Minimizing Long-Term Yield Assessment Uncertainty for Operating Wind Farms

Refining Pre-Construction Analysis Techniques

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Objectives

- Why do a post-construction assessment?
  - What is the uncertainty of a production assessment?
  - When to do a production assessment?
- What are some typical methods?
  - Mean monthly average
  - Monthly linear regression
- What are some advanced methods?
  - What post-construction data is used?
  - How much production data do you need?
  - What are advanced methods to assist with this process?
- How do advanced methods inform pre-construction estimates?

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Typical Operational Assessment Methods

- Operational data to generate yield estimates
  - Invoiced Production (point of metering)
  - SCADA production, nacelle wind speed & flags
- Two common operational assessment techniques:
  - Mean of mean of monthly invoiced production
  - Linear regression between reference wind speeds and monthly production (typically monthly)
- Refinements to linear regression method
  1. Better QC of production data
     - Define periods of normal operation
     - Quantify Losses
  2. Processing of reference wind speed to be more representative of production

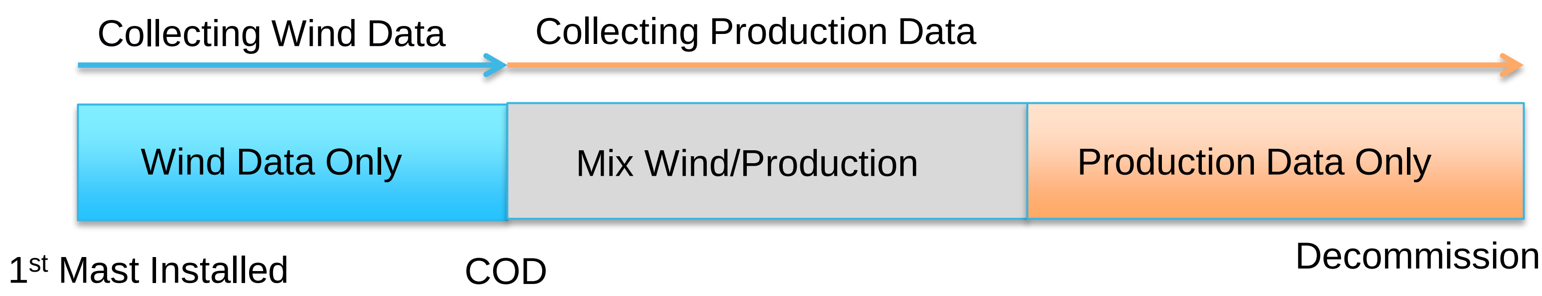
Uncertainty of Operational Data Assessment

- Approach is independent of pre-construction methods and inputs
- Production data significantly reduces or eliminates several sources of uncertainty

Sources of Uncertainty	Pre-Construction	Post-Construction
Site measurements	√	√
Vertical extrapolation	√	x
Historical wind resource	√	√
Future wind variability	√	√
Spatial variability	√	x
Losses	√	x/√

What type of analysis is best for your facility?

- Pre-construction long-term yield analysis are well established
- Post-construction yield estimate methods are not as established



- What is the minimum amount of production data to determine the long-term yield?
  a) Pre-construction methods are preferable to operational assessments
  b) Greater than five years of production data
  c) At least two years after COD
  d) 6-18 months depending on data quality

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Typical Operational Assessment Methods

1. Mean of mean monthly invoiced production

Pros	Cons
-Simple	-Requires a long operating period
-Incorporates realized losses	-Does not quantify losses
	-Hard to identify trends (1st year?)

2. Linear regression between reference monthly average **wind speeds** and facility monthly **production**

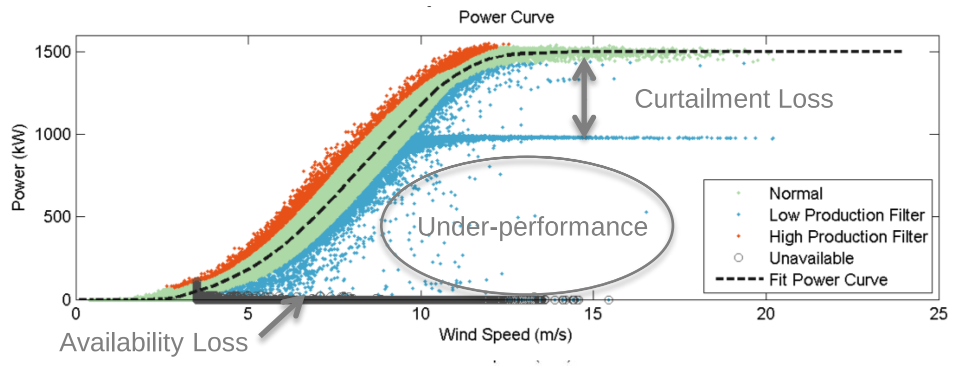
Pros	Cons
-Shorter operating period	-Does not quantify losses
-Incorporates realized losses	-Reference wind speeds may not be representative of production
	-irregular operational periods difficult to characterize

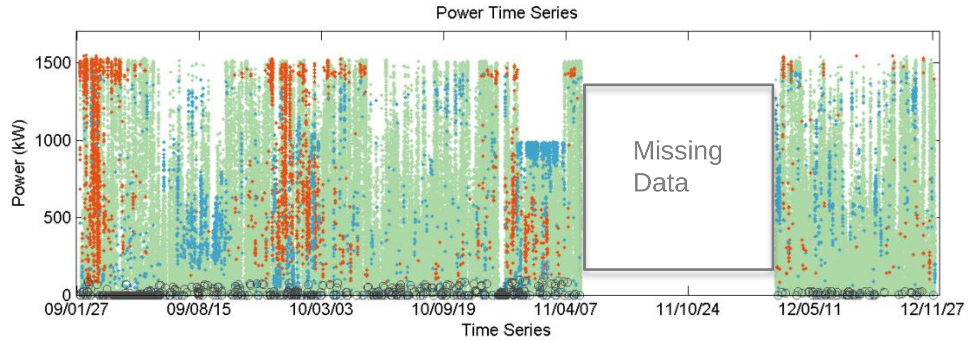
Advanced Operational Assessment Methods

- Addressing the shortfalls of operational assessments:
  - Reduce the amount of data required
  - Better characterize the operational issues of the facility
- Improves the process by:
  - Characterization of downtime and turbine specific performance
  - Quantify losses and identify periods of irregular operation
  - Improve representativeness of reference wind speeds

Characterize Losses from Production Data

- Use the relationship between nacelle anemometer and power/energy to determine normal operation.
  - Nacelle wind speed is different than free stream wind speed
- Determine abnormal production for each turbine
  - Anemometer drag
  - Curtailment
  - Under-performance
  - Availability
- Character of losses
- Magnitude of losses
- Period of losses





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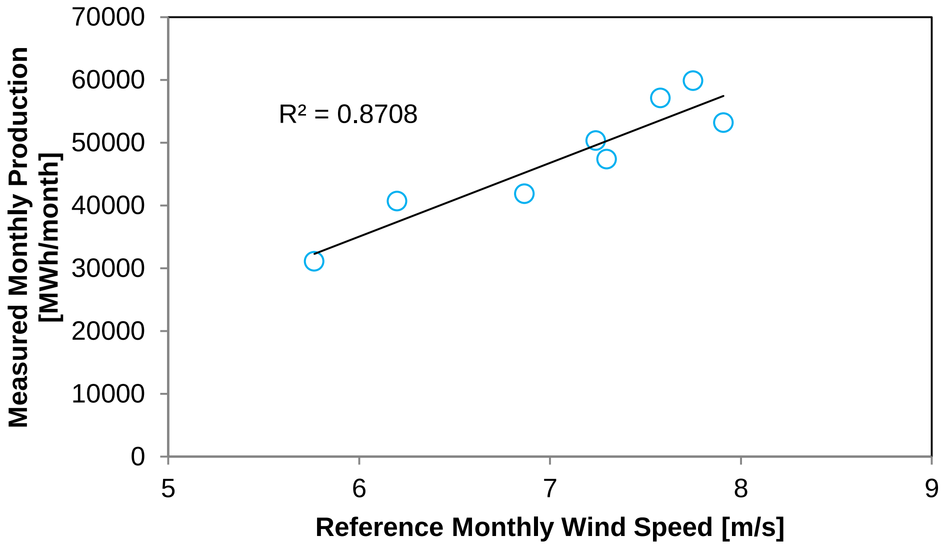
Processing reference wind data for better representativeness.

- Select suitable reference site, same as pre-construction
- Select suitable on-site met mast
  - On-site data should be uniform and representative
  - Can be a period before the installation of turbines
- Transform reference wind speeds to on-site conditions
  - Shear reference for a more representative diurnal profile
  - Linear or non-linear MCP (well documented) to get representative reference wind speed (match distribution)
- Convert wind speeds to production using power curve
  - Relationship between production and wind speed is defined
  - Account for temporal air density change. 40% variation in air density possible on a fine time scale

Advanced methods: Processing reference wind data for better representativeness.

1. Transforming reference wind speeds to be more representative of the facility improves correlation
2. Transforming wind speeds to production improves correlation
3. Air density correcting improves correlation



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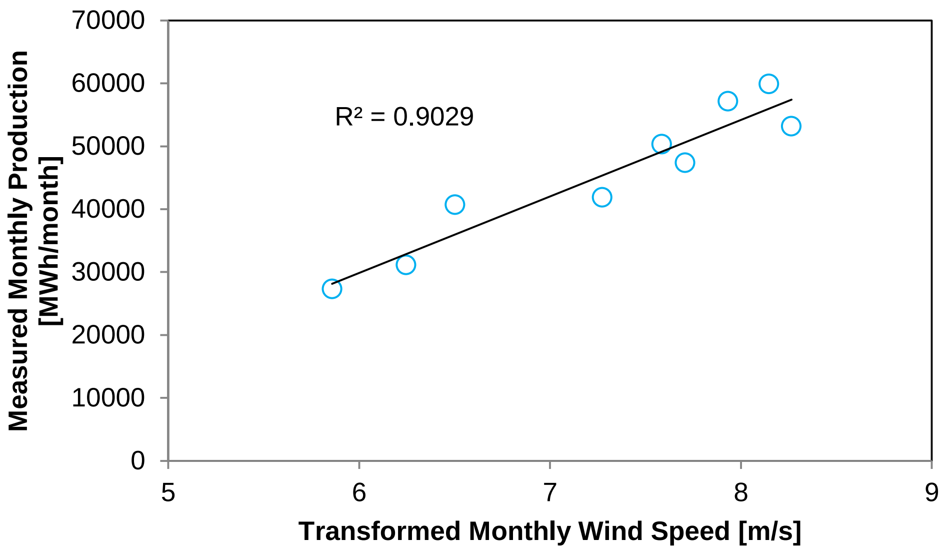

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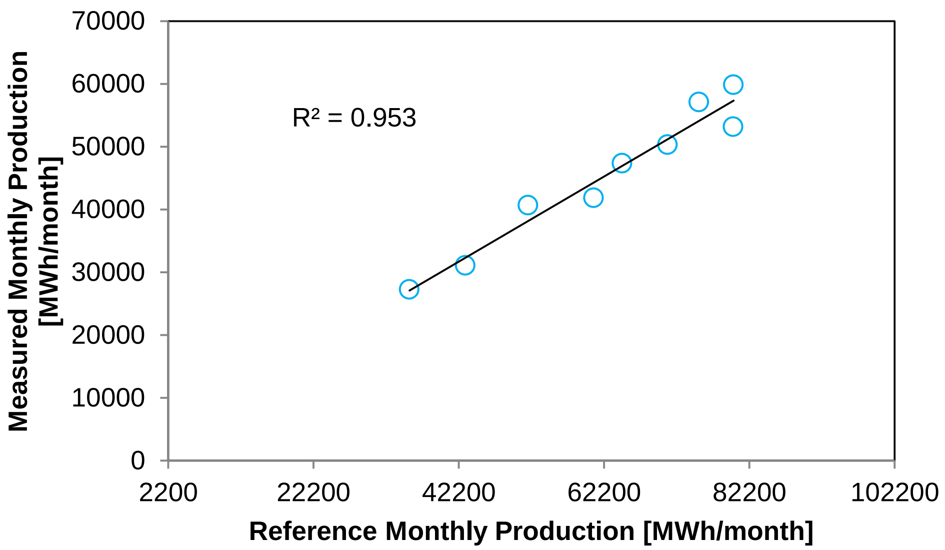

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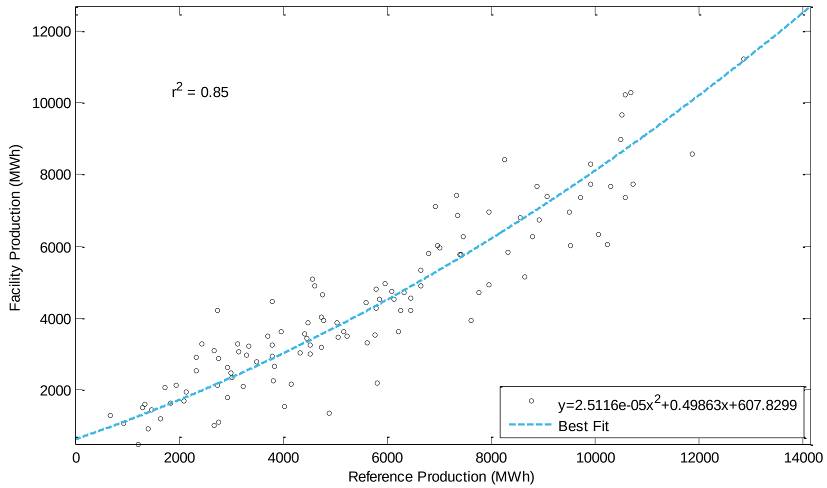
Correlate and Predict of Production

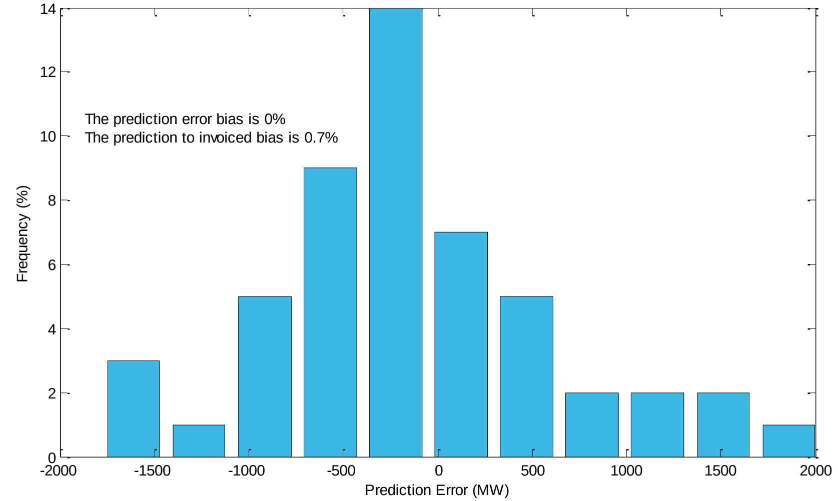
- Correlate: Filtered Data → Reference Production Data
  - Appropriate time scale: hourly, daily, weekly or monthly
  - Appropriate fit: linear, quadratic, sigmodial, etc.



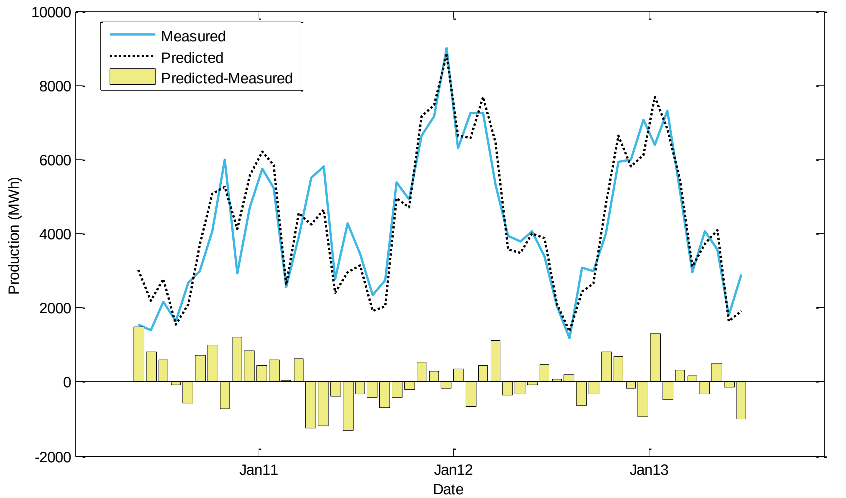
- Apply regression statistics to create a long-term prediction
  - Losses have been backed-out and must be characterized and re-applied

Validation of Prediction

- Check overall result
  - Distribution of residuals
  - Magnitude of bias



- Check temporally result
  - Step changes
  - Most wind farms do not operate consistently
  - Representative period is important



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Question 2:

- Do you know how well your wind farm is performing relative to expectations?
  1. I look at my project on an annual basis
  2. I compare monthly production to long-term monthly average
  3. I use realized wind speeds as a metric for wind resource potential of that month
  4. I account for both the monthly wind resource and realized losses in my expectations

Summary of Operational Assessment

1. Generate a production time series for normal operation
   – Quality control production data, turbine by turbine
2. Transform reference wind speed, temperature and pressure to an on-site production time series
3. Generate a correlation between reference production and adjusted production data
4. **Adjust losses for seasonality and anticipated downtime statistics and apply them to the long-term production**

Advantages to Operational Assessments

- Prediction can be made with shorter periods of record
- Intermittent data quality is accounted for
  - Missing Data
  - Availability and other shutdown losses
  - Icing and other performance losses
- Insight into operational performance

How does this process better inform pre-construction methods?

- Losses are quantified => inform net yield
- Can validate the prediction with the measured data
  - Assess the uncertainty of the analysis
  - Identify changes in the operation of the wind farm
- Independently verify pre-construction yield estimates
  - Inputs are different than pre-construction
  - Method is different
  - Strengths and weakness are different

Conclusions

- Analysis of post construction data is valuable
- Can lower uncertainty in long-term production estimates
- Allows a redundant confirmation of pre-construction estimates
- Allows for a temporal analysis of the performance of the wind farm relative to the realized wind resource and losses