Equivalent wind speed for AEP

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Working group power curve measurement in non-standard flow

12-03-2013

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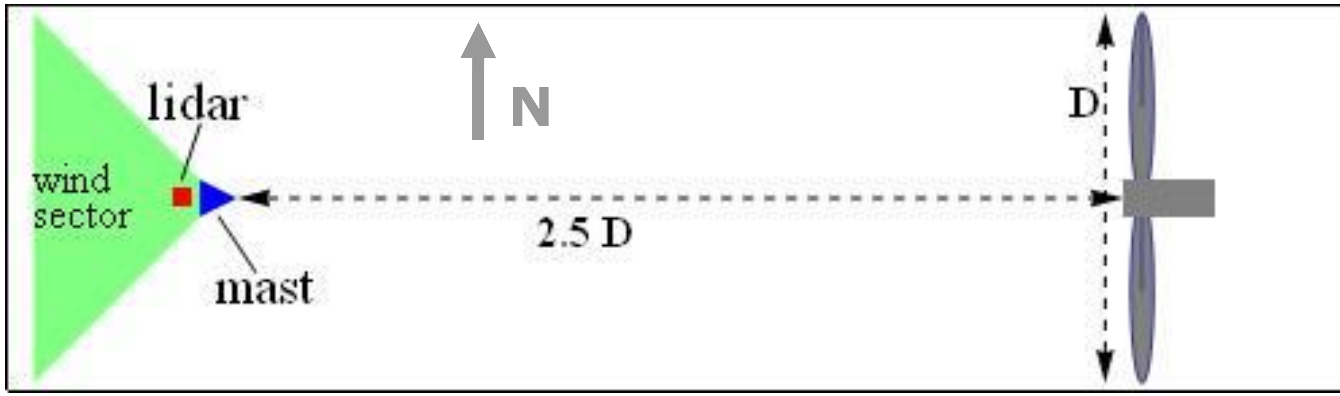
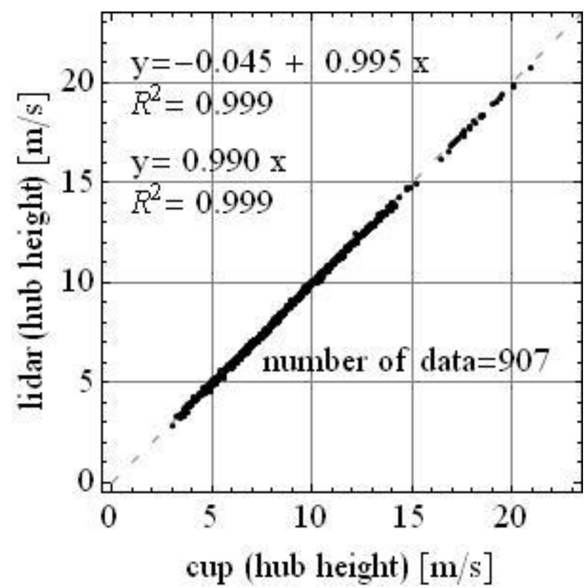
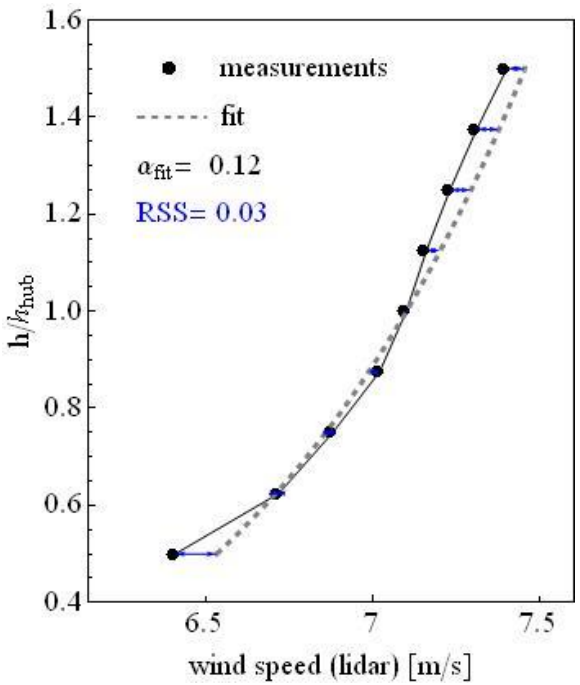
Experimental setup & Data processing

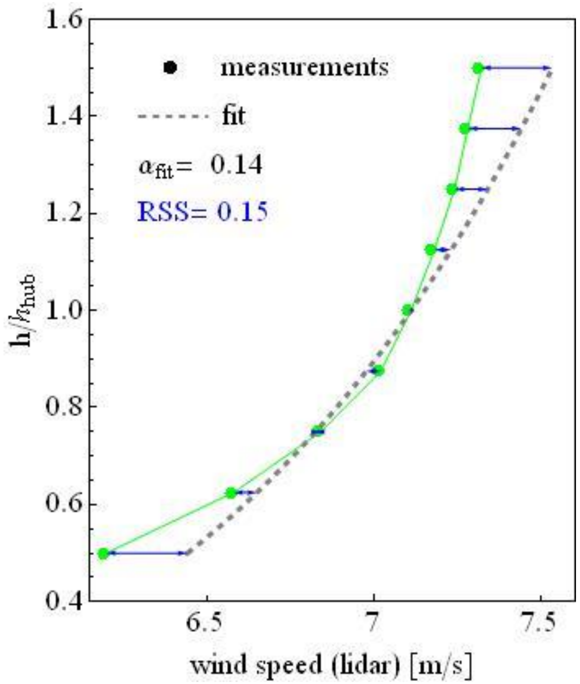


Filters:
- wind direction;
- no rain;
- lidar signal availability 100% at all heights;
- turbine status=1.



Profiles classification





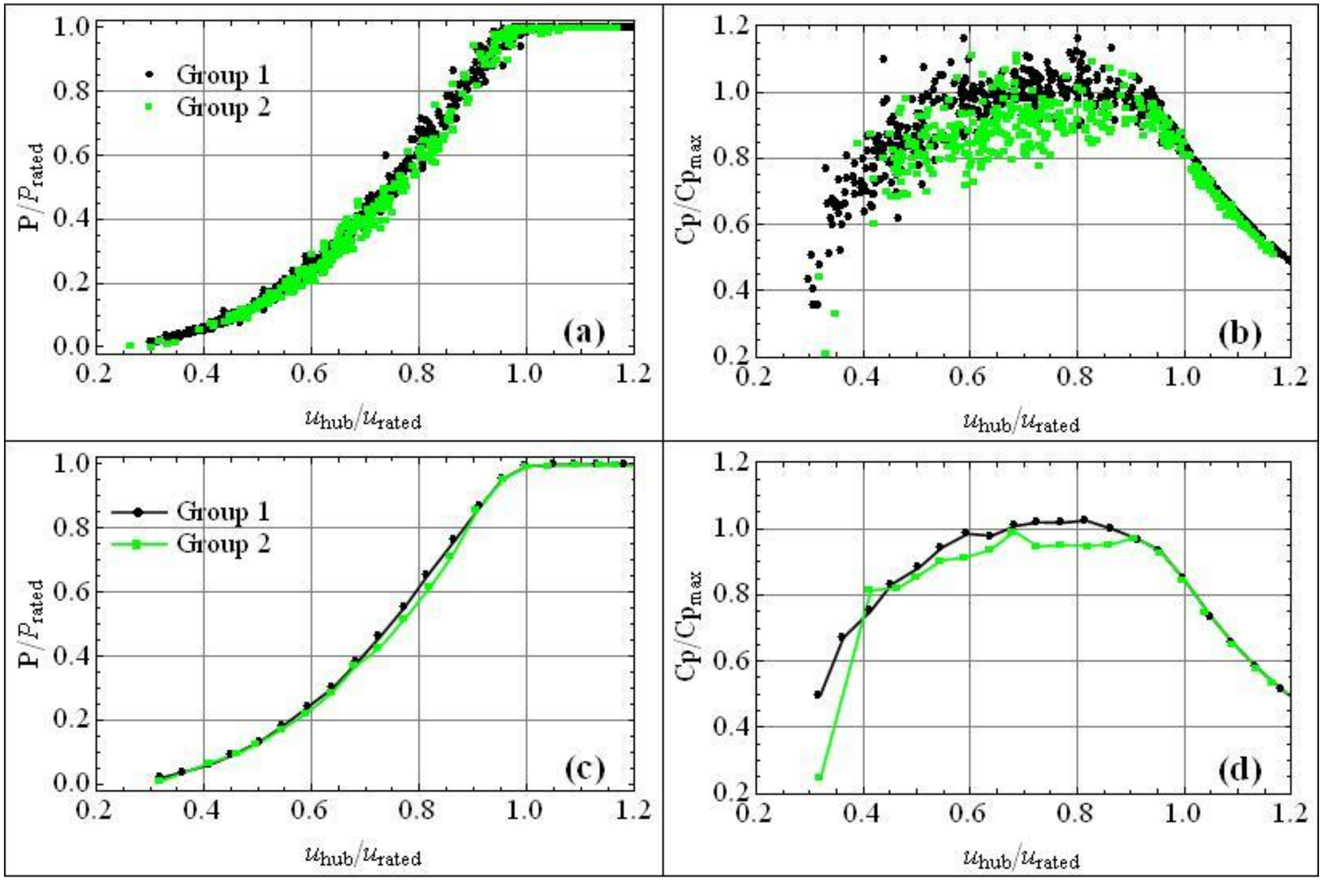
$$u_{fit}(z) = u_{hub}^{m} \left(\frac{z}{z_{hub}} \right)^{\alpha_{fit}}$$

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

RSS<0.1

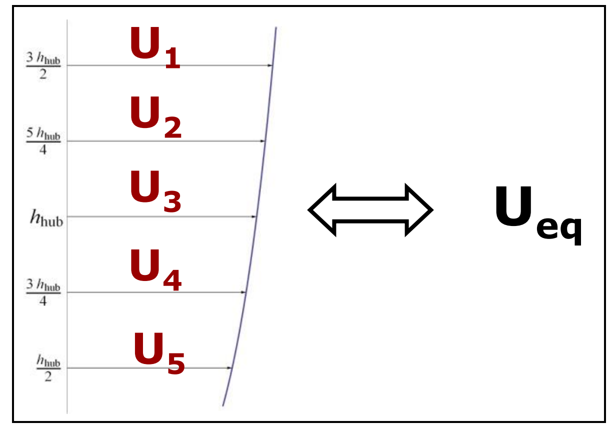
RSS>0.1

Standard power curve



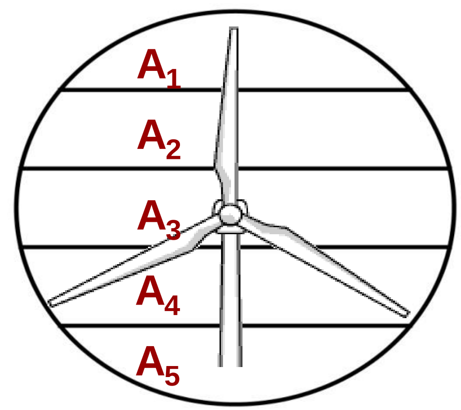
→ 2 groups of profiles result in 2 different power curves

Equivalent wind speed



Concept:

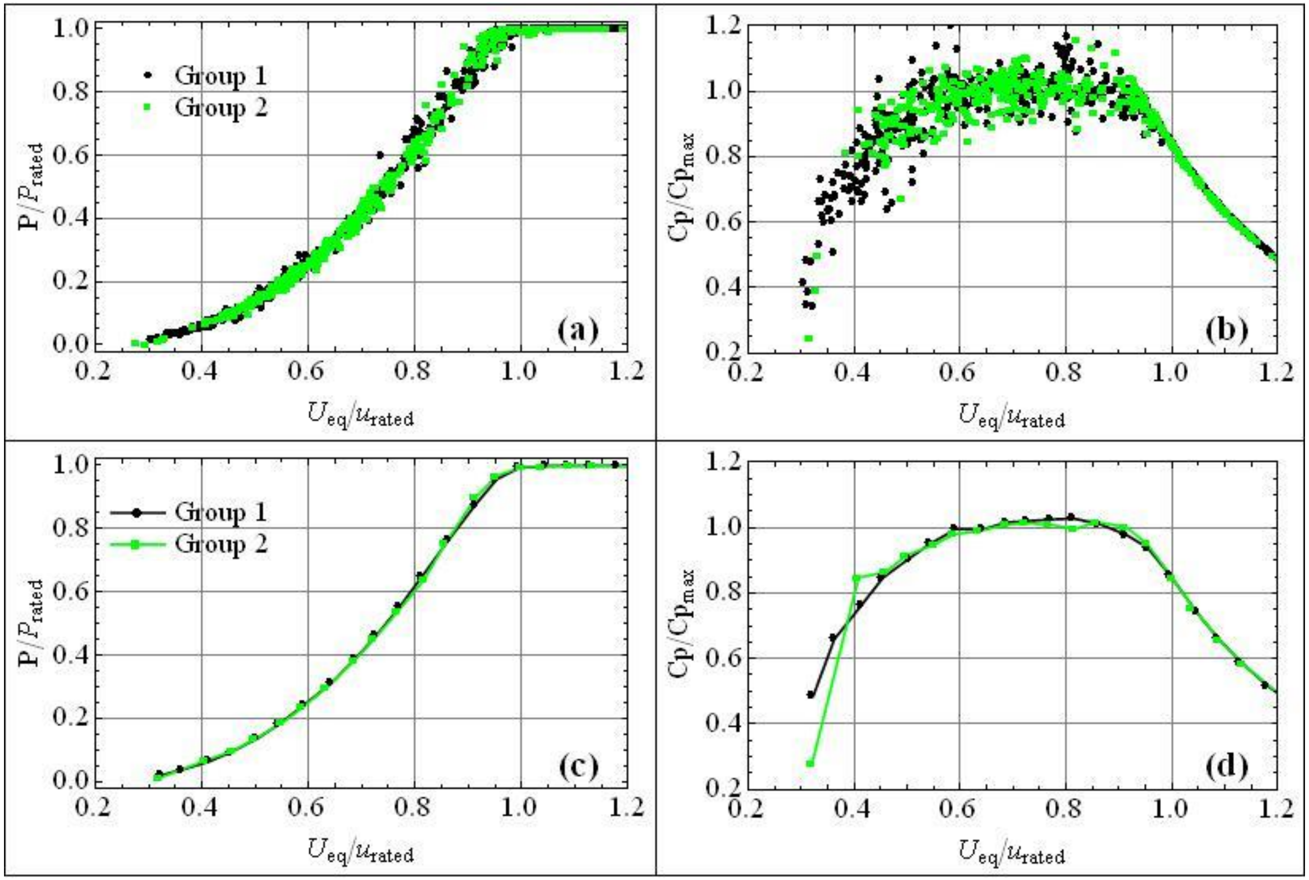
One wind speed representative of the whole wind speed profile in front of the wind turbine rotor in term of power production



Definition:

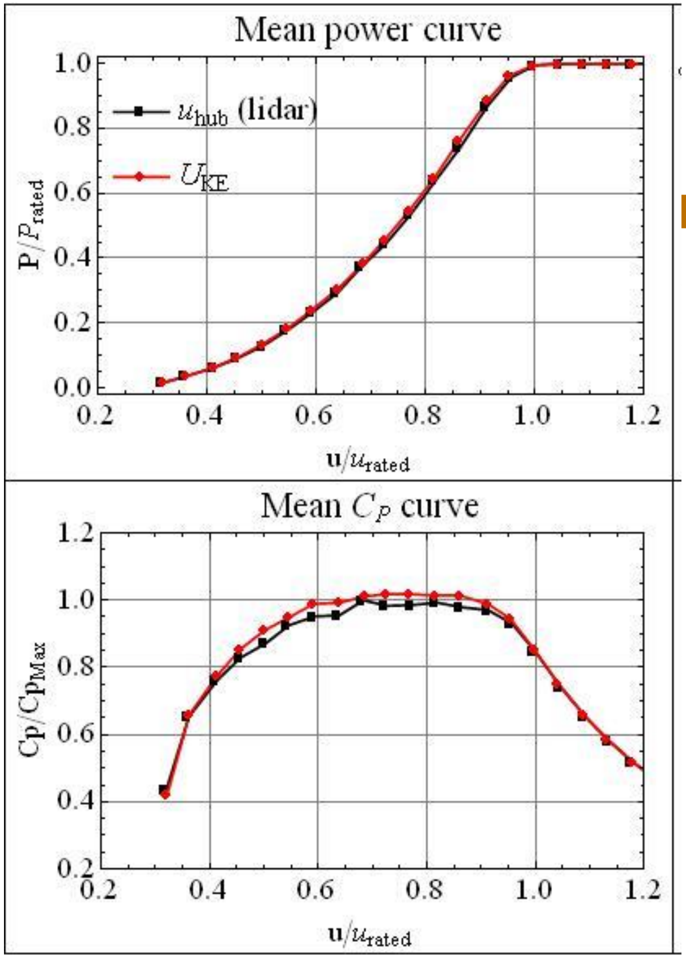
$$U_{KE} = \left(\frac{1}{A} \int_{-R}^{R} u(z)^3 c(z) dz \right)^{1/3} \approx \left(\sum_{i=1}^{N} u_i^3 \frac{A_i}{A} \right)^{1/3}$$

Power curve with equivalent wind speed



→ Similar power curves are obtained for both groups of profiles

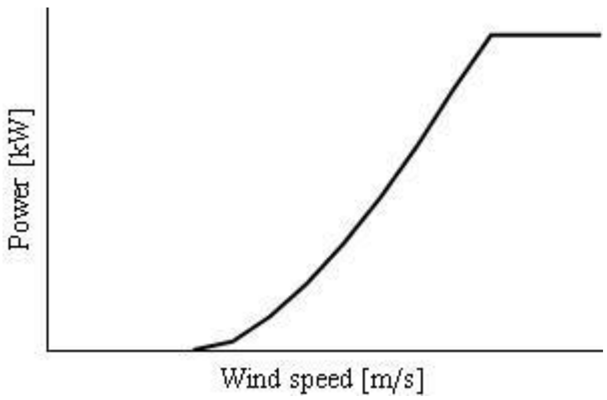
Comparison of the power curves



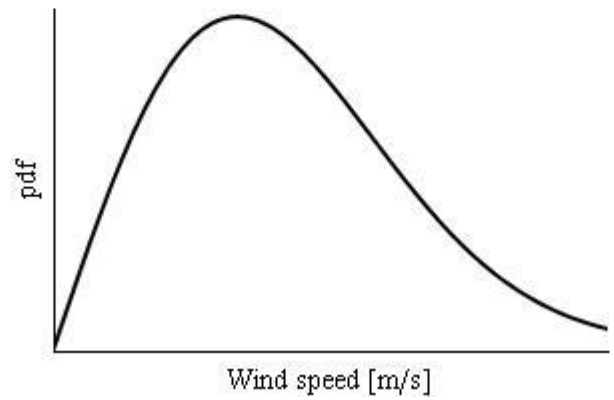
Difference due to the shear distribution during the power curve measurement.

How can the equivalent wind speed power curve be used for AEP estimation?

Annual Energy Production

AEP = 

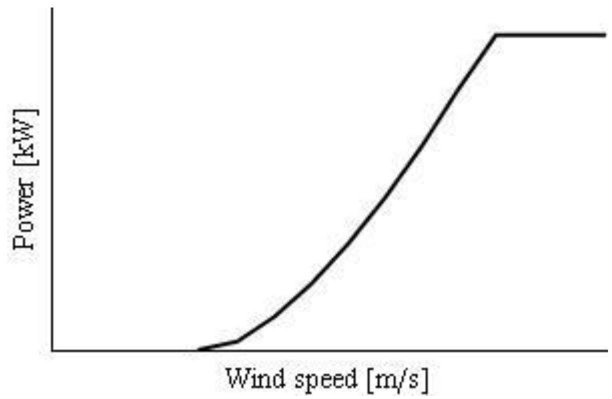
Power curve at
wind farm site

X 

Wind speed distribution
at wind farm site

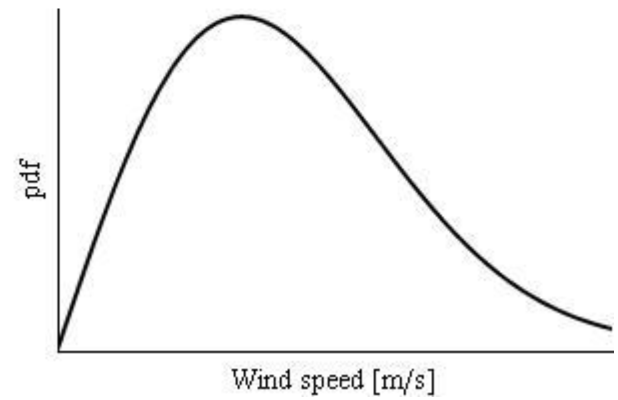
AEP estimation

Predicted AEP =



Reference power curve: measured at a reference site

X



Wind speed distribution at wind farm site

Illustration of the 2 cases with Høvsøre data

Data
Group 1
Reference site

Data
Group 2
Estimated site

Reference power curve

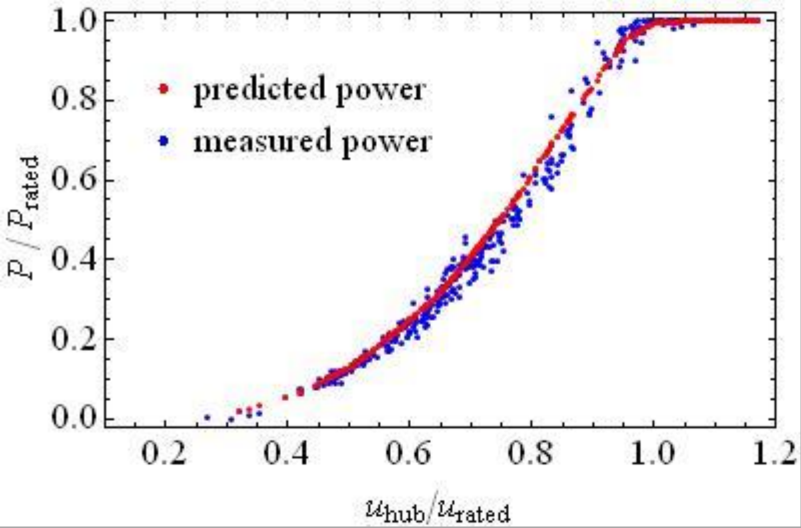
Measured wind speed

Energy yield estimation

U_{hub} power curve	U_{hub} distribution
U_{eq} power curve	U_{eq} distribution

Illustration of the 2 cases with Høvsøre data

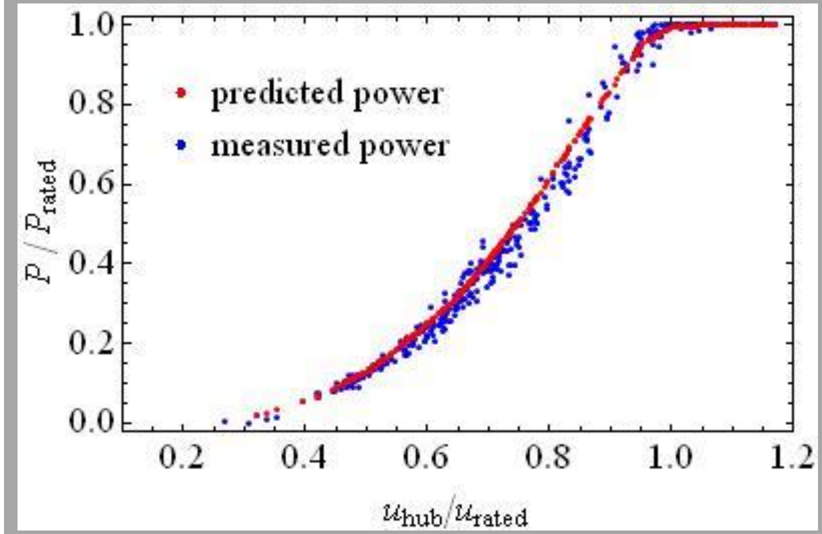
Case 1



prediction: + 1.76%

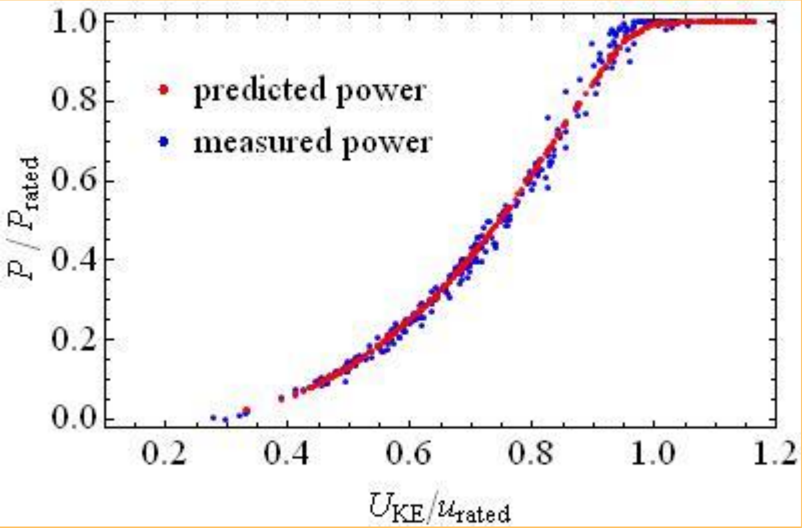
Illustration of the 2 cases with Høvsøre data

Case 1



prediction: + 1.76%

Case 2



prediction: 0.005%

→Improved AEP estimation by using the equivalent wind speed both in the power curve and the wind speed distribution.

BUT…

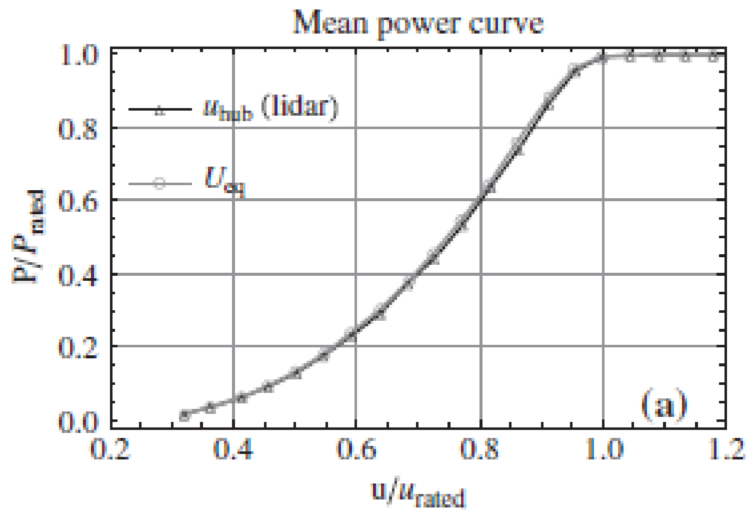
… what if the distribution of the rotor equivalent wind speed at the assessed site is not available?

More realistic application
Power curve and wind distribution from 2 separate sites

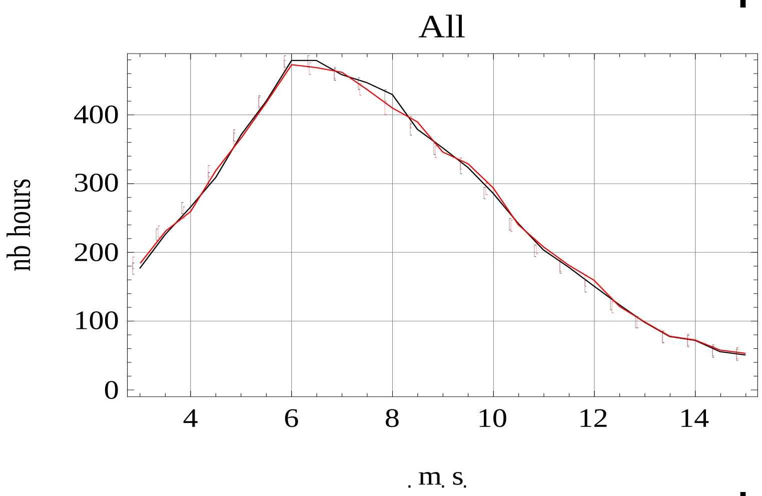
DTU's Test Site for Large Turbines
Høvsøre

More realistic application
Power curve and wind distribution from 2 separate sites

Power curve measured at Høvsøre in Feb-March 2009



Wind speed distribution measured at Østerild May 2010- May 2011



4 possible combinations, but no turbine yet.

Combination 1:

- Equivalent power curve

→ Account for the shear during the power curve measurement; expected to be the same power curve at any site

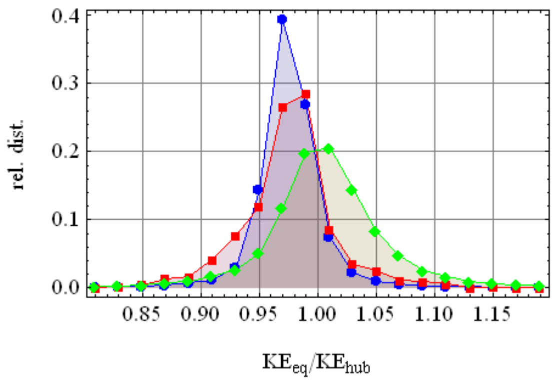
Reference AEP

- Equivalent wind speed distribution

→ Account for the shear at Østerild

Combination 2:

- Hub height power curve



- Hub height wind speed distribution

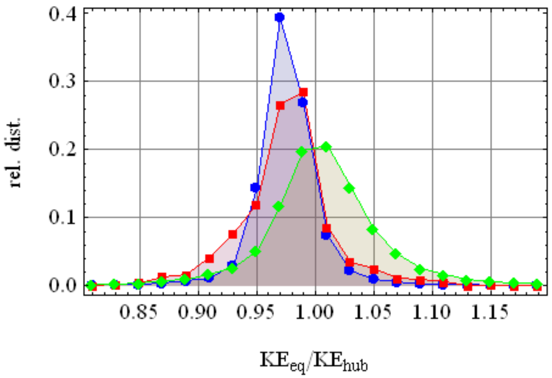
→ Underestimates the power produced because of the shear during the power curve measurement.

-2.3%

→ Slightly underestimates the energy available because does not account for the shear at Østerild (assumes constant wind speed profiles)

Combination 3:

- Equivalent power curve



- Hub height wind speed distribution

→ Account for the shear during the power curve measurement; expected to be the same power curve at any site

-0.5%

→ Slightly underestimates the energy available because does not account for the shear at Østerild (assumes flat wind speed profiles)

Summary

	U_hub power curve	Ueq power curve
U_hub distribution	-2.3%	-0.5%
U_eq distribution		**(ref)**

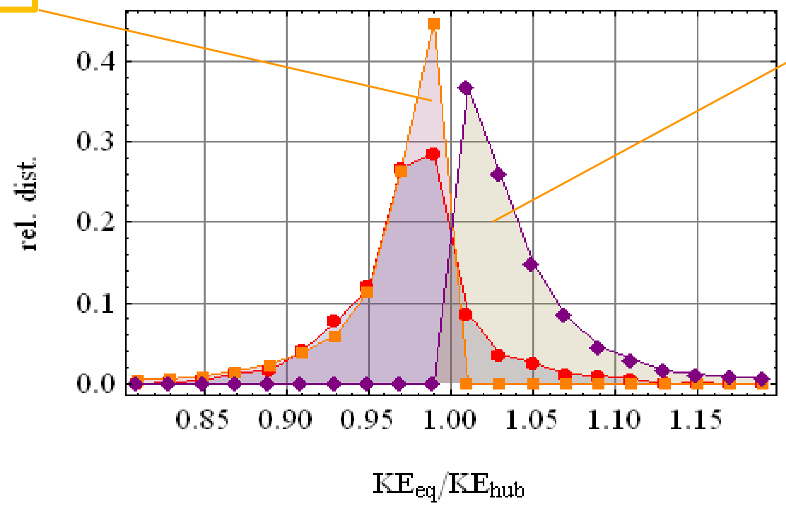
The error depends both on:

- the U_{eq}/U_{hub} distribution during the power curve measurement
- and the U_{eq}/U_{hub} distribution at the assessed site

More examples

$U_{eq}/U_{hub} < 1$

$U_{eq}/U_{hub} > 1$



Case1: $U_{eq}/U_{hub} > 1$

Profiles with larger kinetic energy than flat profiles

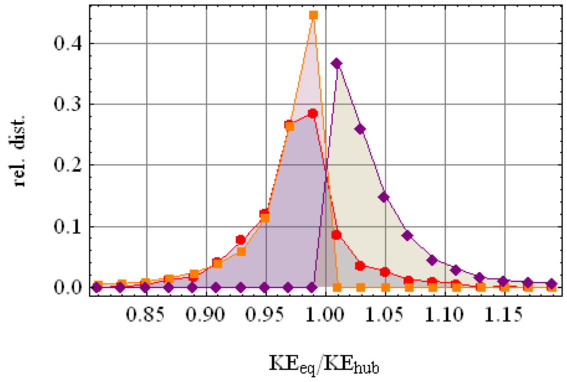
	U_hub power curve	Ueq power curve
U_hub distribution	(-3.8%)	(-2.1%)
U_eq distribution		(ref)

Part of the the error due to U_{eq}/U_{hub} distribution at the assessed site larger than before (-2.1%);
→ Overall error larger than previous case.

Case2: $U_{eq}/U_{hub} < 1$

Profiles with smaller kinetic energy than flat profiles

	U_hub power curve	Ueq power curve
U_hub distribution	(0.00%)	(+1.8%)
U_eq distribution		(ref)



Specific case:
The U_{eq}/U_{hub} distribution are very similar for both datasets.

Conclusions 1

The shear influences the AEP estimation in 2 ways:

1) Error in power curve due to the shear during the power curve measurement
2) Error in available energy at the assessed site.

→ Missing uncertainty terms in the standard AEP estimation

→ Equivalent wind speed results in a repeatable power curve.

→ Improved AEP estimation with equivalent wind speed

→ It requires to measure the wind speed profiles for site assessment

Conclusions 2

What to do if the equivalent wind speed distribution at the assessed site is not available?

→ If the U_{eq}/U_{hub} distributions at the two sites are similar: use the standard AEP calculation (wind speed at hub height).

→ If the U_{eq}/U_{hub} distributions are different: combine the hub height speed distribution with the equivalent power curve.

But to know the U_{eq}/U_{hub} distribution…
… **you need to measure the shear!**

<u>Acknowledgement:</u> EU SafeWind