PCWG Validation Analysis: Turbulence Correction

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Summary of Validation Data

- Data sets from 23 Power Performance tests have been re-analysed. 14,739 hours (~1.7 years) after data quality filters.

- Data covers a wide range of sites in Europe and North America.
  - Five manufacturers
  - Rotor diameter >= 80m
  - Rated power >= 2MW

- Summary of Instrumentation:
  - Reference wind speed at hub height, corrected using site calibration procedure and air density
  - Shear anemometers at lower tip height and near hub height
  - Reference wind direction and in some cases inflow angle
  - Turbine power transducer
  - Turbine OK, Running, grid frequency and logger quality signals for most tests

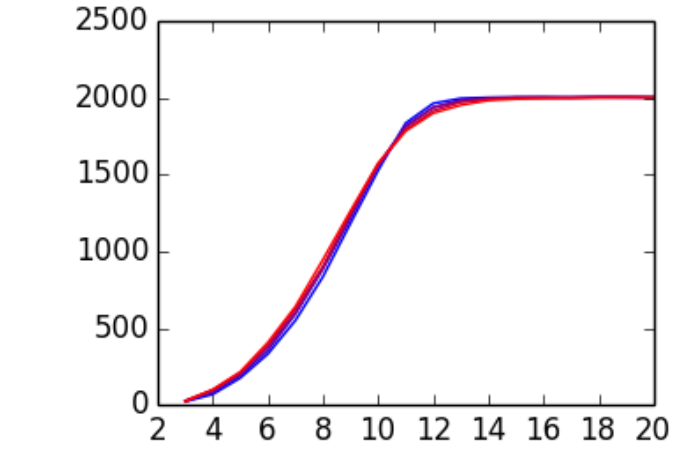
Which signals are related to power curve variation?

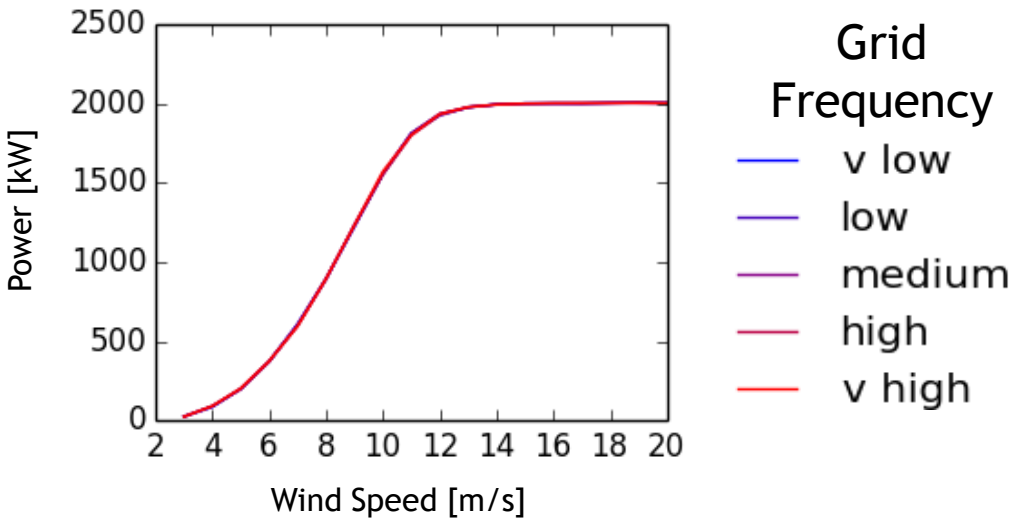
- The following procedure was done to find signals relevant to power curve variation:
  - Choose a signal which may be related to power curve variation (e.g. TI)
  - For each wind speed bin, split the data into 5 bins based on that signal. The split is done such that all bins have approx. the same amount of data.
  - Create 5 power curves from the 5 bins
  - Compare each power curve with the overall mean power curve by summing the absolute energy differences
  - Call the sum of these differences the **power curve variation**, normalise by specific energy and express as a percentage

Power curve variation

- A large amount of power curve variation (9%) is apparent when binning by TI

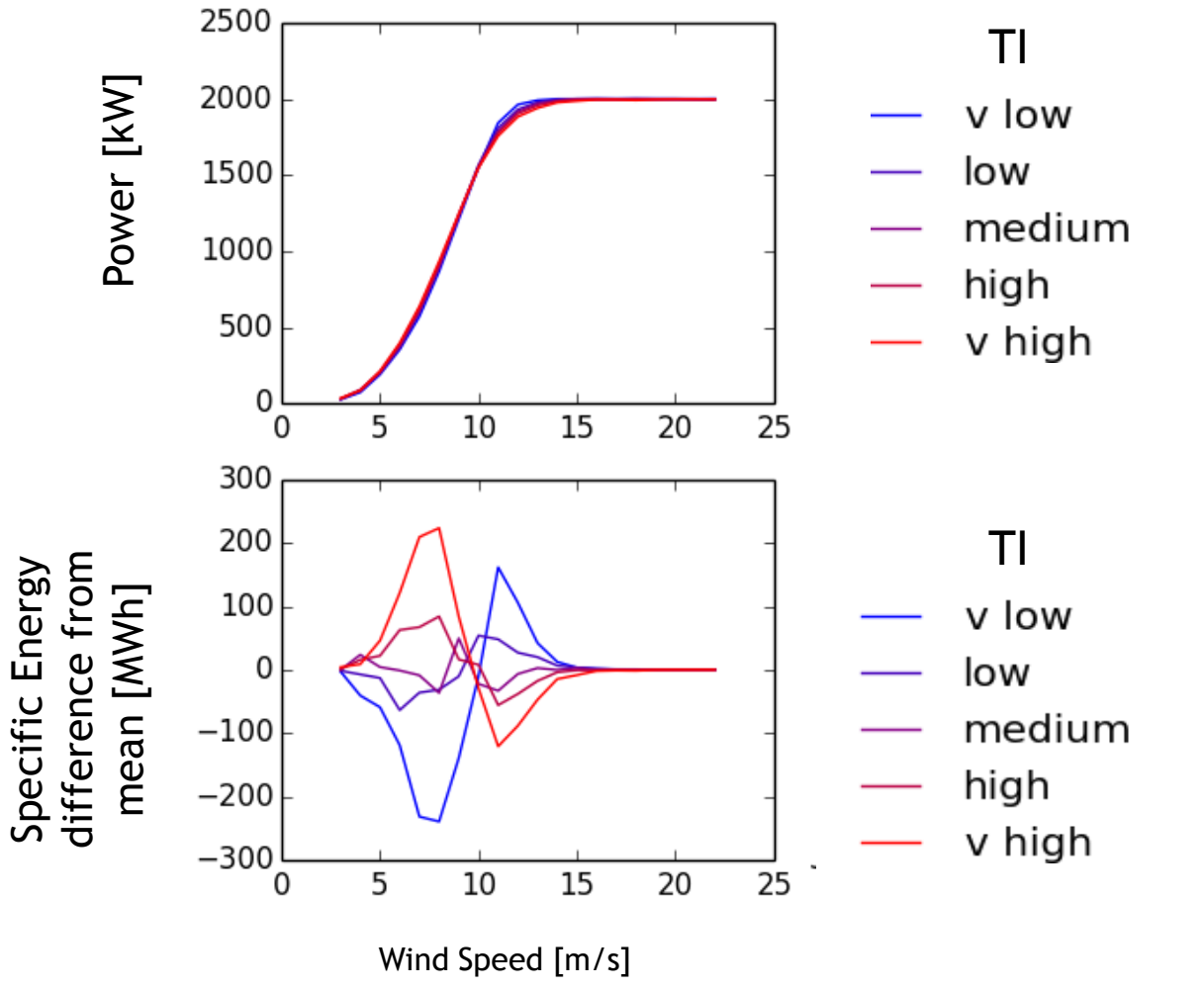
- By comparison, very little power curve variation (2%) is associated with grid frequency.





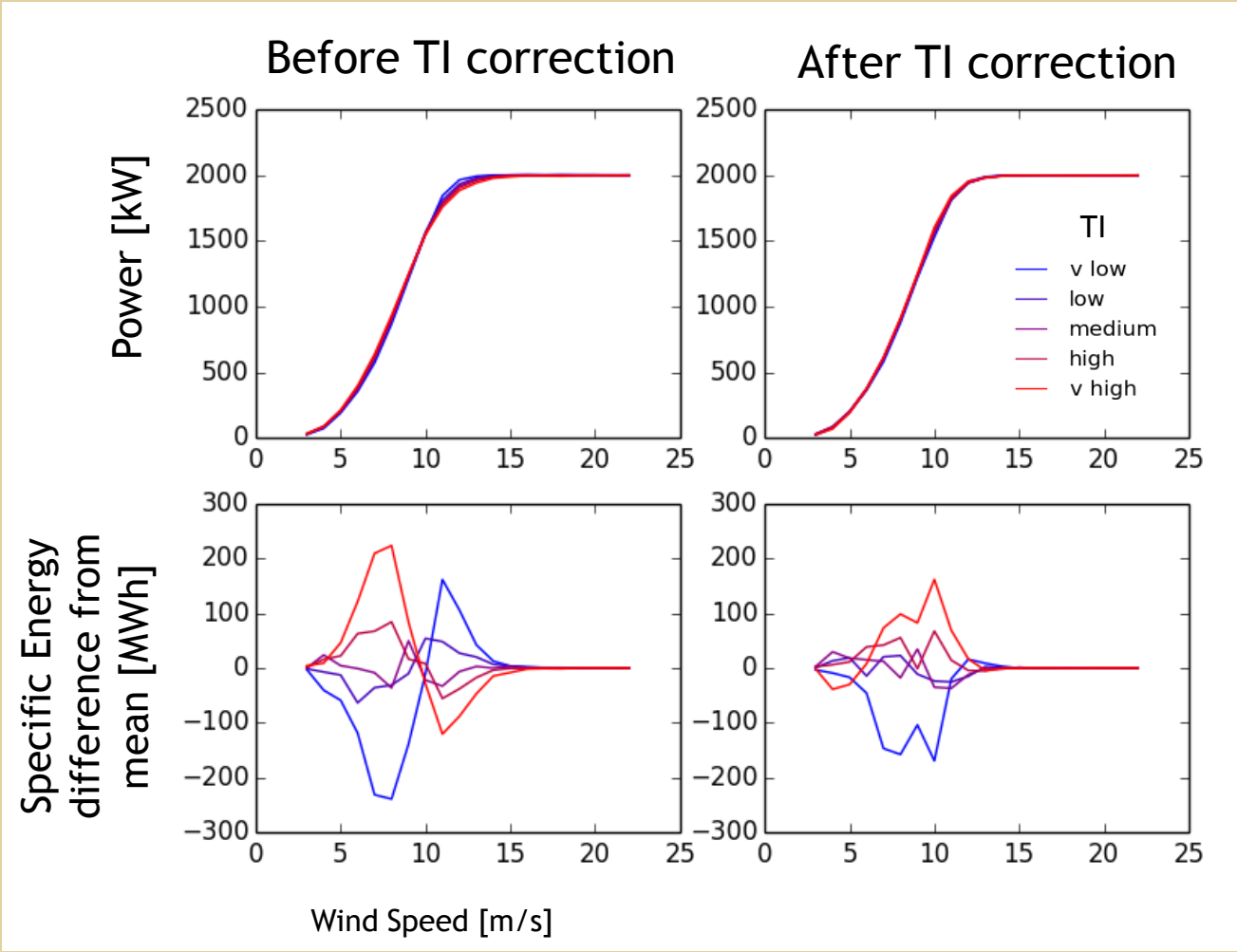
Power curve variation

- When TI is **high**, the power curve is more energetic at the ankle (4-8 m/s)
- When TI is **low**, the power curve is more energetic at the knee (11-14 m/s)



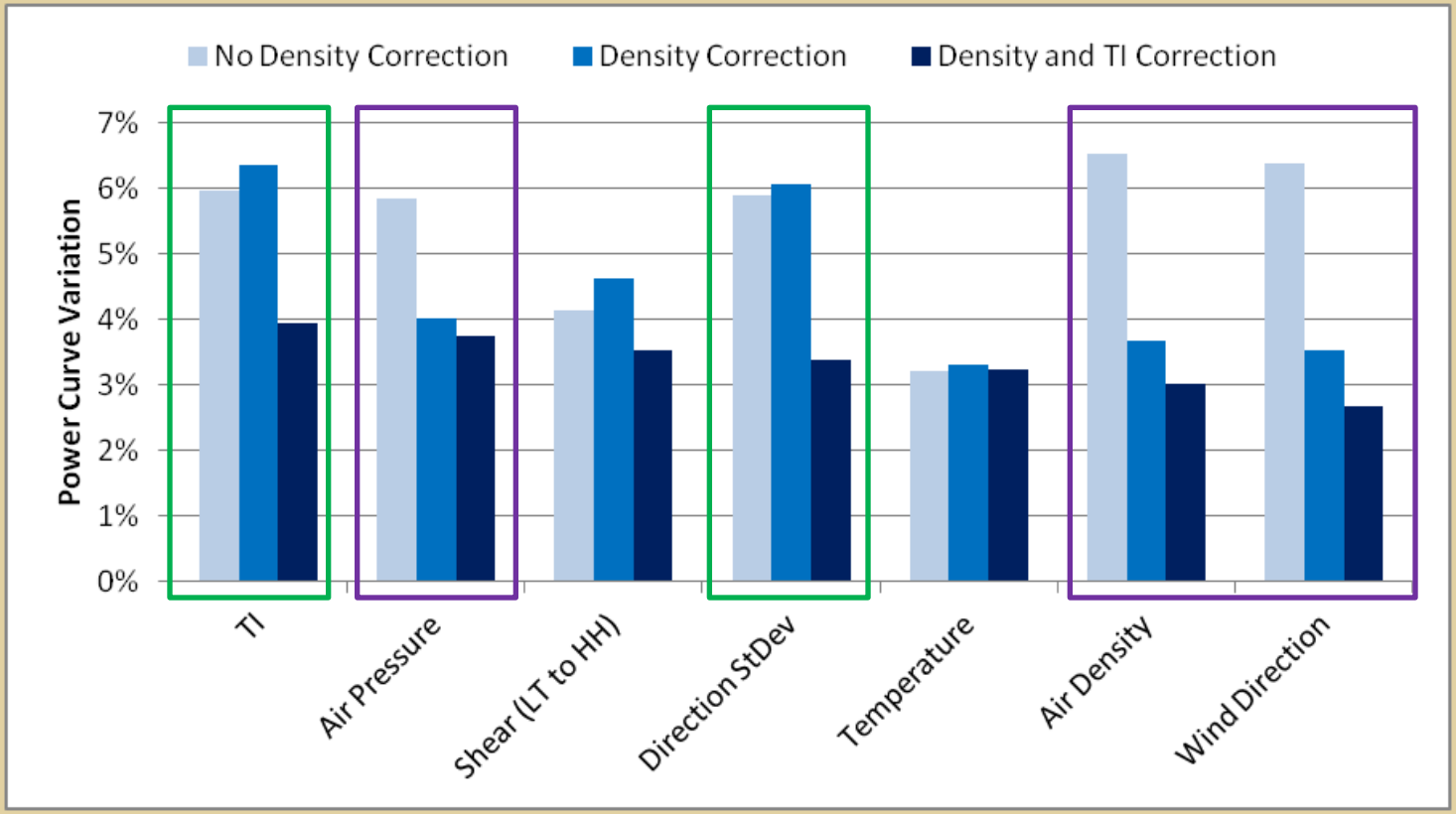
Effect of TI correction on Power Curve variation

- The TI correction successfully removes variation, particularly at the ankle and the knee
- Variation remains at 7-10m/s
- Possible over-correction for some wind speeds



Power curve variation after corrections

- Power curve variation can confirm the effect of a correction. For example, the standard air density correction and the PCWG TI correction.



Density correction reduces variation associated with Air Pressure, Air Density and Wind Direction

TI correction deals with TI and Direction StDev

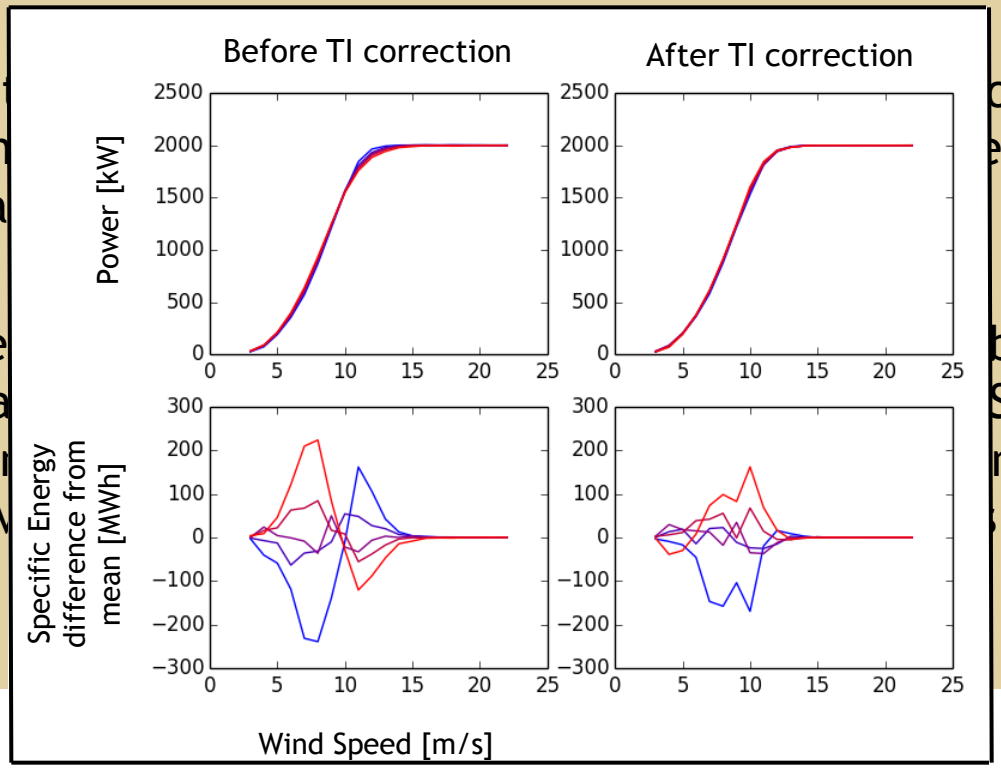
Effect of TI correction on energy prediction

- The TI correction decreases power curve variation, but would it actually increase the accuracy of an energy prediction?

- Tried predicting specific energy using the inner range power curve (proxy for warranted power curve):
  - No TI correction:
    - average error is **0.2%** (under-prediction)
    - absolute average error is **0.5%**
    - maximum error is **1.1%** (under-prediction)
  - With TI correction:
    - average error is **0.1%** (over-prediction)
    - absolute average error is **0.2%**.
    - maximum error is **0.4%** (over-prediction)

Conclusions

- Variation associated with TI and Wind Direction StDev is significantly reduced by the TI correction.
- After the TI correction is applied, significant variation remains between the ankle and the knee (approx 7-10 m/s).
- The TI correct on. This was shown by usin er range energy with a
- A suitable me been found with this data S from the shear exponer no effect on power curve v .



Next steps

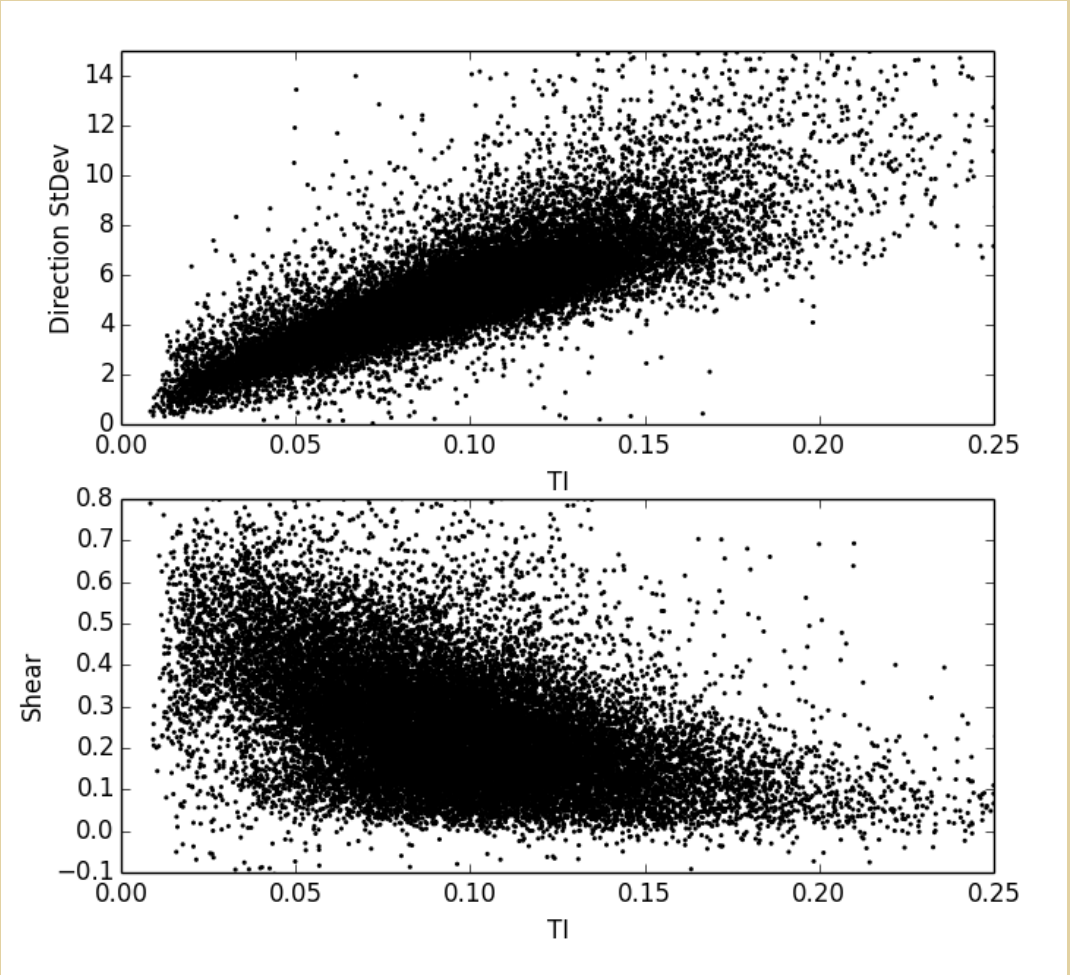
- In this data set, shear is measured only over the lower half of the rotor. By including RSD data we can hopefully:
  - Validate the shear correction in the same way the TI correction has been validated.
  - Further study the power curve variation between the ankle and knee.

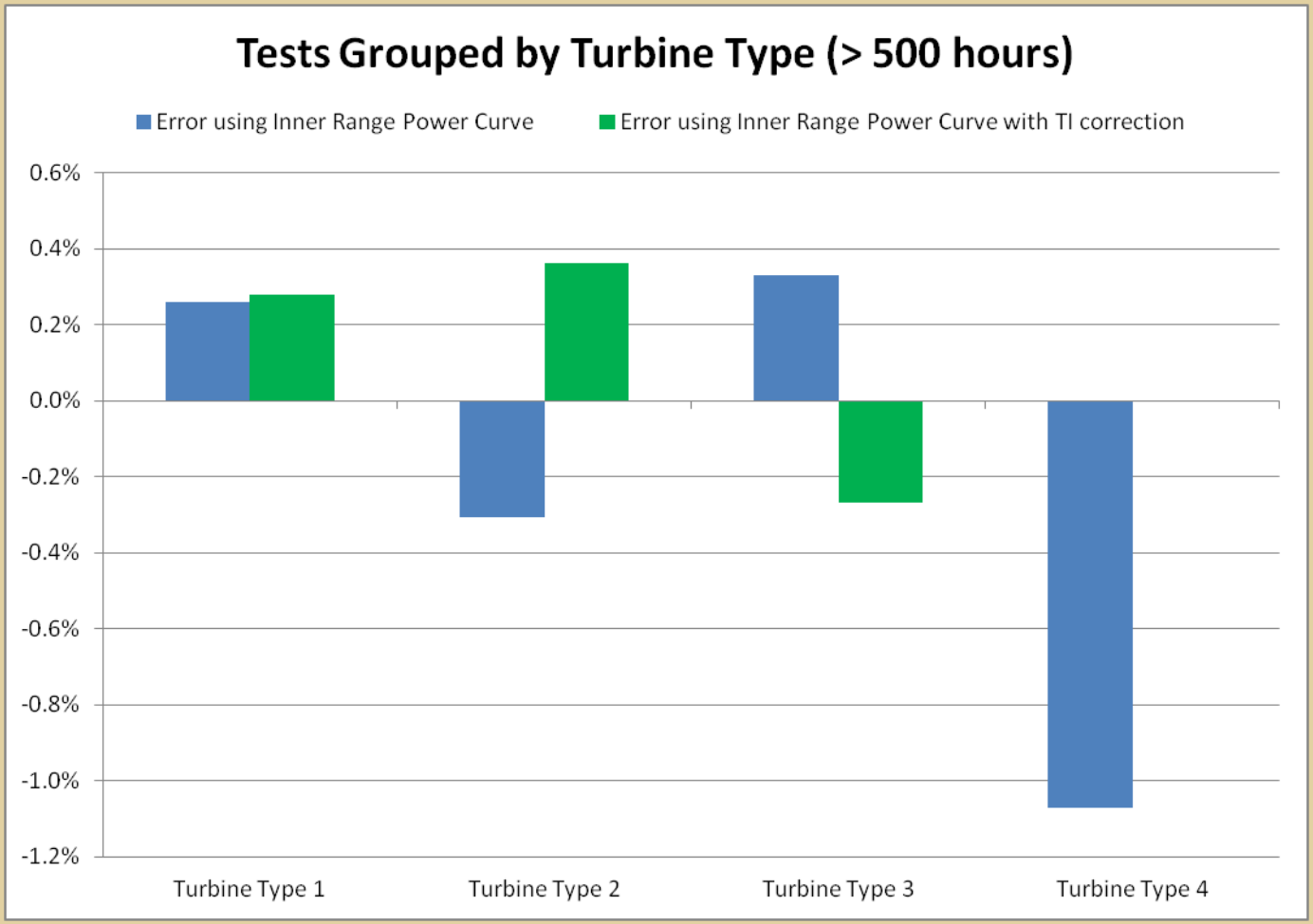
- The TI correction seems to work well with real data. Is the TI correction applicable to a **warranted power curve**? This is a key question for pre-construction energy yield predictions.

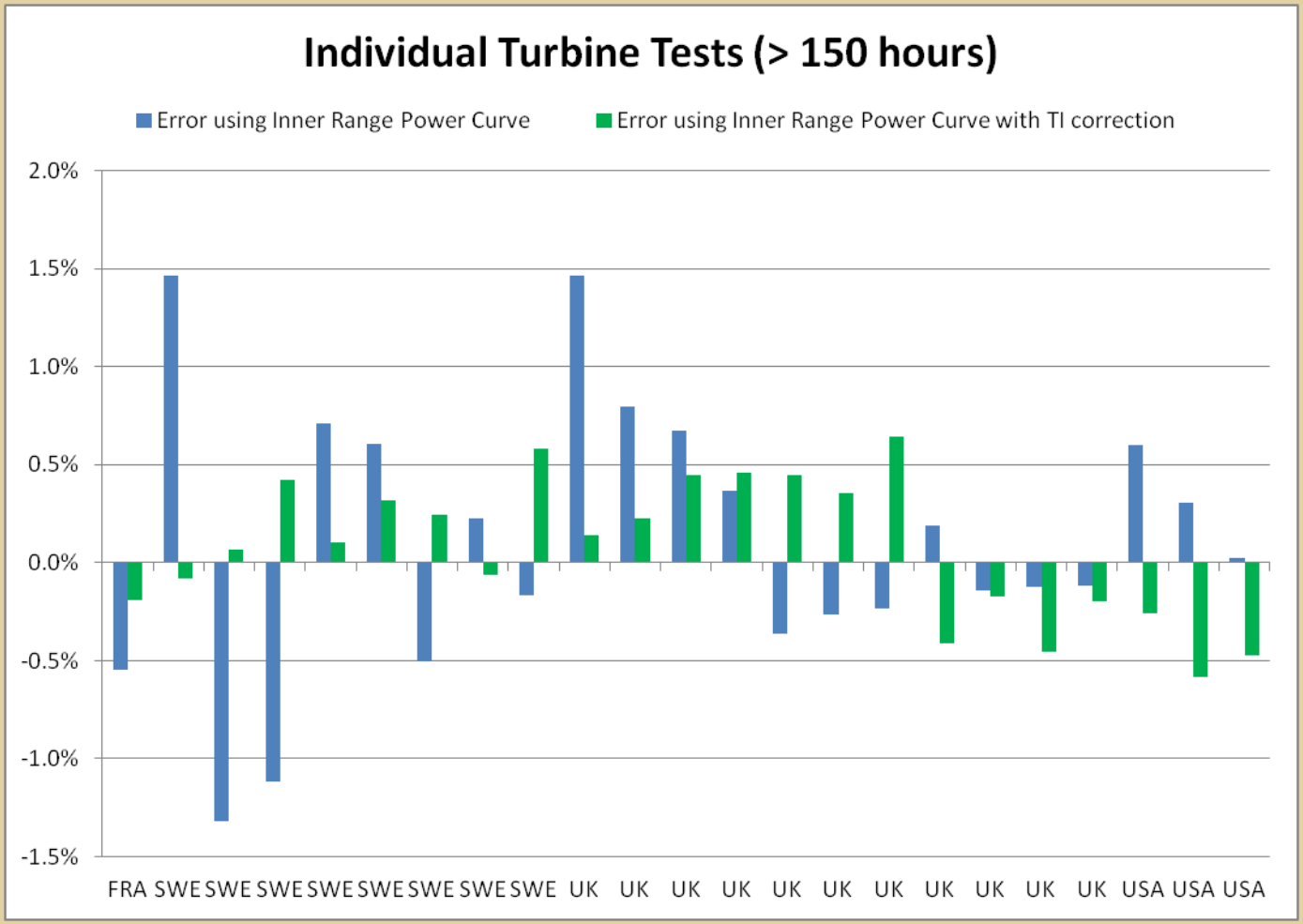

power for good

TI and StDev of Wind Direction

- r^2 is 0.6 for TI and Wind Direction StDev
- r^2 is 0.1 for TI and Shear




Tests Grouped by Turbine Type (> 500 hours)
Error using Inner Range Power Curve
Error using Inner Range Power Curve with TI correction
0.6%
0.4%
0.2%
0.0%
-0.2%
-0.4%
-0.6%
-0.8%
-1.0%
-1.2%
Turbine Type 1
Turbine Type 2
Turbine Type 3
Turbine Type 4


Individual Turbine Tests (> 150 hours)
Error using Inner Range Power Curve
Error using Inner Range Power Curve with TI correction
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
-1.5%
FRA SWE SWE SWE SWE SWE SWE SWE SWE UK UK UK UK UK UK UK UK UK UK UK USA USA USA

longest single test in data set, ~1600 hours, UK