Wind Farm Degradation: An Alberta Case Study

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matthew.breakey@wsp.com

Introduction: Exploring Turbine Degradation

What:

— Does a wind farm's performance change over time?

Why:

1. *What are life-time average performance expectations for a wind farm?*
2. *Time value of money; production now is better than production later*
3. *How much energy can be expected if a wind farm's life is extended?*
4. *How can we calculate future performance based on past performance*

Historic Economic Modelling

Net Capacity Factor	Confidence level (%)				
	50%	75%	90%	95%	99%
1-Yr Average Production	40.0%	33.8%	28.2%	24.8%	18.6%
10-Yr Average Production	40.0%	35.7%	31.8%	29.5%	25.1%
20-Yr Average Production	40.0%	35.8%	32.1%	29.8%	25.6%

- Gross Yield (i.e 50%)
- Losses (i.e. 20%)
  - *Constant over life of project*
  - *All losses applied as long-term averages*
- Net Yield
  - *Economic models assume constant net capacity factor*
  - *If losses are constant, 10-Yr value is same as next 10-years*

Are Losses Constant or Vary with Time?

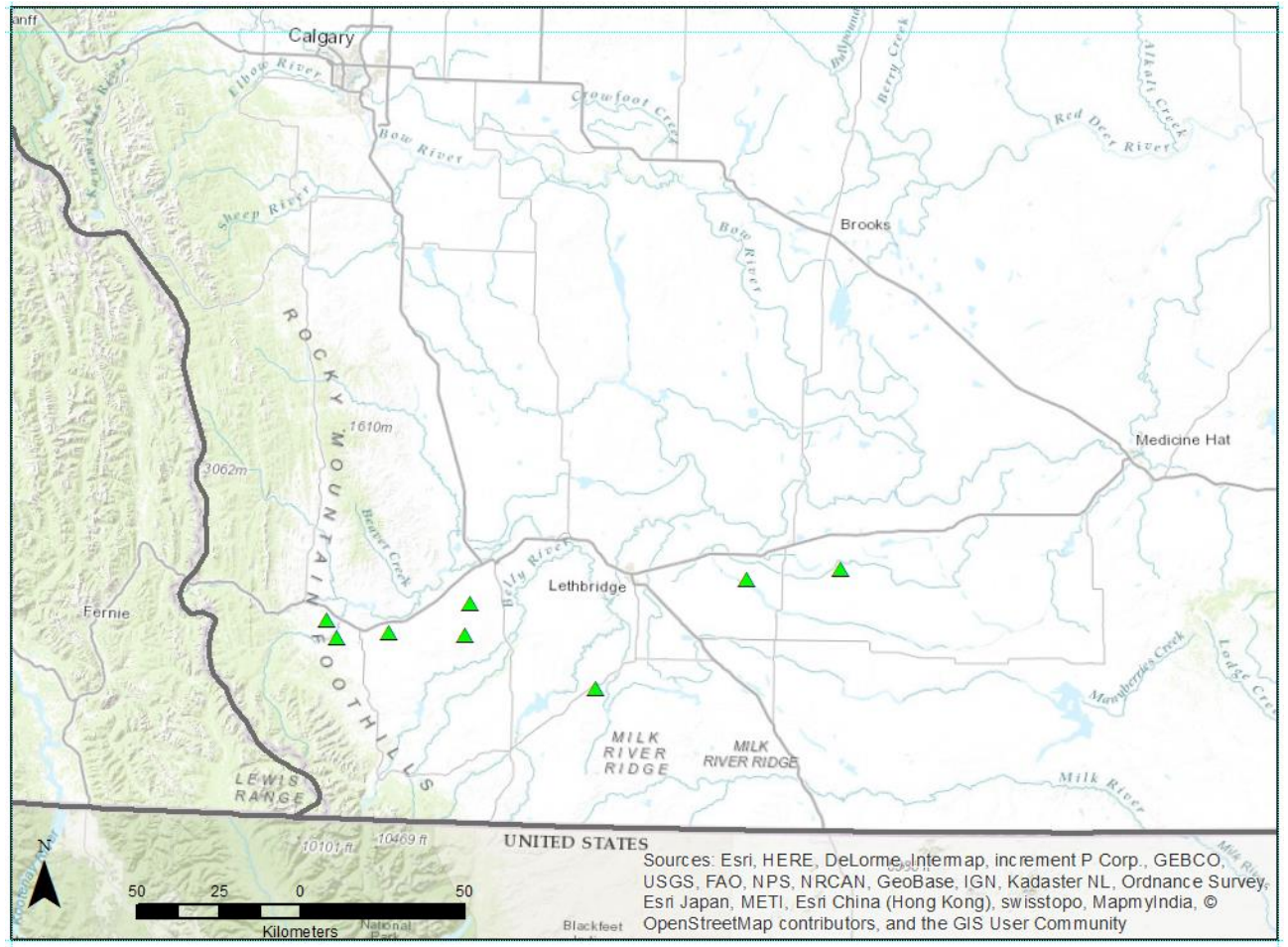
Included in Degradation Loss

- Availability Losses
  - *Failure rate increases with turbine age (-)*
  - *Severity increases as facility ages (-)*
  - *Turbine mortality (-)*
  - *Maintenance upgrades (+)*
- Turbine Performance Losses
  - *Blade soiling (functionally constant)*
  - *Blade degradation (-)*
  - *Drive-train wear (-)*
  - *Turbine upgrades (+)*

Excluded in Degradation Loss

- Wake
  - *Increases with regional build-out? (-)*
- Curtailment
  - *Grid congestion (- or +)*
  - *Increased regulation i.e. Bat Curtailment (-)*
- Environmental Losses
  - *Climate change (- or +)*

Verify Degradation Rates: An Alberta Case Study



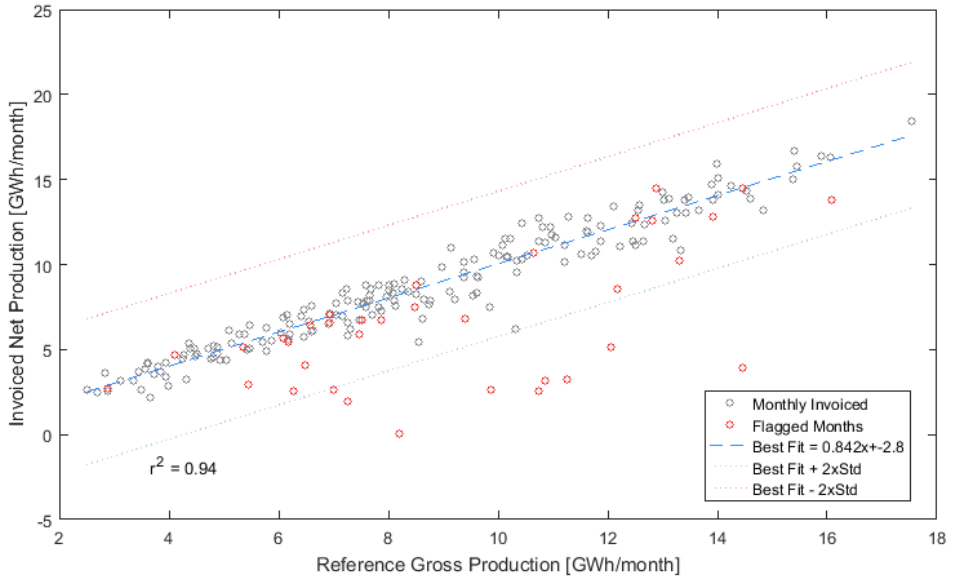
- Publicly available data:
  - *AESO [1]*
- Summary of Population
  - *8 of 20 Wind Farms*
  - *414 MW*
  - *Well understood*
  - *Average age of 14.2 years*
  - *Consistent operation*
  - *Low environmental losses such as icing*

[1] Alberta Electric System Operater: http://ets.aeso.ca/ets_web/ip/Market/Reports/CSDReportServlet

Validation Study Design

- Obtain monthly invoiced production from AESO
  - *Filter data (break-in period)*
- Generate prediction of resource using MERRA2[1] and ERA5[2]

$$Energy = [C_1 \times Energy_{ERA5} + C_2 \times Energy_{MERRA2} + C_3] \times [1 - Degradation]^{Age}$$



[1] Global Modeling and Assimilation Office, NASA
[2] ECMCF – Copernicus (C3S) Data Store

Validation Study Design

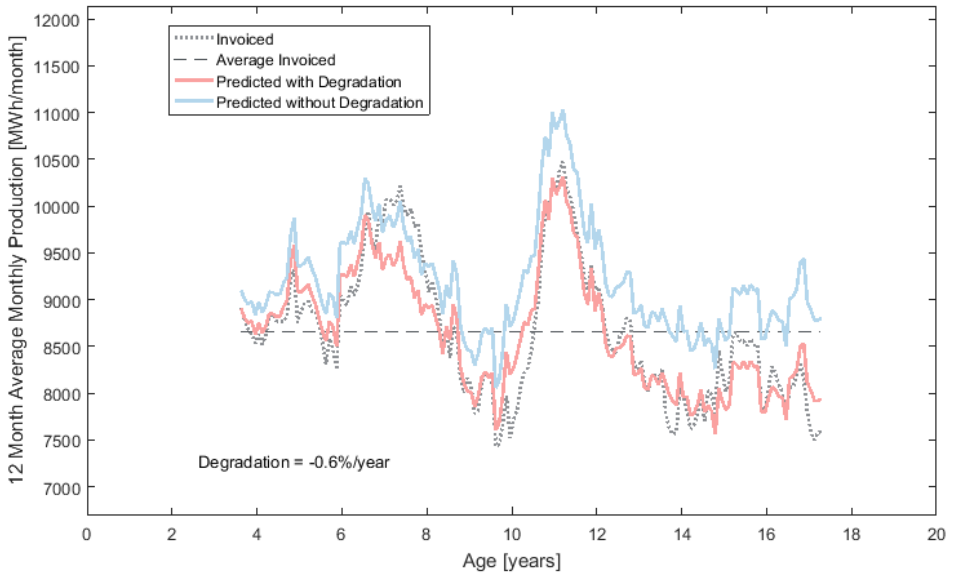
— Generate prediction of resource => Baseline

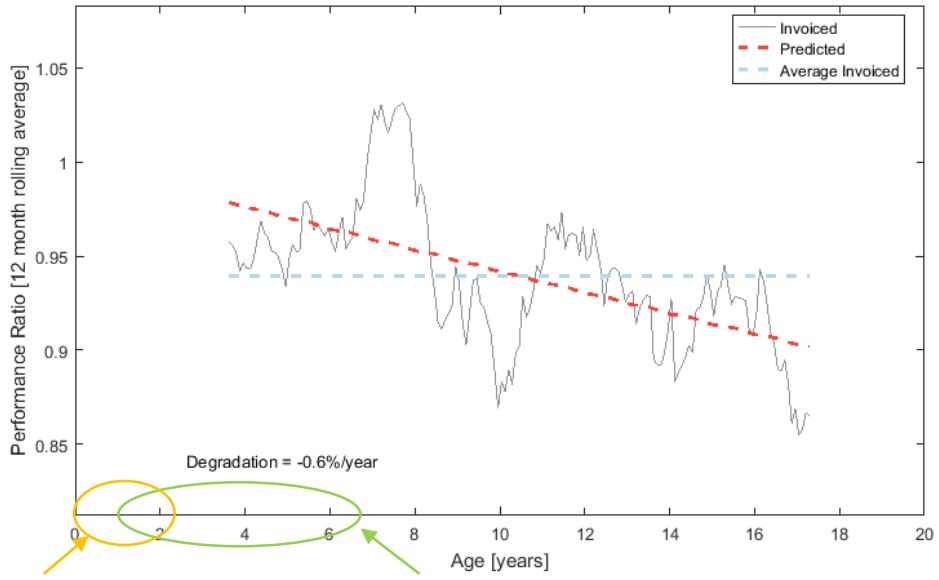
Resource & Performance

$$Performance\ Ratio = \frac{Invoiced\ Energy}{Predicted\ Energy\ without\ Degradation}$$

Performance Only

Resource Only





Period of Power Performance tests

Period of fleet availability statistics

Alberta Degradation Rates

— Profile:

$$Energy_{year} = [Energy_{New}] \times [1 - Degradation]^{Age}$$

➢ *Range of R^2 of 90%- 94% for 8 projects*

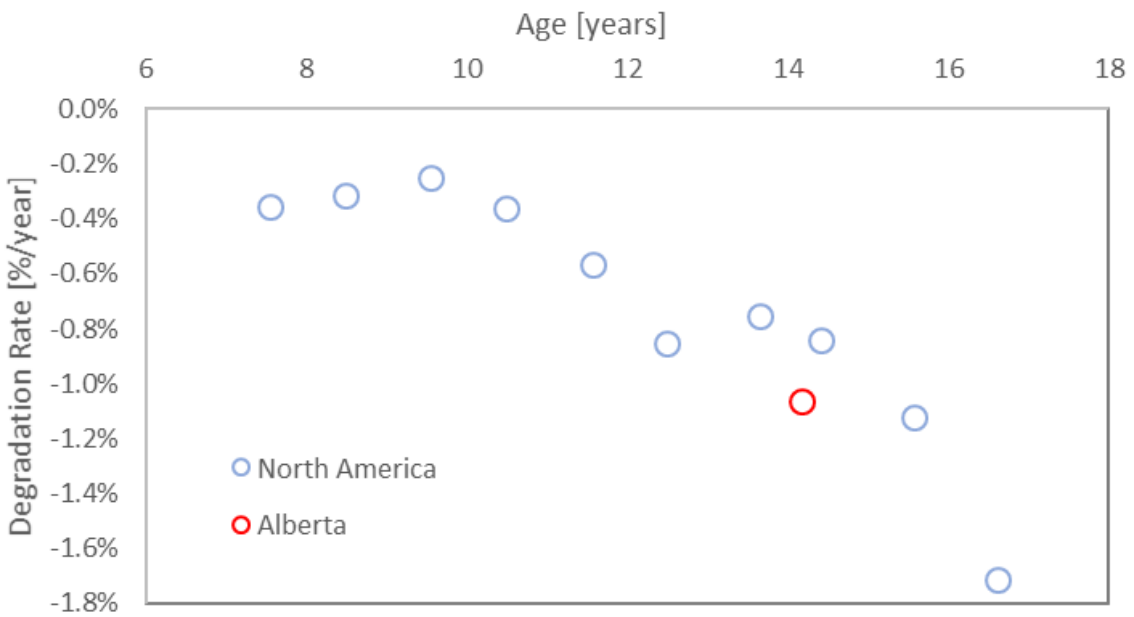
— Alberta Degradation Rate

— *1.1%/year for an average age of 14.2 years (8 wind farms)*

— *Depends on age of turbines [1]*

[1] « Wind Farm Production Variation: A Case Study of Net Production Variation of Alberta, Ontario and the USA » Matthew Breakey (Presentation: 2014 CanWEA, Oct 2014)

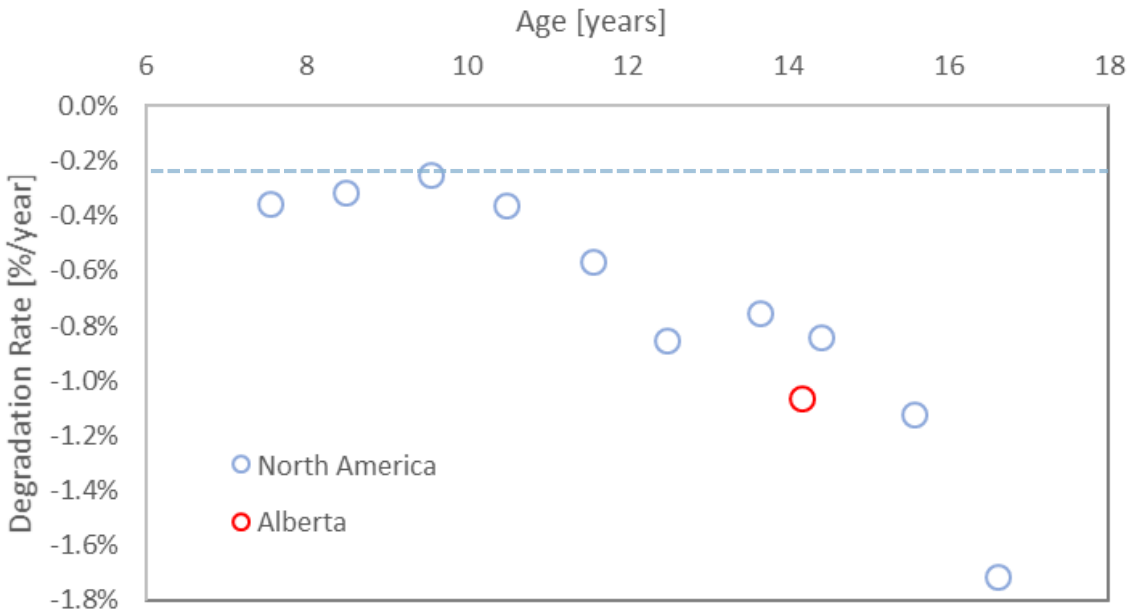
North American Degradation Rates



- 147 wind farms (17.3 GW) from Across North America
- Filtered by:
  - *NPC > 10 MW*
  - *Period of record > 7 years*
  - *High quality prediction*
- Degradation was found to be age dependent [1]
- Degradation has stabilized

[1] « Wind Farm Production Variation: A Case Study of Net Production Variation of Alberta, Ontario and the USA » Matthew Breakey (Presentation: 2014 CanWEA, Oct 2014)

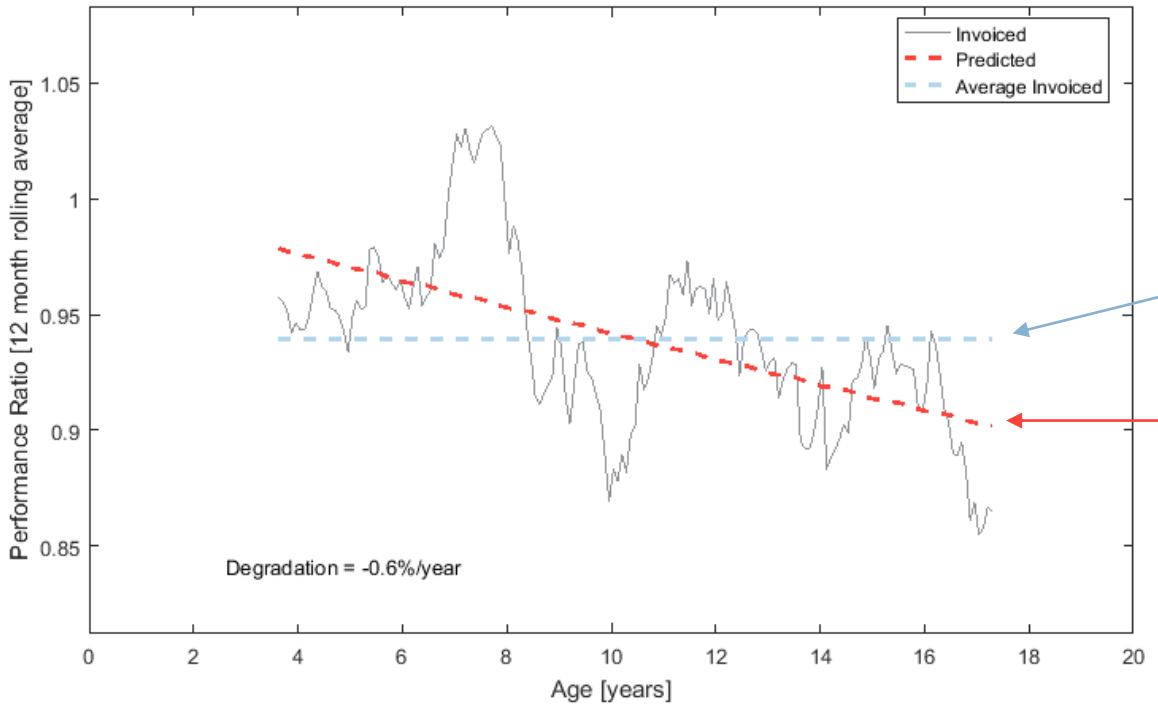
WSP's Loss Approach



- Turbine Performance:
  - *Database of power performance tests (~1 year)*
- Turbine Availability
  - *Fleet statistics (~4 years)*
- WSP applies 0.25%/year for new facilities.
  - *Blade degradation*
  - *Drive-train wear*
  - *Increased frequency and severity of failures (decreased availability)*
  - *Turbine mortality*

Time Dependent Losses & Economic Modelling

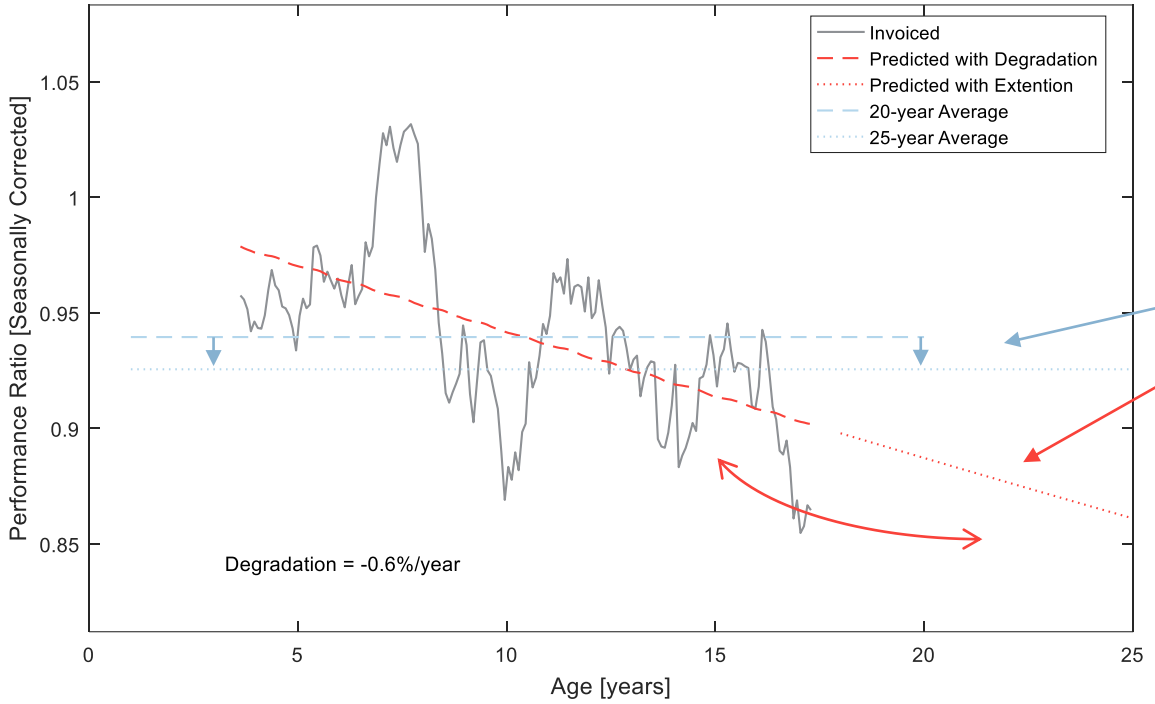
- If losses vary with time:
  - *Assume long-term losses represent real performance*
  - *Economic modelling can look better with no change to average energy*
  - *Time value of Money*



Degradation [%/year]	IRR [%]
Constant Loss	6.9%
Varied with 0.25%/year trend	7.0%
Varied with 0.50%/year trend	7.1%

Extending the Life of a Project

- To assess the benefit of the life extension
  - *Production for initial period should not change*
  - *Loss for extension should be larger than initial period*



Degradation	IRR	
	20-year	25-year
Constant	6.9%	8.0%
0.50%/year	7.1%	8.2%

Conclusions:

- Degradation rates are significant
- Degradation changes when power is produced
- Accounting for degradation can improve economic modelling:
  - *Time value of money*
  - *Life extension*
  - *Better agree with evidence*

Questions?

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