Renewables

# Review of the Uncertainty of Operational Assessment Energy Estimates

Actual wind plant variability AWEA TR-1 operational uncertainty (hourly)

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# Where are we going?

I. Assumptions

II. US Wind Fleet Annual Production Estimated Variability

III. IEC 61400-12-1 Wind Turbine Performance Uncertainty

IV. AWEA TR-1 Wind Plant Performance Measurement

V. Next Steps

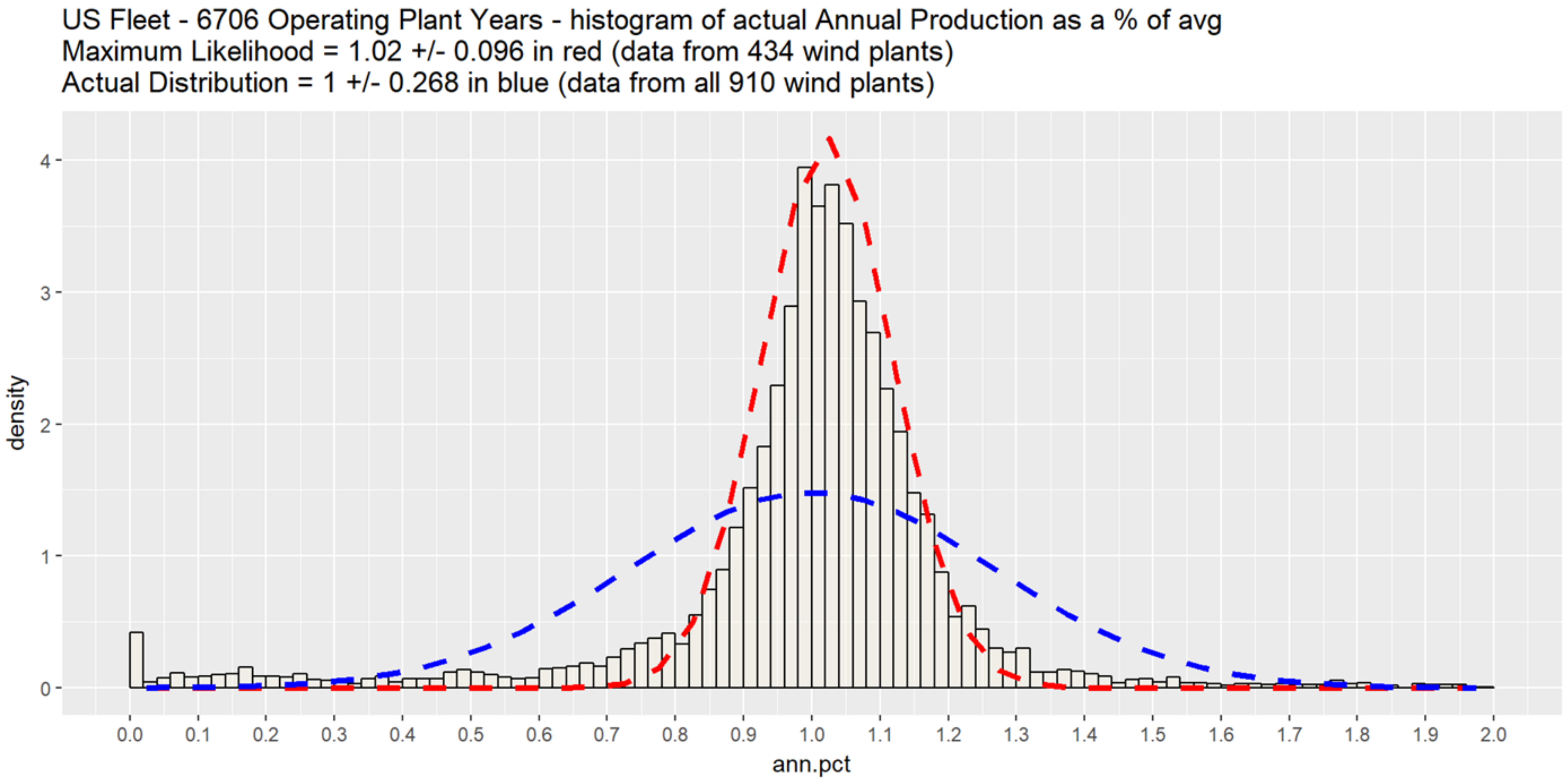
# Relationship – uncertainty/variability

## Assumptions:

- Preconstruction estimate uncertainty **>** operational estimate uncertainty – aggregate (monthly data – linear model) **>** operational estimate uncertainty – detailed (2d+ hourly plant power model – AWEA TR-1) **>** actual variability
- The Uncertainties in energy estimates do not represent **all possible** sources of lost energy, most notably insurable events
- Turbine Power Curves and Plant Power Models are related and most likely overlap in sources of uncertainty
- Actual variability can be estimated from EIA data on the US fleet of wind plants, which have 6000+ plant years of data, filtered for insurable (outlier/abnormal) events
- Actual variability does not capture all sources of uncertainty

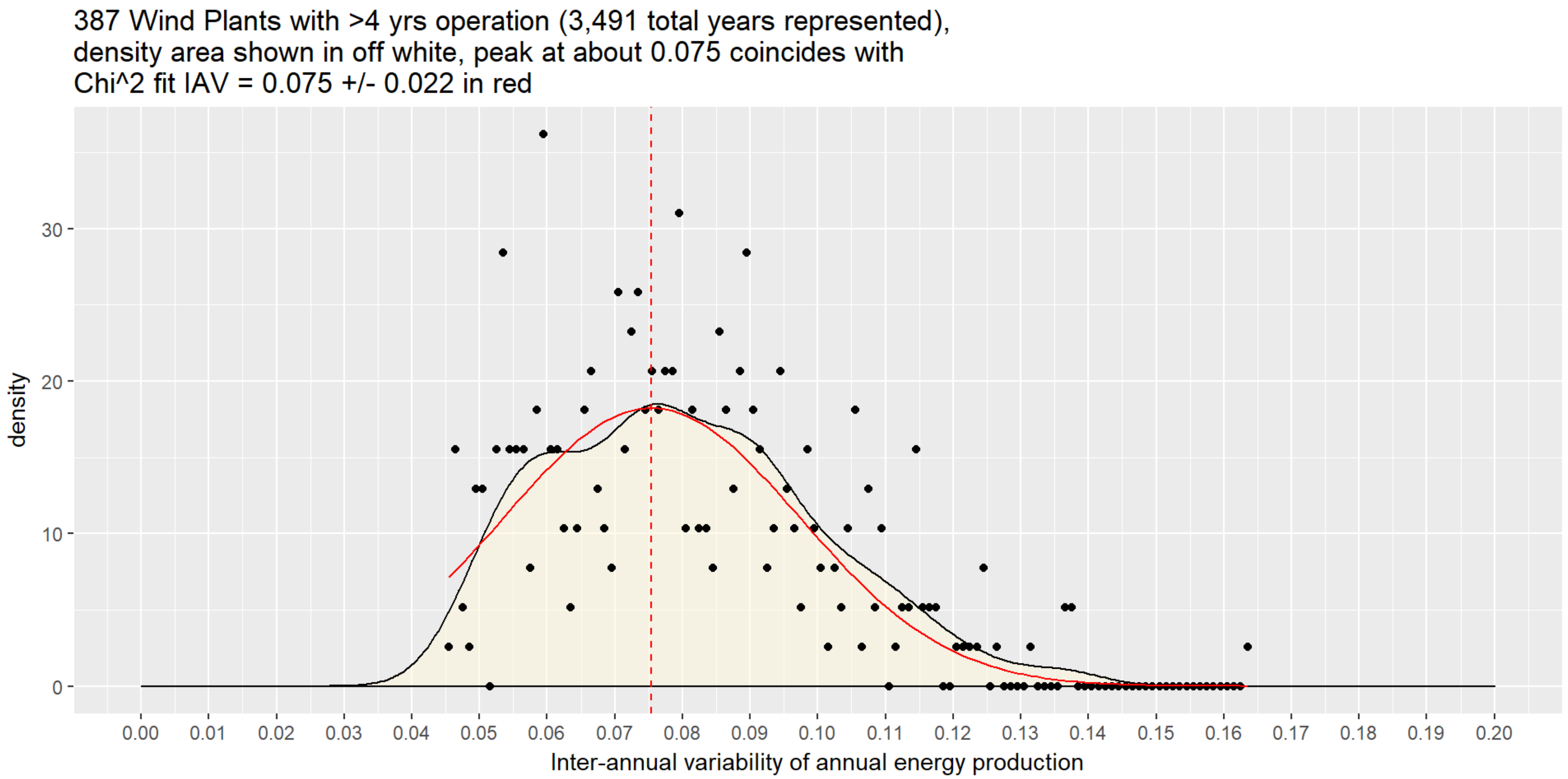
# US fleet annual energy variability

- Apparent variation because of suspected insurable events/bad reporting is about 26.8%
- Variation of all data, fitting just the center filtered data using MLE, is around 9.6%
- There are 910 wind plants represented before but only 434 after filtering (48%)



# Annual variability of representative EIA wind plants

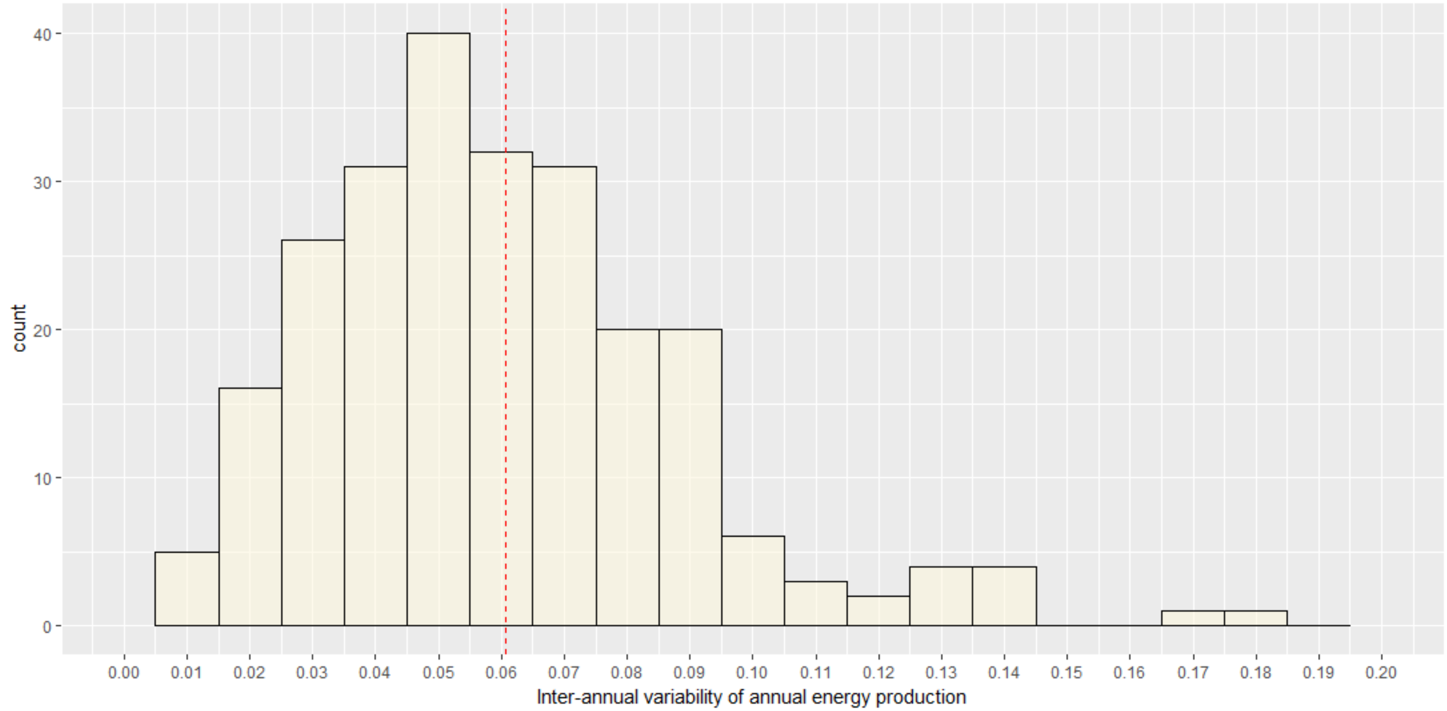
The chi-squared MLE and actual distribution fits are at about 7.5% on average +/-2.2%. There are 387 wind plants with 3,491 years of data represented in this plot.



# Another Perspective

Another organization noted that some of the data included in our estimate might not be appropriate, and undertook an independent evaluation. They screened for plants >50 MW, and regressions r-squared values of >0.6 using ERA-I and MERRA reanalysis data. After filtering there are 243 wind plants represented by just under 1300 years of data

Their results are shown here, with an inter-annual variability in fleet annual average production 6.1% with a standard deviation of 3.5%.



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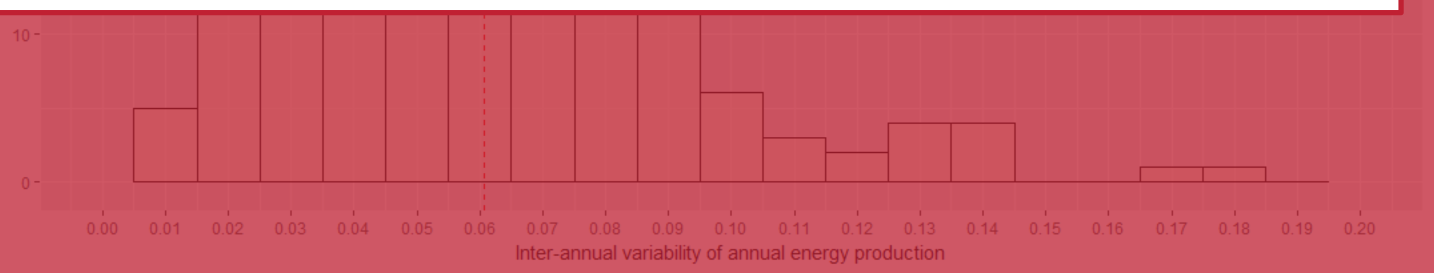
**Take aways** –

- US Wind Fleet Average Annual Energy production varies somewhere around 6-7.5%, but values as low as 4% or as high as 9% are still within 1 standard deviation and considered relatively normal
- More care is needed in reporting data to EIA, if it’s to be a useful source of data for metrics



# IEC 61400-12-1 Power performance measurements of electricity producing wind turbines

Bottoms up approach to uncertainty:

$$u_{\mathrm{AEP}}^2 = N_{\mathrm{h}}^2\left(\sum_{i=1}^{N} f_i^2 s_{\mathrm{P},i}^2 + s_{\mathrm{SC},i}^2 + \left(\sum_{i=1}^{N} f_i \sqrt{u_{\mathrm{P},i}^2 + c_{\mathrm{V},i}^2 u_{\mathrm{V},i}^2 + c_{\mathrm{T},i}^2 u_{\mathrm{T},i}^2 + c_{\mathrm{B},i}^2 u_{\mathrm{B},i}^2 + c_{\mathrm{RH},i}^2 u_{\mathrm{RH},i}^2 + c_{\mathrm{V},i}^2 u_{\mathrm{M},i}^2}\right)^2\right)$$

- Complex – just the description of the calculation is about 63 pages long
- While calculated, still relies on many assumptions for key values
- For most commercial wind plants, a well run test will usually have an AEP uncertainty of 3-5% for the associated site average annual wind speed
- Does not address resource variability

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**Take aways** –

- Turbine power performance measurement uncertainty is roughly 3-5% for most US commercial wind plants
- The procedure used for individual turbines does not translate well to plant level equivalent metrics
- BUT the turbine measurement uncertainty and plant power measurement uncertainty are related and most likely overlapping

# AWEA TR-1 wind plant performance

Document has two areas of focus:

- 10 minute plant power model based on turbine only or turbine and met mast data – most accurate method to estimate time series lost power during outages, curtailment, for energy based availability, etc
- Hourly plant power models with MERRA-2/WRF data for estimating AEP (and secondarily lost energy for time series when turbine/met mast data not available)

Focus of this discussion is on the second aspect:

- Estimation of AEP using the plant power model based on hourly data

AWEA TR-1 Wind Plant Performance Measurement

## Method

- Filter plant data for ‘normal’ operations
- Merge with reference data – aggregate as necessary
- Build power model – minimum 2 parameter wind speed and direction to estimate either revenue meter or sum or turbine energy
- Apply model to 20 year WRF/MERRA2 time series to estimate future energy (most likely gross)
- Apply losses if not part of model

  - availability, blade degradation, other
- Calculate uncertainty

# Common Sources of Uncertainty in Operational Assessments

1. **Wind Resource Variability – 61400-15 committee**
   i. wind speed/direction/TI/shear/veer measurement uncertainty
   ii. historical wind resource (POR)
   iii. future wind resource speed/direction/TI/shear/veer
   iv. wind speed/direction/TI/shear/veer frequency distribution
2. **Wind Speed Conversion to Energy – focus of next slides**
   i. turbine power curve/plant power model
      a. power/energy measurement uncertainty
      b. air density adjustment if used
3. **Future Loss Uncertainties – work in progress**
   i. Availability/Curtailment
   ii. Blade Degradation
   iii. Other (if any – Avian/Bat, Icing, WSM, etc)
4. **Data Selection Variability – under study**

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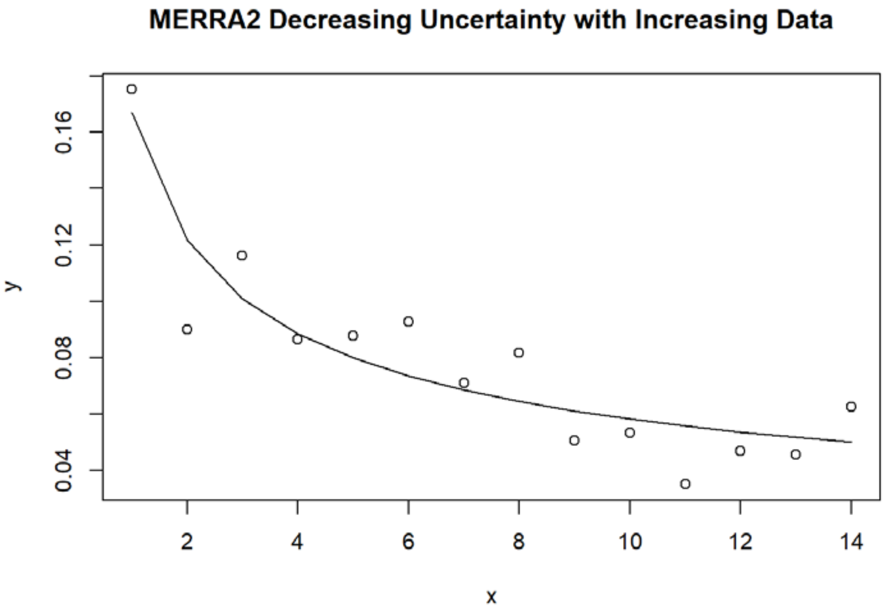
   ii. Blade Degradation
   iii. Other (if any – Avian/Bat, Icing, WSM, etc)
4. **Data Selection Variability – under study**

**Take aways –**

- Wind Resource Uncertainty being addressed in IEC 61400-15, will not be duplicated here
- Current focus of AWEA TR-1 committee is Plant Power Model uncertainty and possible relationship to Turbine Power Curve uncertainty

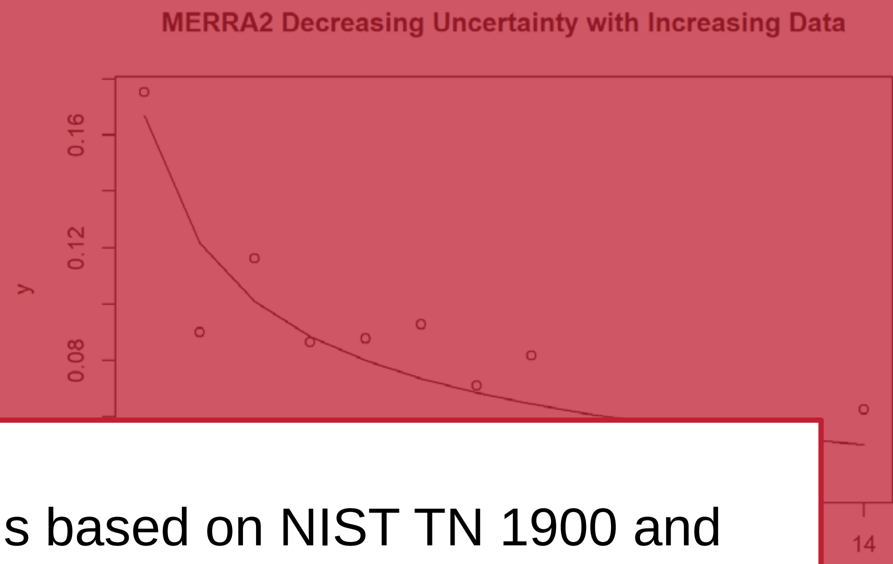
# Plant Power Model Uncertainty




Basic Procedure:

- Each month, as data is collected and validated
- Divide data into 5 equal segments, building model from 4/5 of data and testing model on remaining 1/5 – repeat 5x
- Measure standard deviation of the difference between sum of actual and predicted power
- Repeat monthly, noting improvement in model strength/reduction in variance, fit a model to the monthly results to extrapolate to 1 year

# Plant Power Model Uncertainty




**Take aways –**

- This top down approach is based on NIST TN 1900 and the basic concept was reviewed with the author of the technical note – Dr. Antonio Possolo, Chief Statistician
- The method allows early use of the test results with higher uncertainty, but shows the improvement over time as additional data is added

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- Measure standard deviation of the difference between sum of actual and predicted power
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# Next Steps

1. **Wind Speed Conversion to Energy**
   i. Relationship/overlap of turbine power curve and plant power model
2. **Future Loss Uncertainties**
   i. Availability/Curtailment
   ii. Blade Degradation
   iii. Other (if any – Avian/Bat, Icing, WSM, etc)
3. **Data Selection Variability**
4. **Use of Monte Carlo in estimating uncertainty**
   i. Capture proper shape of suspected non-normal distributions – availability, curtailment

# Key Points

I. US Fleet measurable annual energy production – AEP – variability is somewhere around 6-7.5%, but with a wide distribution, resulting in a range of 4-9% being considered normal

II. Any uncertainty estimate of AEP based on modeling will necessarily be higher than this actual variability due to the added uncertainty of the model

III. Where turbine power performance measurement uncertainty is a complex bottoms up process, the AWEA TR-1 group working on plant performance measurement is taking a simpler tops down approach

IV. AWEA TR-1 uncertainty team to focus on how to leverage turbine power performance measurement uncertainty

# Thank you!

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Other references
NREL paper – http://iopscience.iop.org/article/10.1088/1742-6596/1037/5/052021/pdf
NIST Dr. Antonio Pissolo Bio  -  https://www.nist.gov/people/antonio-possolo
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