Challenges accompanying the use of the Rotor Equivalent Wind Speed

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Motivation (1)

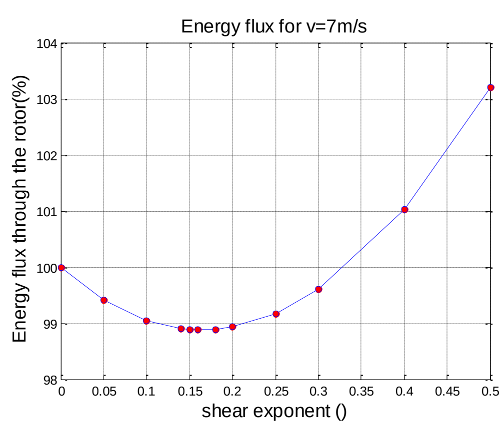
- The Rotor Equivalent Wind Speed (REWS) definition introduced in the coming IEC 12-1 standard:
- $V_{eq} = \left(\sum_{i=1}^{n} v_i^3 \frac{A_i}{A}\right)^{1/3}$
- The definition of the AEP estimation:
- $AEP = N_h \sum_{i=1}^{Nn}[F(V_i) - F(V_{i-1})]\left(\frac{P_{i-1}+P_i}{2}\right)$

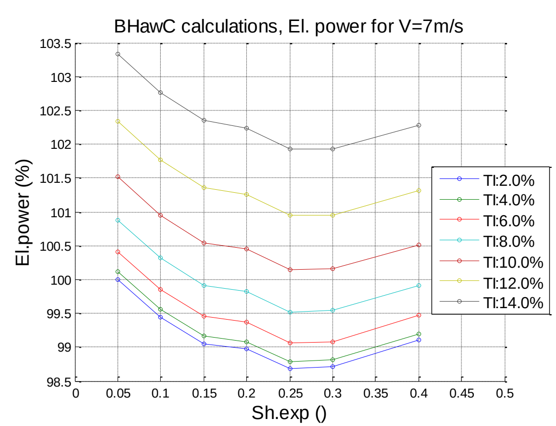
distribution. *AEP* estimations shall be made for hub height annual average wind speeds of 4, 5, 6, 7, 8, 9, 10 and 11 m/s according to the equation:

- Annex P of 12-1 standard: Wind shear normalization procedures (informative)

wind speed at hub height ignores the shear at both sites. The power curve obtained with the rotor equivalent wind speed is much less dependent on the shear than the power curve obtained with the wind speed at hub height. Therefore, the power curve based on the rotor equivalent wind speed enables us to account for the shear during the power curve measurement. Ideally to calculate the AEP with this power curve, one needs to estimate the

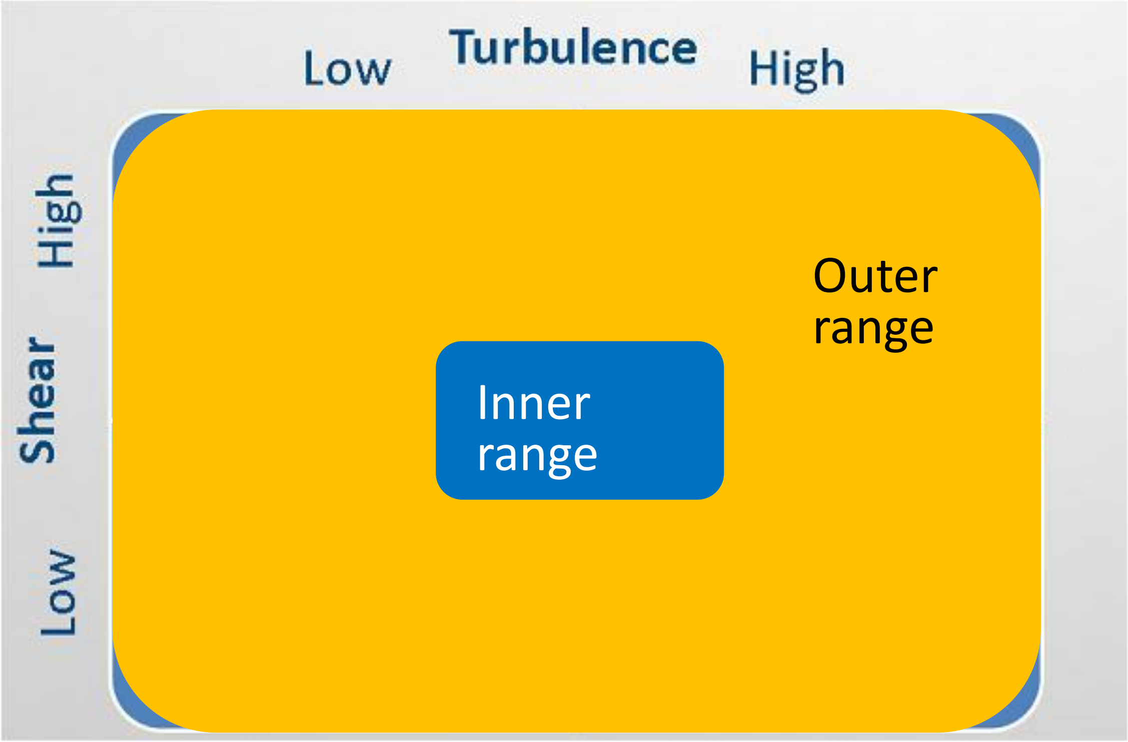
- Old references





Motivation (2)

- **Assume a turbine is pc tested within the below 5 distinct flat sites:**
  - How will the turbine's power curve/AEP be affected by the local conditions?
  - Is it possible to use the REWS (as indicated by the standard) and reproduce the power curve/AEP of a turbine between different locations characterized by different atmospheric conditions and roughness?
  - Or is the inner-outer region considerations the only way forth?



(*) Courtesy D. Bernadett, "5 Distinct Power Curves As a Function of Shear and Turbulence In Time-Series Energy Capture Calculations", PCWG, Brande 2013

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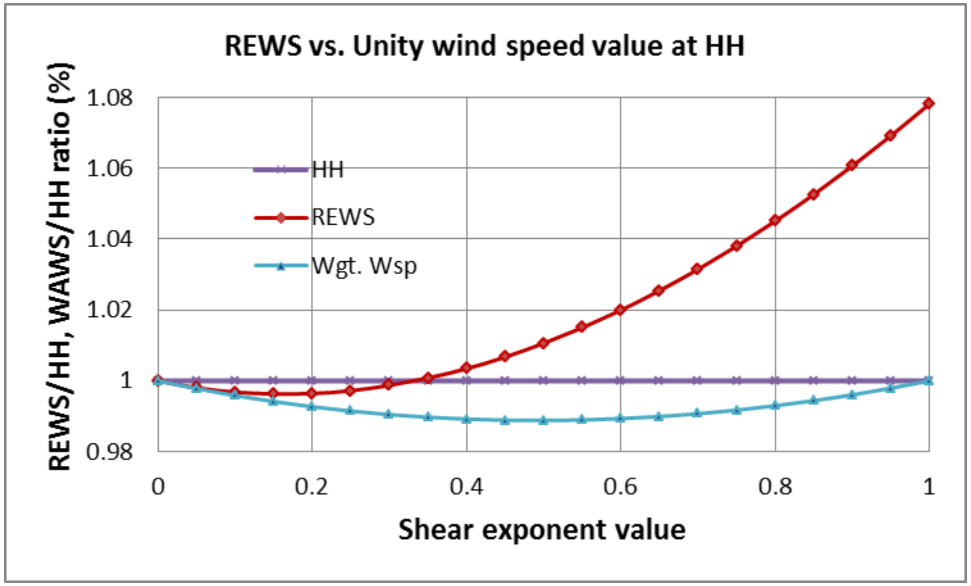
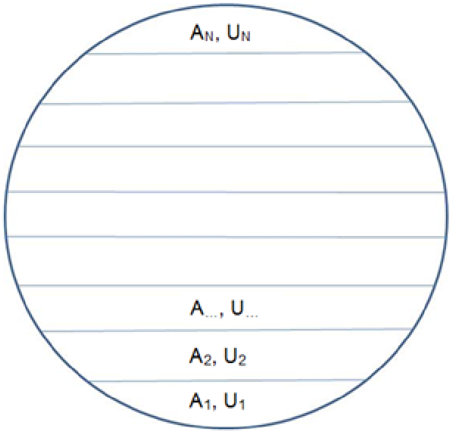
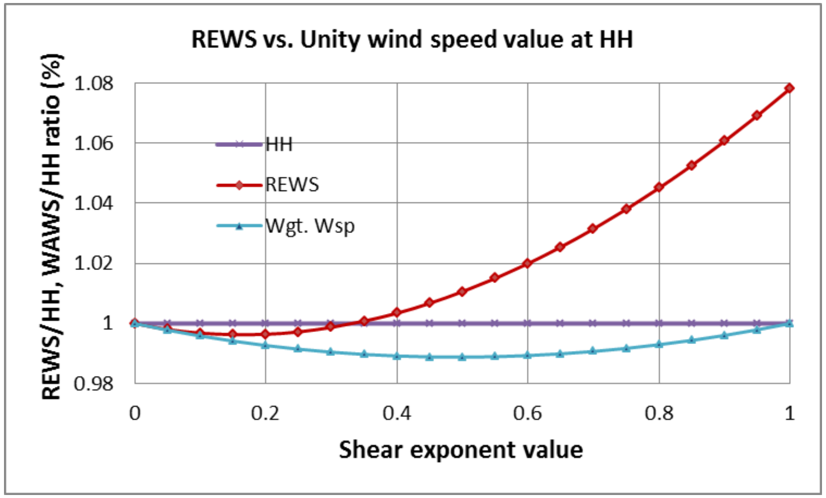
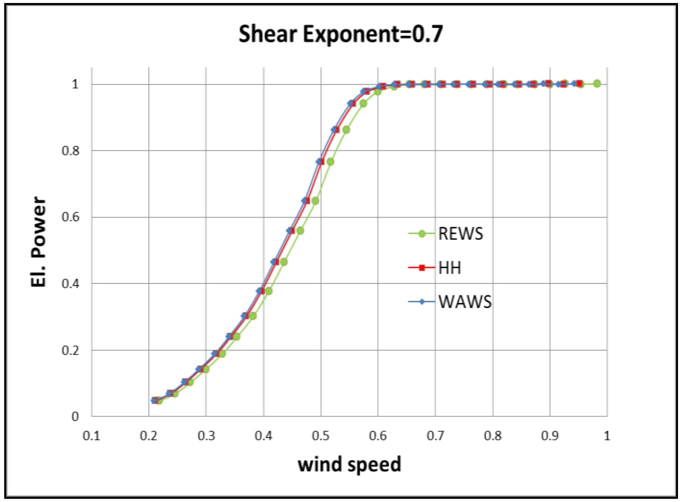
- A turbine rotor divided in segments of 1m height
- Assume exponential wind profiles of varying shear exponent
- Assume unity wind speed at hub height
- $V = \sqrt[3]{\frac{1}{A}\sum_{i=1}^{N}(v(z_i)\cos(\varphi_i)\,k)^3 A_i}$ $(Rotor\ Equivalent\ Wind\ Speed)$ (1)
- $V = \frac{1}{A}\sum_{i=1}^{N} v(z_i)\cos(\varphi_i)\,k\,A_i$ $(Weighted\ Average\ Wind\ Speed)$ (2)





- BEM simulations for wind speeds between cut-in and up to nominal power
- Exponential wind shear between 0.1 and 1
- Turbulence intensities between 5% and 25%
- Zero wind veer assumed

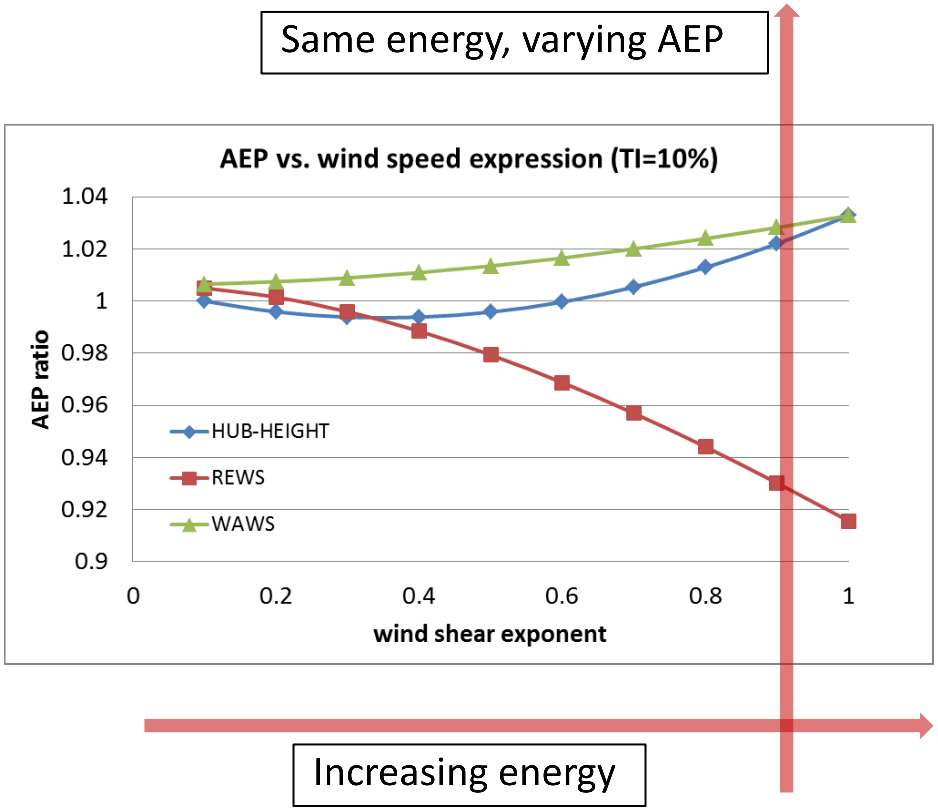




- Three different power curves for three different expressions of the wind speed
- Same energy production (at a specific site) yet… three different AEP values, why?
- Are we allowed to use the same Rayleigh distribution? (remains the distribution unchanged for the three wind speed expressions?)

AEP values influenced strongly by the wind speed expression

- BEM simulations for annual wind speed=X m/s and TI=10% vs. the shear exponent from 0.1 to 1 and different wind speed expressions
- $V = \sqrt[3]{\frac{1}{A}\sum_{i=1}^{N}(v(z_i)\cos(\varphi_i)\,k)^3 A_i}$ $(REWS, energy\ through\ the\ rotor)$ (1)
- $V = \frac{1}{A}\sum_{i=1}^{N} v(z_i)\cos(\varphi_i)\,k\,A_i$ $(WAWS, mass\ through\ the\ rotor)$ (2)
- (Same Weibull used for all three wind speed expressions)



Experimental results and o2o(*) BEM simulations indicate the same tendency

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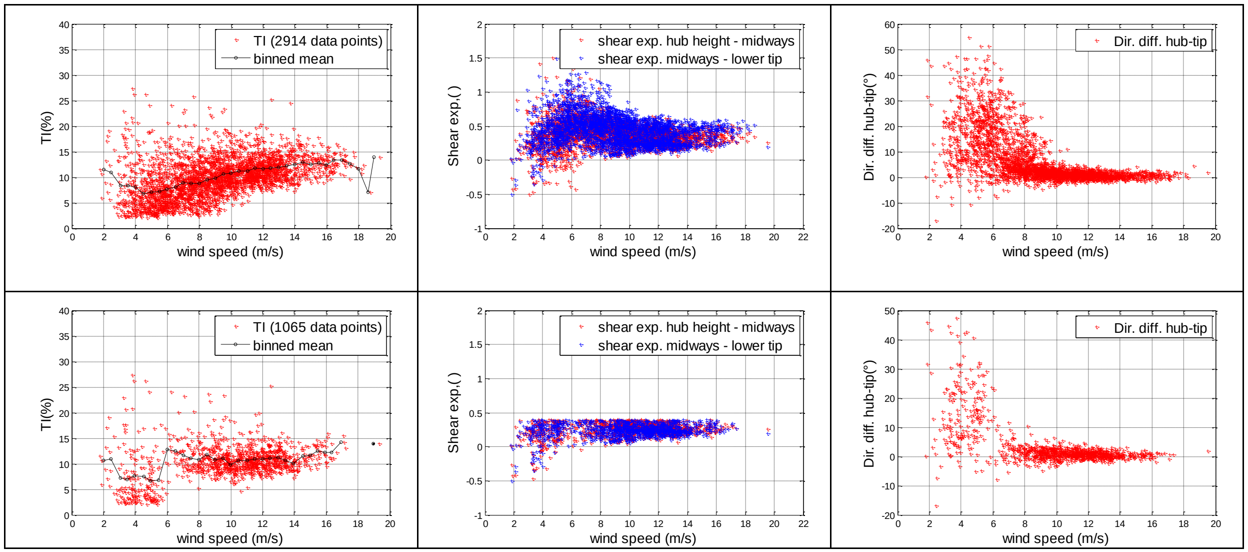
- Forested flat terrain data
  - High shear
  - High veer
  - Medium-high TI



  - AEP ratios

	REWS (eq. 1)				WAWS (eq. 2)			
	(shear below HH<0.4)/(all data)		(shear below HH<0.3)/(all data)		(shear below HH<0.4)/(all data)		(shear below HH<0.3)/(all data)	
MAWS	BEM results	Measurements	BEM results	Measurements	BEM results	Measurements	BEM results	Measurements
7.5m/s	1.013	1.012	1.017	1.019	1.000	0.999	0.999	1.001
8.5m/s	1.010	1.009	1.014	1.015	1.000	0.999	1.000	1.001
9.5m/s	1.009	1.008	1.012	1.012	1.000	0.999	1.000	1.001

(*): one-to-one, simulations using the measured profile

Need for unifying the AEP results for different wind speed expressions

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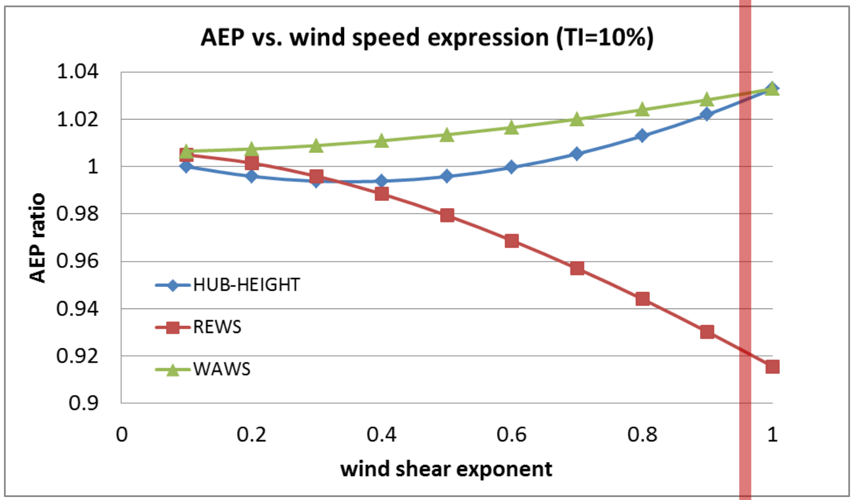
- Side-effects of the wind speed definition:
  - Dependency on the wind shear values
  - Varying power curves, AEP values
- Challenge: Present IEC ed.2 needs a unifying procedure
- Example: doable in the (ideal) case of a constant exponential shear:
  - The ratio between the HH and the REWS or WAWS (figure in slide p.5) is constant
  - Thus the wind speeds of the REWS or the WAWS power curves need just be devided by this ratio value

Same energy, varying AEP

Wind speed ratios

Shear exponent	HH	REWS	WAWS
0	1	1	1
0.1	1	0.9922	0.9897
0.2	1	0.9916	0.9820
0.3	1	0.9970	0.9769
0.4	1	1.0076	0.9741
0.5	1	1.0230	0.9735
0.6	1	1.0425	0.9750
0.7	1	1.0658	0.9784
0.8	1	1.0928	0.9838
0.9	1	1.1233	0.9910
1	1	1.1571	1



Increasing energy

Conclusions

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- The equivalent wind speed concept accounts for the wind profile deficit but..
- … inherently influences the turbine's AEP.
- Ambiguities exist in the use of the frequency distribution for the calculation of the AEP when using other than the hub height wind speed.
- Additional clarifications are needed in the coming IEC standard in order to make the above transparent .
- These ambiguities do not allow consistent AEP values to be produced when using different wind speed expressions
- Further standardization is needed in order to calculate specific site production (AEP), based on a "IEC standard" PC
- In the light of the previous points, the inner-outer region concept seems, until further, to be the only way forth.