Accounting for wind shear and turbulence in power curves

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Ice and Rocks III
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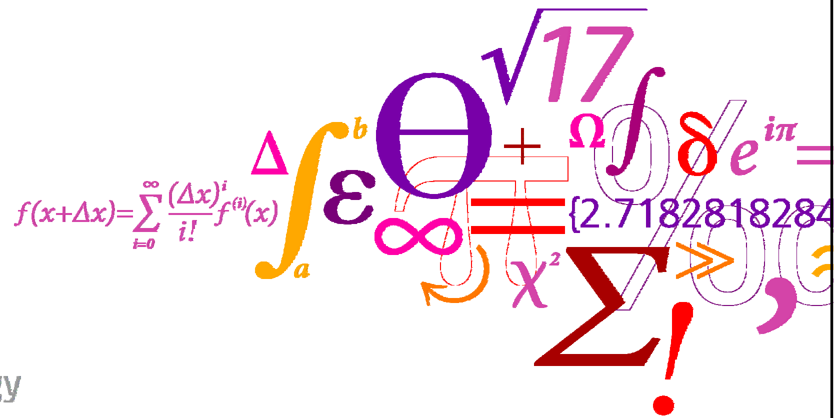
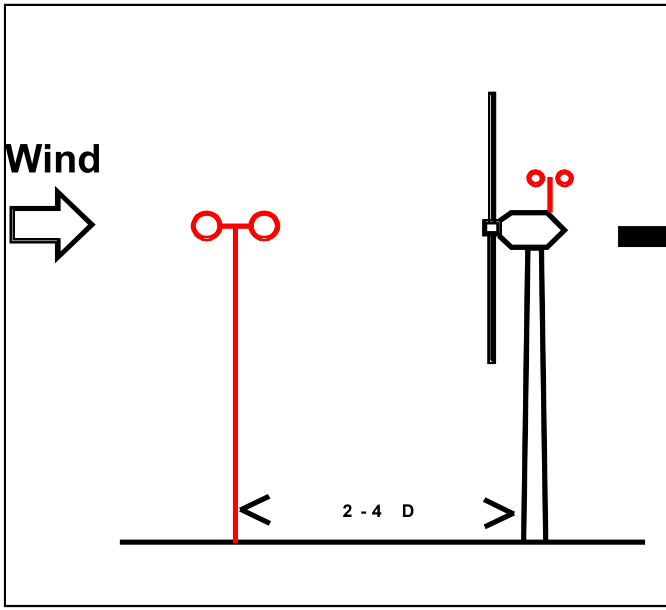


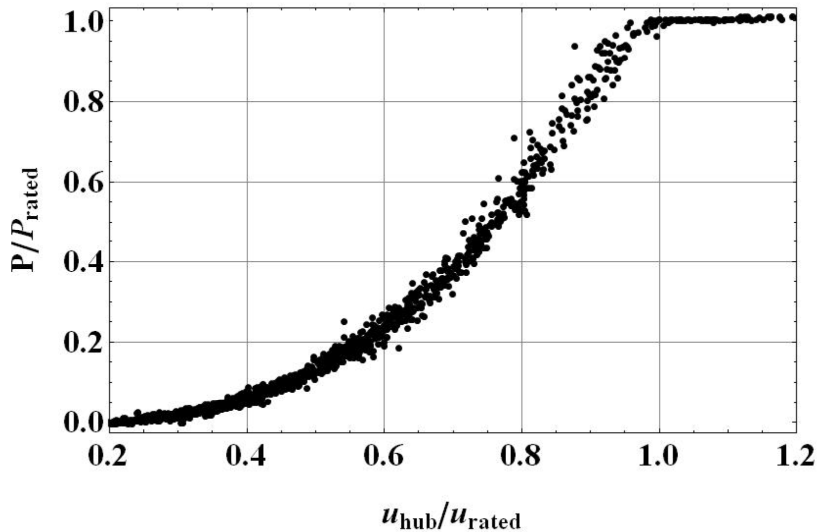
Outline

- Problem
- Wind shear effect on power curve
- Equivalent wind speed
- Turbulence effect on power curve
- A. Albers' normalisation method
- Combination of both methods
- Conclusions

Power curve measurement

IEC standard 61400-12-1





Scatter in power curve:

-wind turbine operation (control,…)

-measurements error (anemometer, …)

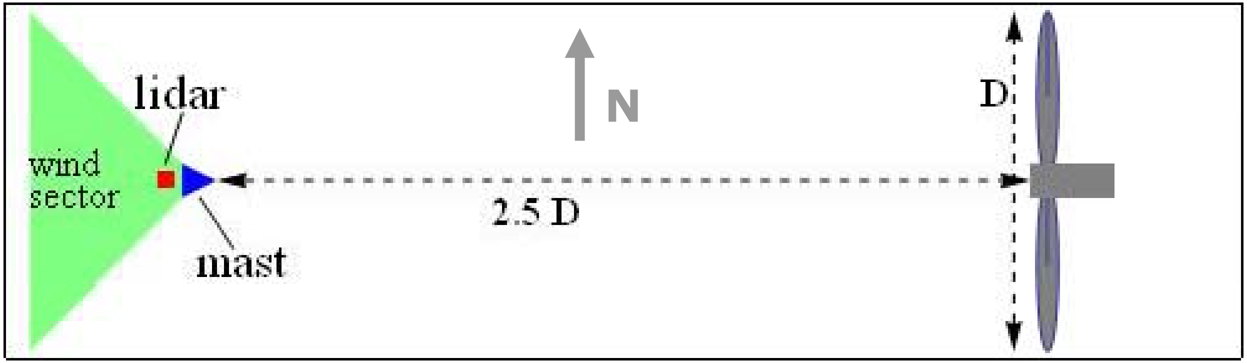
-**wind conditions (shear, veer, turbulence)**

Experimental Setup

Risø DTU's Test Site for large Wind Turbines,

Høvsøre,

Western Denmark



Experimental Setup

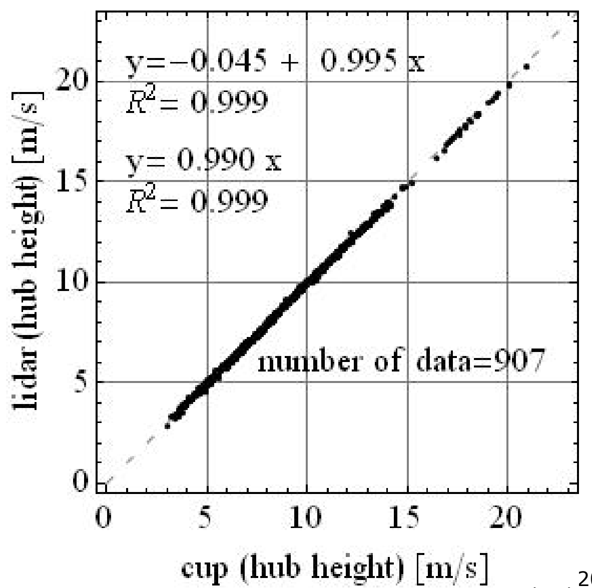
Filters:

•wind direction;

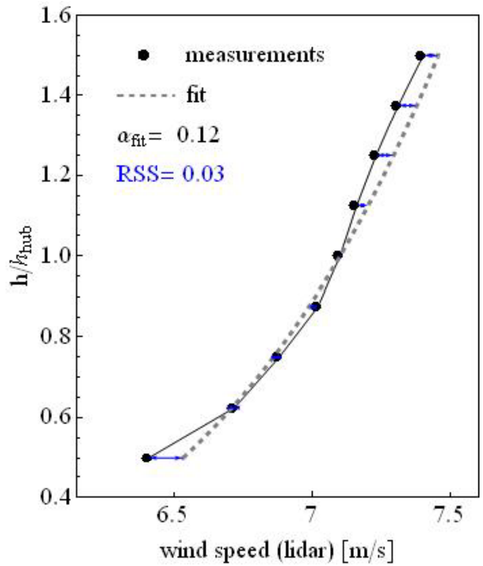
•no rain;

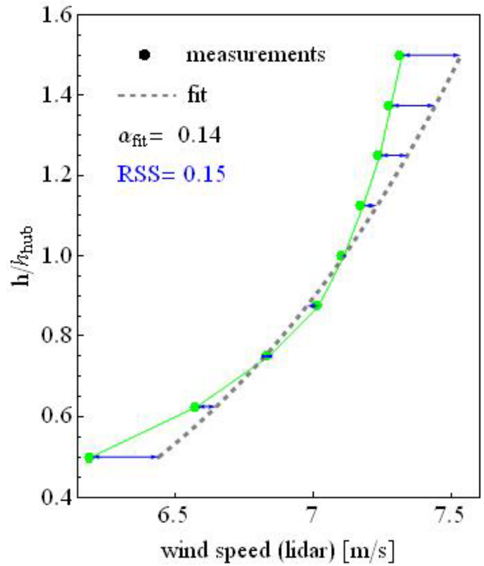
•lidar signal availability 100% at all heights;

•turbine status=1.



Profiles classification





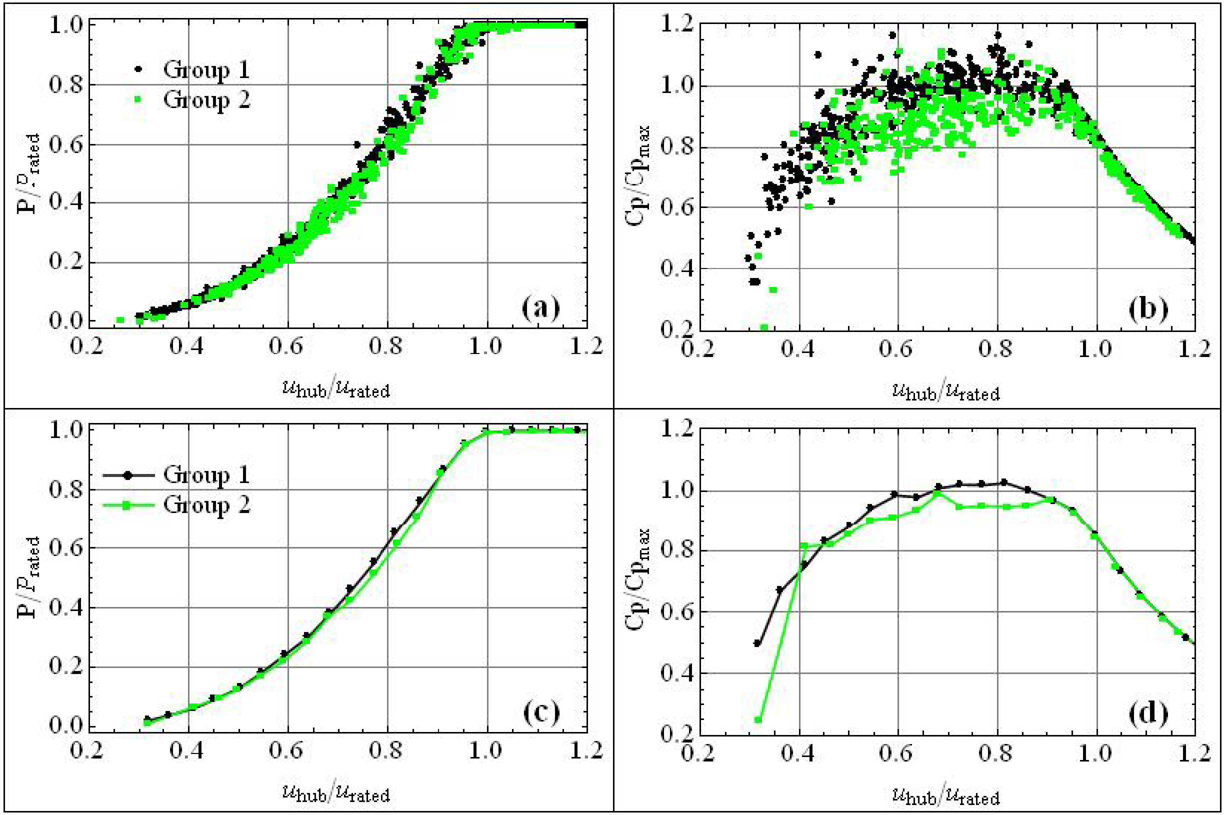
$$u_{fit}(z) = u_{hub}^{m}\left(\frac{z}{z_{hub}}\right)^{\alpha_{fit}}$$

$$RSS = \sum_{i}\left(u_{fit}(z_i) - u_i^{m}\right)^2$$

RSS<0.1

RSS>0.1

Effect of ignoring the wind speed shear on the power performance measurement



→ 2 different power curves for the 2 groups of profiles

Kinetic energy flux approximation

Kinetic energy in the wind
(assuming horizontal homogeneity):

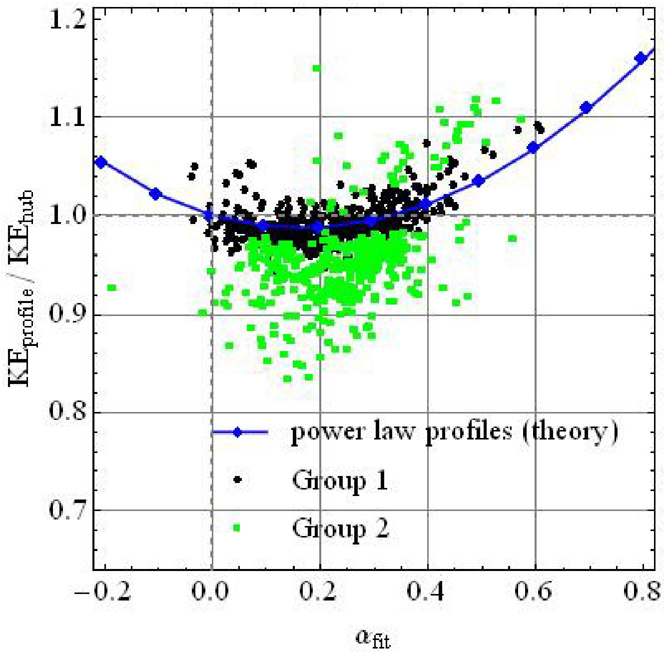
$$KE = \left\langle \int_z \tfrac{1}{2}\rho(z)u(z)^3\, C(z)dz \right\rangle$$

First approximation
(constant profile):

$$KE \approx \tfrac{1}{2}\rho_{hub}\left\langle u_{hub}\right\rangle^3 A = KE_{hub}$$

Better approximation
(measured profile):

$$KE \approx \tfrac{1}{2}\sum_i \rho_i \left\langle u_i\right\rangle^3 A_i = KE_{prof}$$



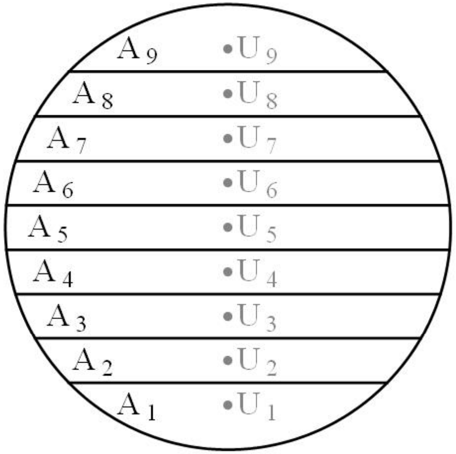
→ Overestimation of the kinetic energy flux because speed shear is ignored.

Equivalent wind speed

$$KE_{prof} = \tfrac{1}{2}\sum_i \rho \langle u_i \rangle^3 A_i$$

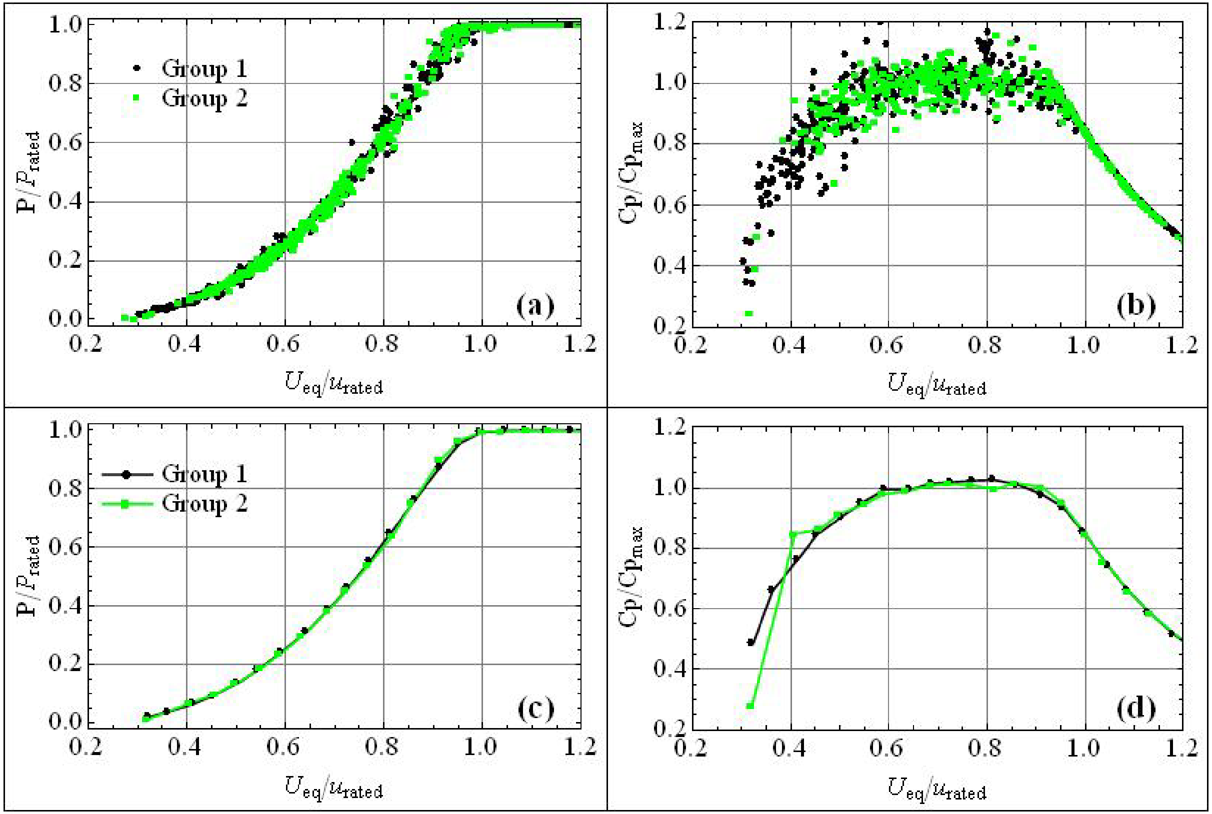
$$= \tfrac{1}{2}\rho U_{eq}^3 A$$

with $$\boxed{U_{eq} = \left(\sum_i \langle u_i \rangle^3 \frac{A_i}{A} \right)^{1/3}}$$



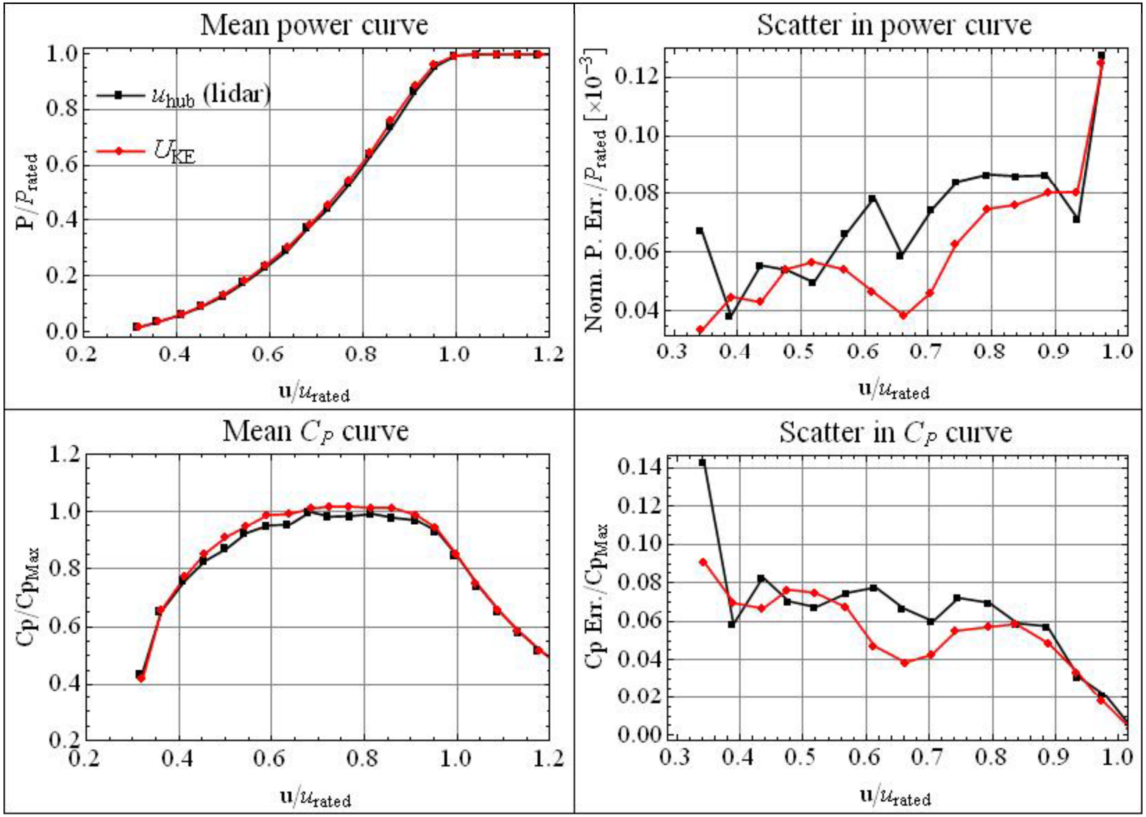
Then $$C_p = \frac{P}{\tfrac{1}{2}\rho U_{eq}^3 A} = \frac{P}{KE_{prof}}$$

Using the equivalent wind speed



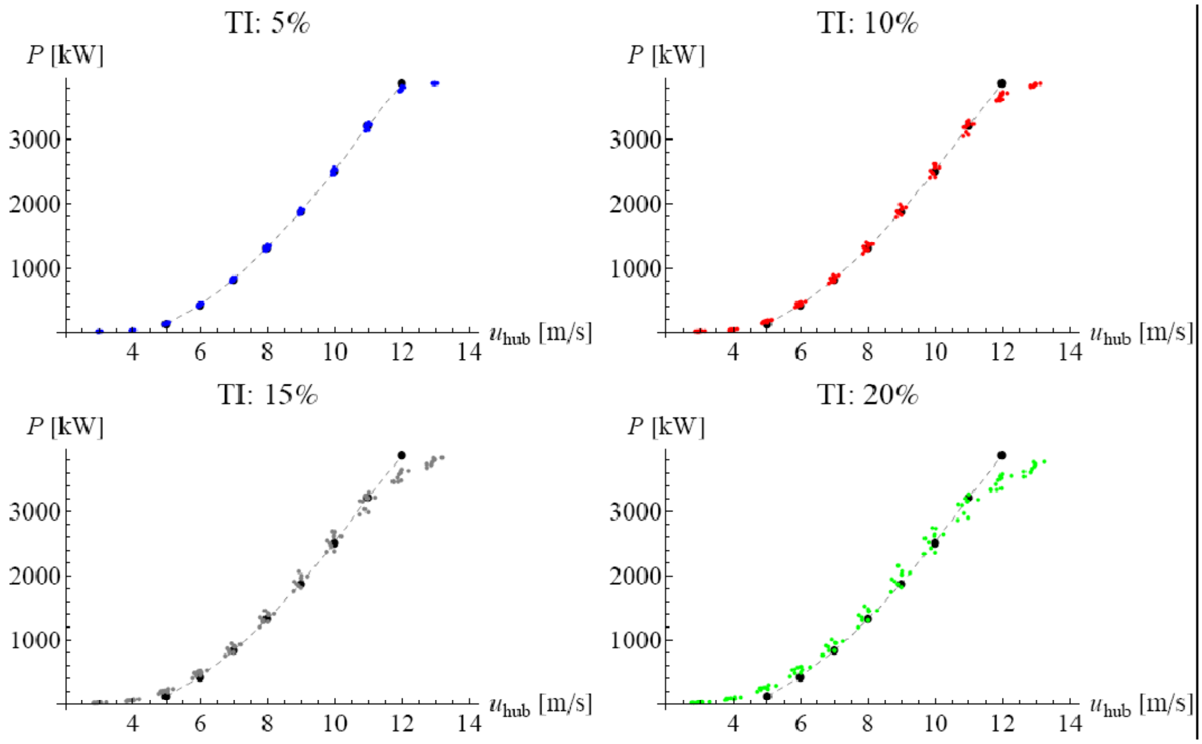
→ Same power curve for the both groups of profiles

Consequence on the unified dataset

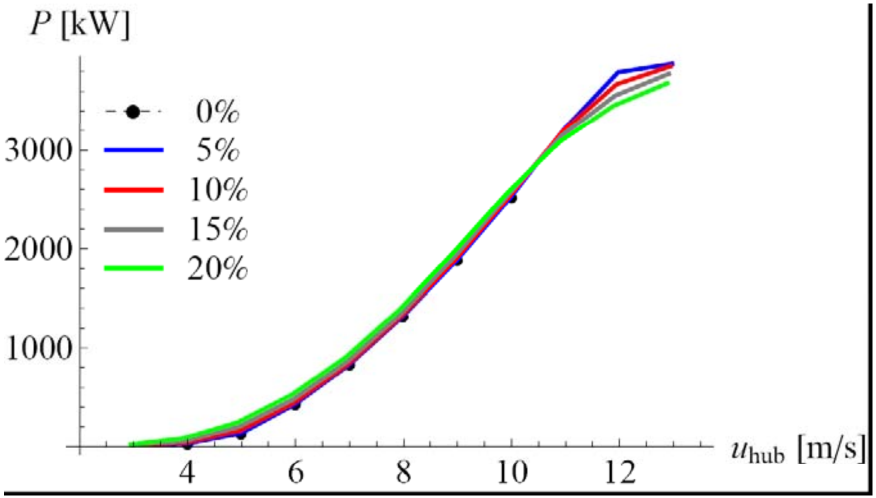


→ Reduction of the scatter

Effects of turbulence



Effects of turbulence



Increasing turbulence intensity:

1 – Increases the scatter;

2 – Modifies the shape of the mean power curve

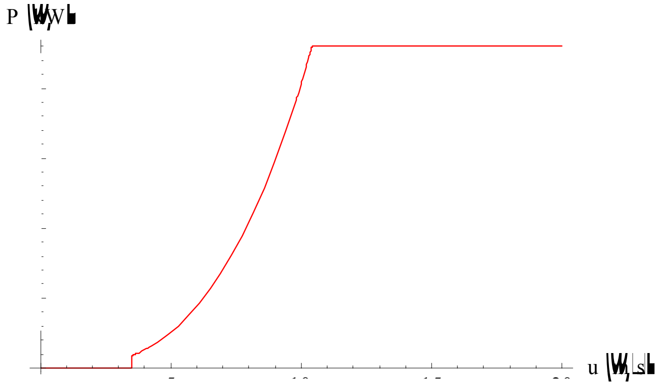
A. Albers' turbulence normalisation method

Based on the assumption:

"the turbine always follows the same power curve (the 0%-TI power curve)"

Step1:

0% turbulence intensity power curve



Step2:

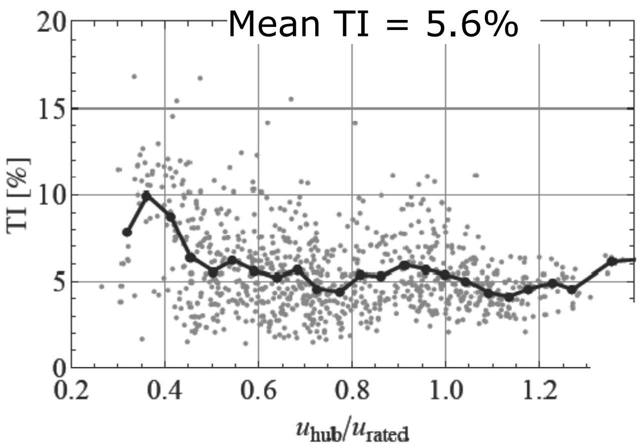
Simulation of the power curve for a given turbulence intensity (TI_{target})

$$P_{sim} = \int_{v=0}^{\infty} P_{0\%}(v) f(v) dv$$

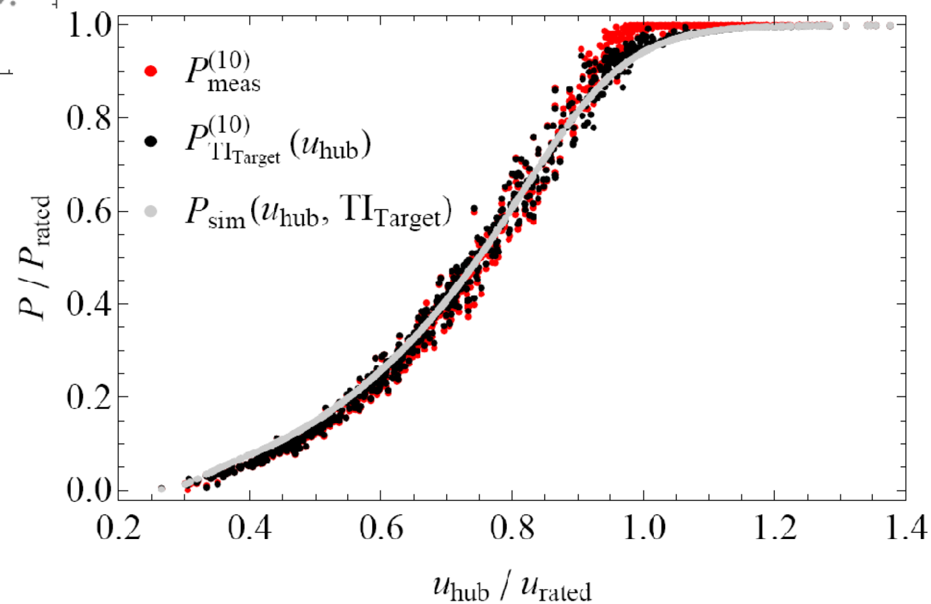
f(v): 10 minute wind speed distribution

Reference: A. Albers, *Turbulence normalisation of power curve data*, EWEC 2010

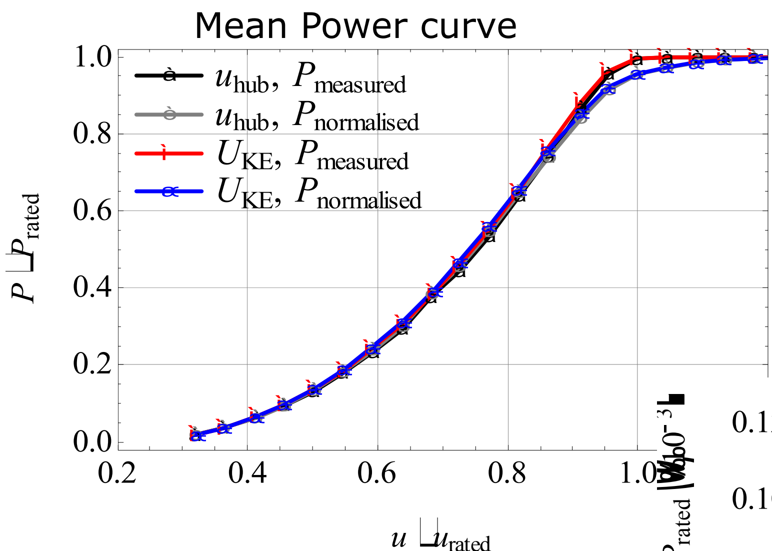
A. Albers’ method: Application

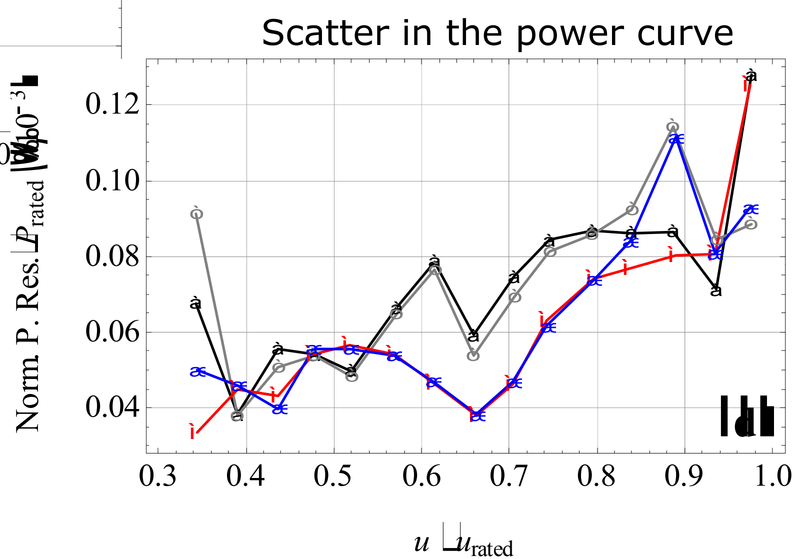


Normalisation to 10%



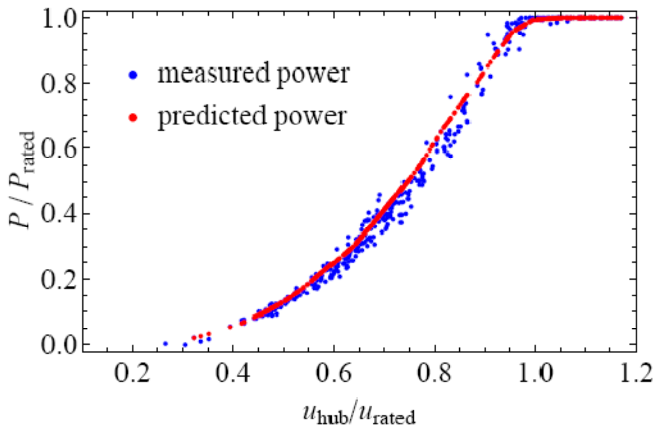
Combination of A. Albers' method with the equivalent wind speed

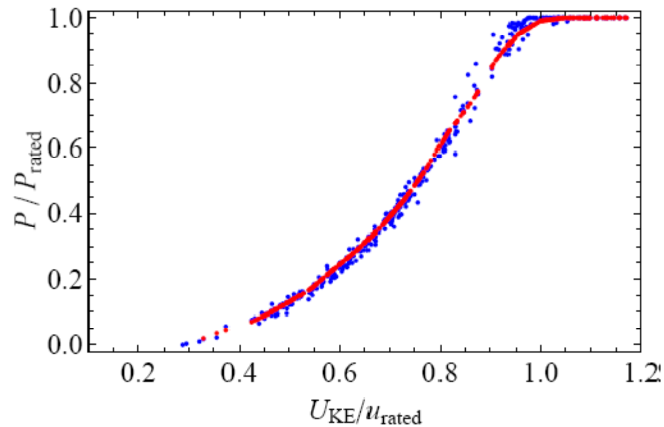




More repeatable power curve

Power curve less sensitive to wind conditions → More repeatable power curve ("transferable") → Better prediction of AEP





Conclusions

- Equivalent wind speed method normalises the power curve for the wind shear effect;
- A. Albers' method normalises the power curve for turbulence intensity;
- Both methods can be combined;
- Results in a power curve less sensitive to shear and turbulence;
- More repeatable power curve;
- Successful experimental application of the method with a lidar.

- Methods need to be fully proven in flat terrain;
- then to be adapted to complex terrain:
  - Terrain calibration accounting for whole wind profile
  - Lidar measurements

  → could use CFD modelling?

Thank you for your attention

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