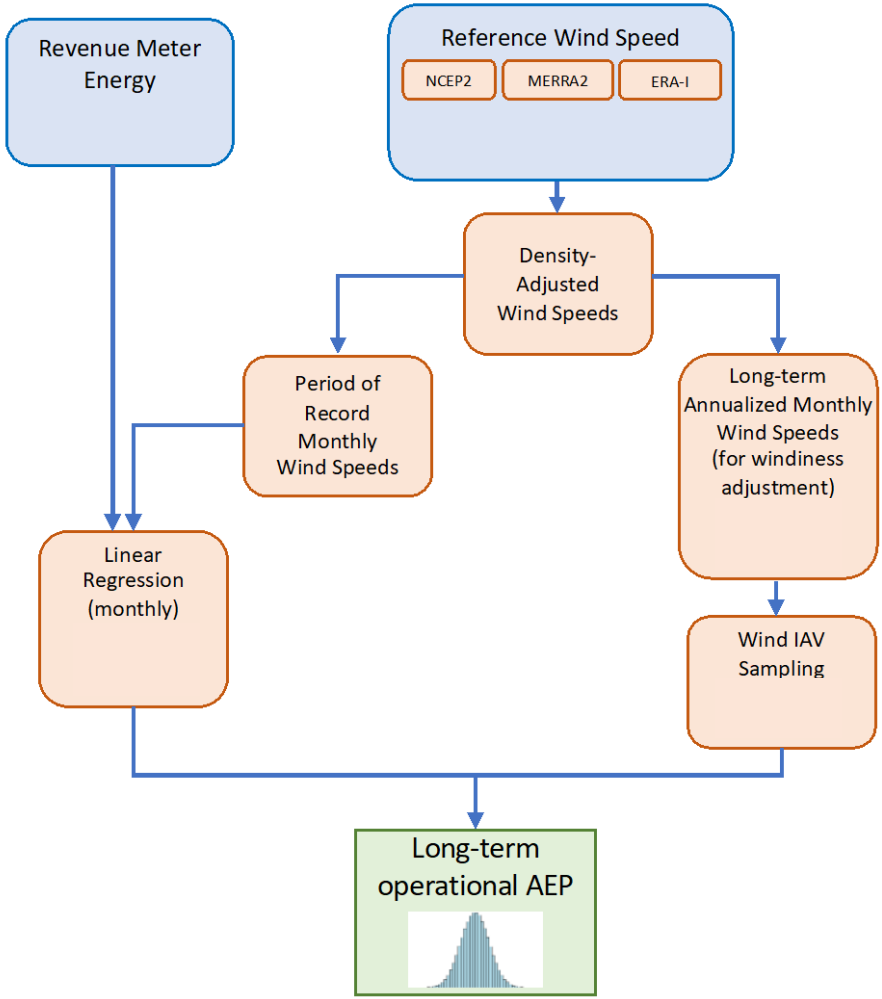


Filter for wind farms with at least 8 months of data, and moderate correlation with all reanalysis products (R^2>0.6).

472 wind farms, mostly in simple terrain

Derive single AEP uncertainty components via Monte Carlo

- We follow ‘conventional’ steps for operational AEP analysis
- A Monte Carlo approach provides a direct estimate of AEP uncertainty by sampling the relevant physical parameters
- 5 operational uncertainty components considered, turned on one at a time in Monte Carlo



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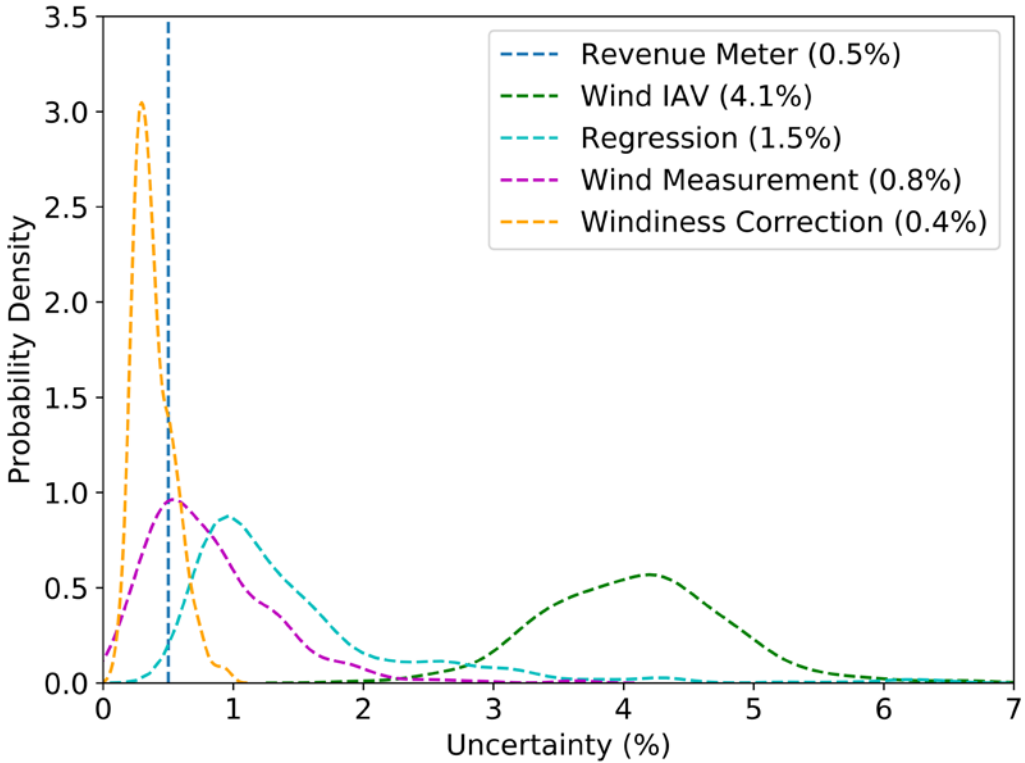
Which are the largest AEP uncertainty components?



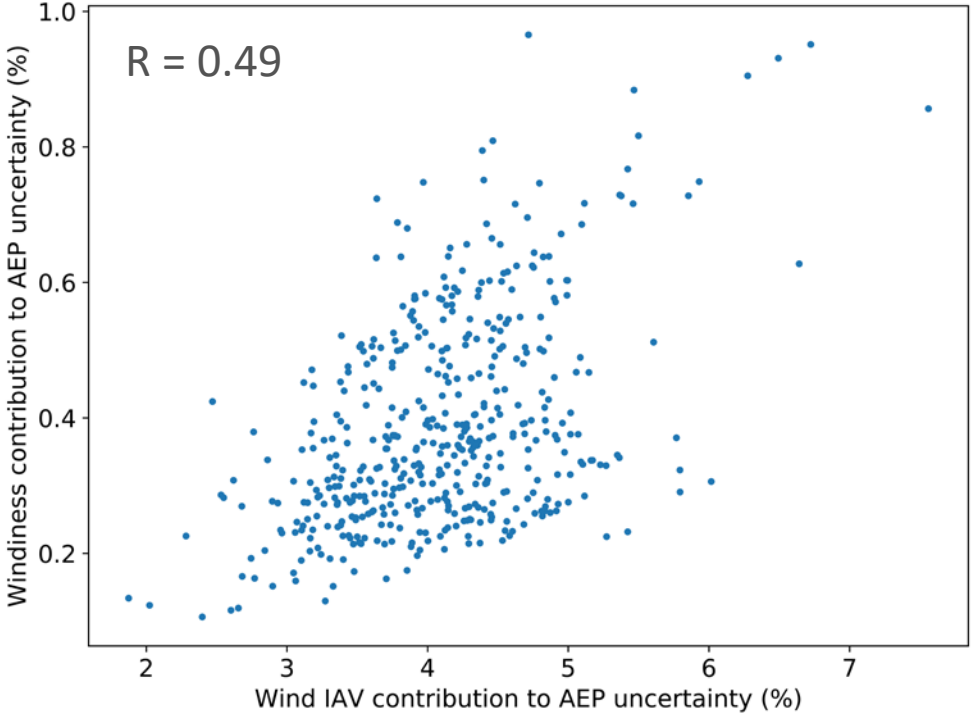
IAV by far largest uncertainty contribution

Windiness adjustment uncertainty is lowest

Note: revenue meter uncertainty was assigned in MC

How do AEP uncertainty components correlate?

Determine correlation between operational AEP uncertainty from pairs of single component



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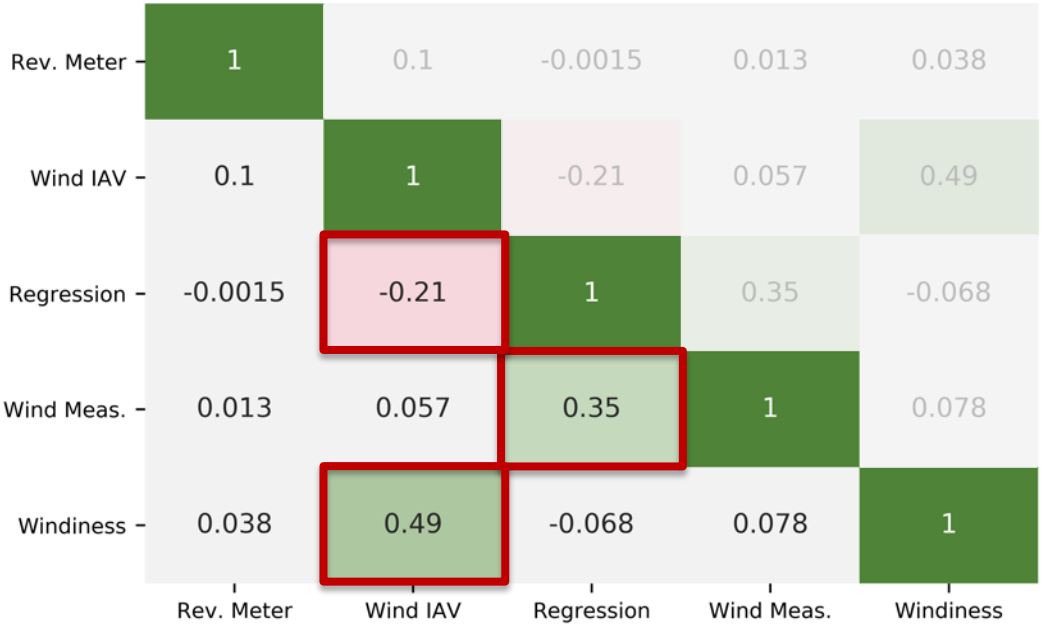
How do AEP uncertainty components correlate?

Correlation matrix – Pearson's correlation coefficients R_{ij} between AEP uncertainty components



Statistically significant $p < 10^{-5}$

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Let's combine all AEP uncertainty components

a Uncorrelated assumption

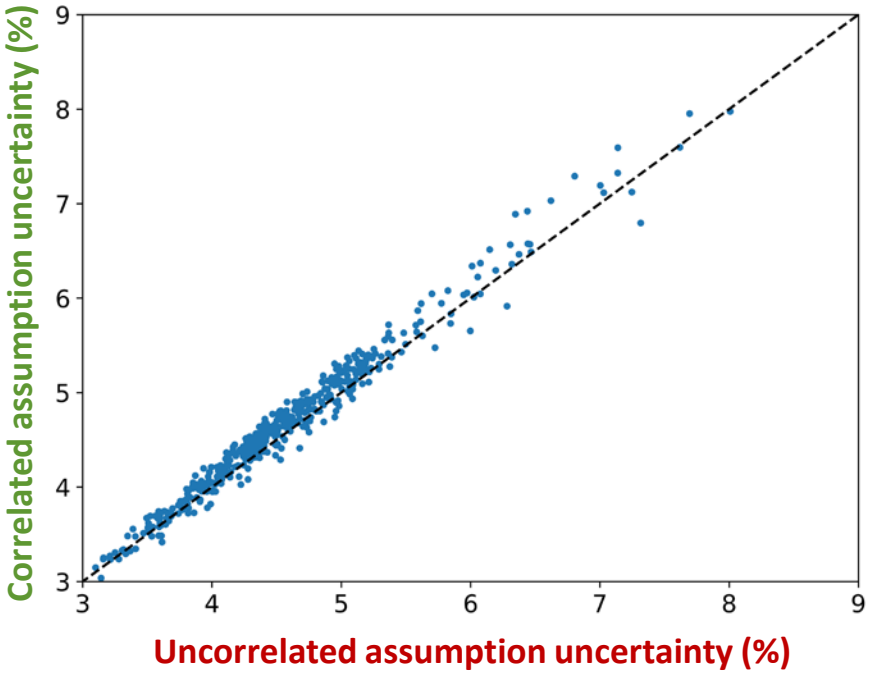
$$\sigma_{TOT} = \sqrt{\sum_{i=1}^{N} \sigma_i^2}$$

b Allowing for correlation

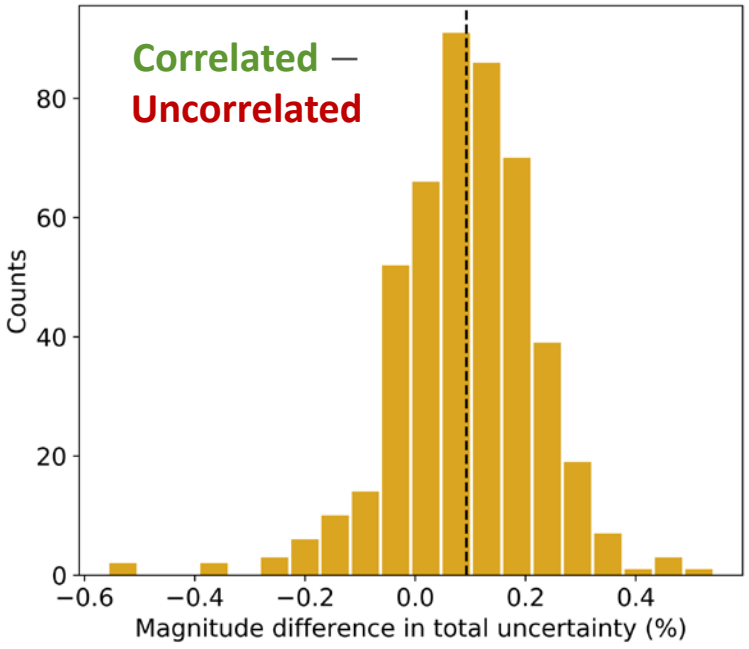
$$\sigma_{TOT} = \sqrt{\sum_{i=1}^{N} \sigma_i^2 + \mathbf{2} \sum_{\boldsymbol{i=1}}^{\boldsymbol{N-1}} \sum_{\boldsymbol{j=i+1}}^{\boldsymbol{N}} \boldsymbol{R_{ij}\sigma_i\sigma_j}}$$

How do AEP uncertainties combined with different assumptions compare?

Errors in more uncertain sites can be, on average, more than twice as large.

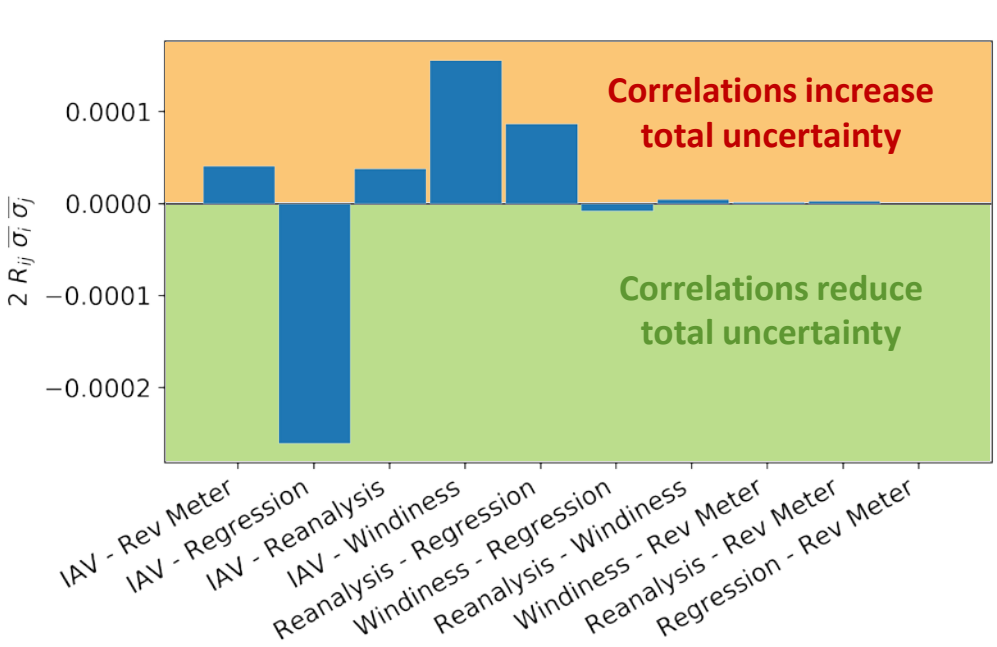


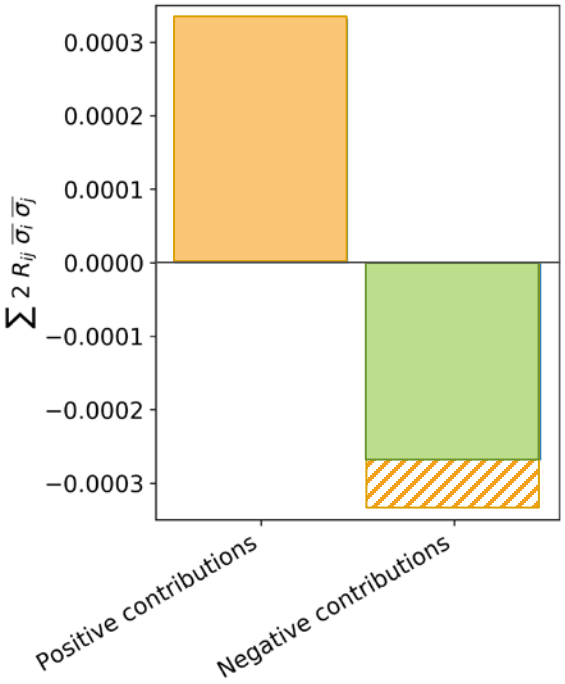
Average difference on total uncertainty: +0.1%



Deeper dive: what drives these differences?

$$\sigma_{TOT} = \sqrt{\sum_{i=1}^{N} \sigma_i^2 + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} R_{ij} \sigma_i \sigma_j}$$

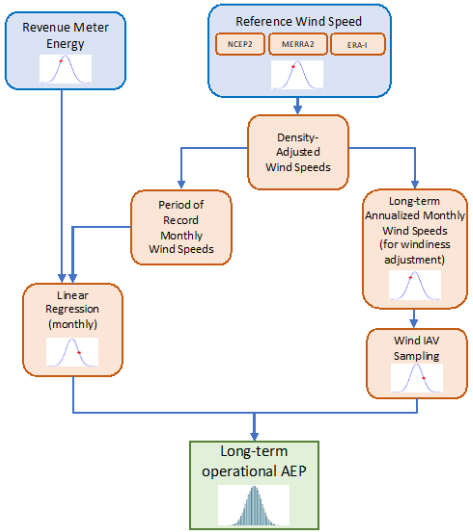




In more complex sites, impact of correlations would change

Conclusions

- A Monte Carlo approach provides a direct estimate of AEP uncertainty by sampling the relevant physical parameters
- Correlations between operational AEP uncertainty components DO exist
- Ignoring these correlations underestimates the total AEP uncertainty by on average 0.1%, and up to ~0.5% (for simple flows)
- Future work: expand analysis at more complex sites, consider additional uncertainty components, apply to pre-construction AEP estimates



THANK YOU!

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