Measurement Matters

What is Windpower?

$$P_{wind} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$$

3rd power of wind speed v (m/s)

Temperature (K)
Pressure (mbar)
Humidity (%)
→ Air Density ρ → Wind Power P_{wind}

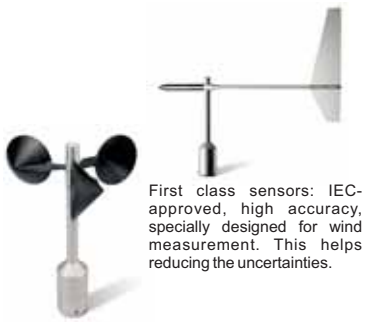
Rotor area A (m²)

Influence on Wind Power

	Change	Change in wind power
Humidity	0 ⇨ 100% RH (40°C) 0 ⇨ 100% RH (0°C)	- 0.03% - 0.002%
Barometric Pressure	970 ⇨ 1020 hPa	+ 5.0%
Temperature	-10 ⇨ +30°C	- 13.0%
Wind speed	4 ⇨ 8 m/s	**+ 800%**

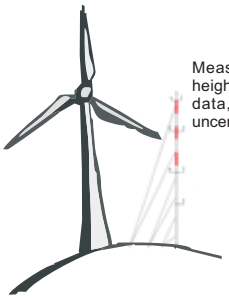
Small changes in wind speed result in great changes in wind power !!!

Influences on the measurement - sensors -



First class sensors: IEC-approved, high accuracy, specially designed for wind measurement. This helps reducing the uncertainties.

meteorological sensors, low budget version: lower accuracy, uncertainties added.



Measurement at hub height: most accurate data, helps reducing uncertainties

Measurement fairly below hub height: inaccurate data, uncertainties will be added

Examples: the costs of poor measurement

To see how poor measurement affects the project development two scenarios were calculated: Scenario 1 with an IEC-standard tower, first class sensors, and measurement at hub height. Scenario 2 assumes a tower below IEC-Standard, inappropriate (cheap) sensors, measurement fairly below hub height.
All other conditions (Turbine type, location, terrain, obstacles, etc.) are assumed to be exactly the same to estimate the effect of the different measurement types.

assumptions:
- **The energy yield is calculated from the wind power and the full load hours the turbine runs: P(W)*h=Wh.**
- **Wind turbine: 2,5 MW, 2400 full load hours, 6.000 GWh/a**
- **Fee 0,092€ / kWh**
- **Same conditions, different measurement**

The Tables are showing the energy yield which can be gained or exceeded with a certain probability – P90 shows the energy yield which can be reached or exceeded with a probability of 90%. Vice versa the *risk* of *failing* the energy yield at the P90-Level is 10%.

Example I: 3 Wind turbines

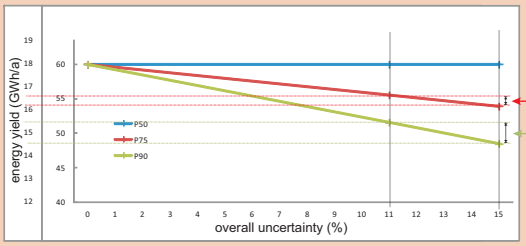
probability	Scenario 1: low uncertainty (11%) (IEC-Standard measurement adds only 5% uncertainty. The overall uncertainty is 11%)		Scenario 2: high uncertainty (15%) (poor measurement adds 12% uncertainty. The overall uncertainty is 15 %)		Difference between scenario 1 & 2 in €
	Gwh/a	Mio €/a	Gwh/a	Mio €/a	Diff (€/a)
P50	18,000	1,656	18,000	1,656	0
P75	16,665	1,533	16,179	1,488	45.000
P90	15,463	1,423	14,540	1,338	85.000

The profit which can be lost with a 10%-risk per year is 85.000€ higher with poor measurement – more than an usual measurement tower according to IEC standard would cost

Example II: 10 Wind turbines

probability	Scenario 1: low uncertainty (11%) (IEC-Standard measurement adds only 5% uncertainty. The overall uncertainty is 11%)		Scenario 2: high uncertainty (15%) (poor measurement adds 12% uncertainty. The overall uncertainty is 15 %)		Difference between scenario 1 & 2 in €
	Gwh/a	Mio €/a	Gwh/a	Mio €/a	Diff (€/a)
P50	60,000	5,520	60,000	5,520	0
P75	55,548	5,110	53,930	4,962	148.000
P90	51,542	4,742	48,466	4,459	283.000

The profit which can be lost with a 10%-risk per year is 283.000€ higher with poor measurement – much more than an usual measurement tower according to IEC standard would cost

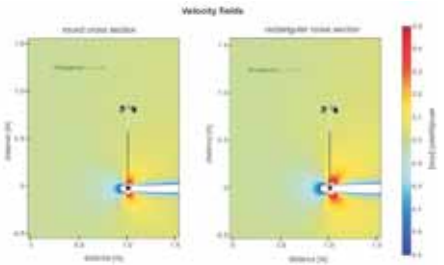


Resume

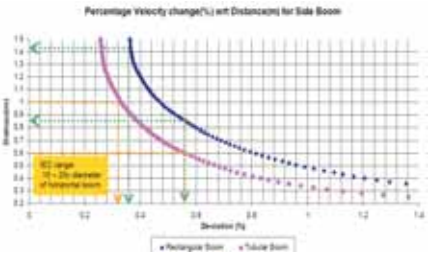
In both scenarios the *risk* at a certain probability level (P90,P75) is the same, but the *amount of profit* which can be lost at the same risk is different: it is significantly higher when the uncertainty is high, in our example only due to poor measurement.

Gaining 283.000,-€ less profit is a *risk* during planning - but when financing the project it can turn into *bad credit rates*, or into *lower prices* when selling the project.

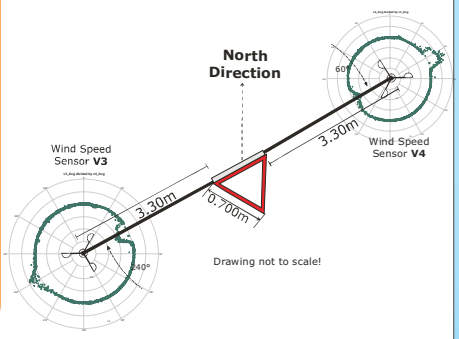
Influences on the measurement - tower design -



Even the boom on which the sensors are mounted influences the wind field and thereby the measurement. The important factors are the cross section of the boom and the distance tbetween sensor and boom.



The bigger the distance between sensor and boom the better the accuracy. A rectangular boom can achive the same accuracy as a tubular boom if the sensor is mounted in a greater distance.



The wind shadow of the tower shows a significant deviation in the wind speed the anemometers measure. The closer the sensor to the tower, the higher the deviation. The higher the deviation, the more uncertainties will be added.

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