Introduction to the Power Curve Working Group

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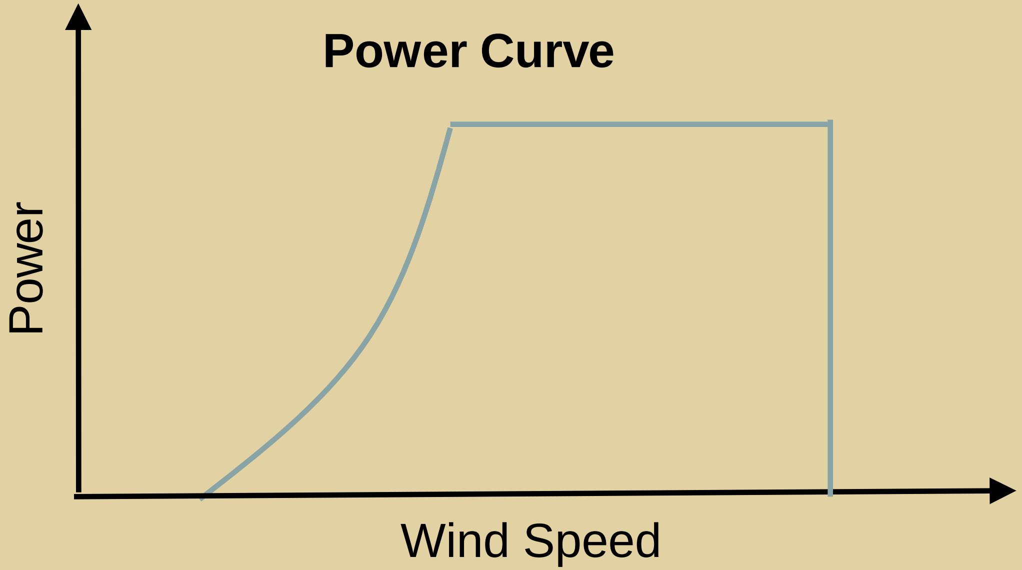
- What will my wind turbine realistically produce?



- Is a power curve based on just wind speed and density the ‘whole truth’?
- The **Power Curve Working Group (PCWG)** has formed to examine these questions and work together to find practical and meaningful ways of predicting turbine performance in the ‘real world’.

Turbine Performance in the Real World

- The real world has…

  low wind speed

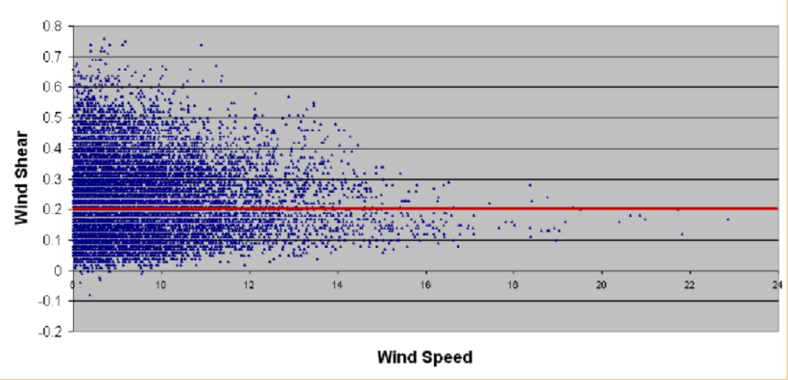
  high wind speed

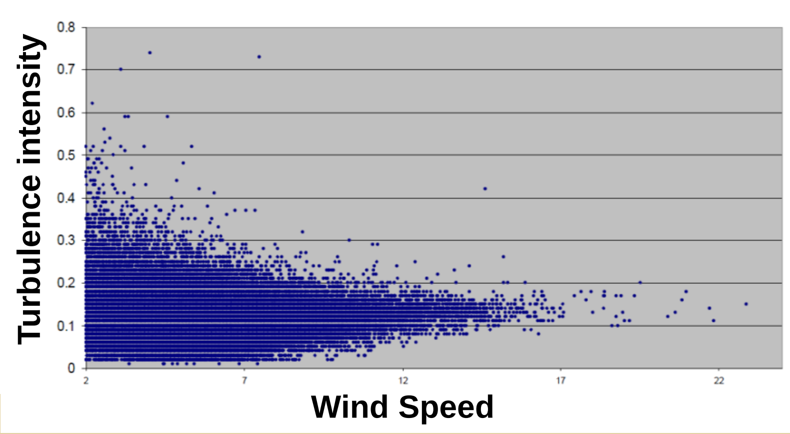
  low turbulence

  high turbulence

  low wind shear

  high wind shear





- and many combinations of the above (on same site at different times)…
- Wind conditions change all the time, and so does turbine performance.

Power Curve Working Group: Who are we?

The power curve working group (PCWG) is a **balanced and broad industry group** encompassing Developers, Consultants, Manufacturers and Academics/Researches.

RES
Vattenfall
Crown Estate
Dong
Iberdrola
SSE
RWE
EDF
EON

GLGH
DNV
Natural Power
AWS True Power
Sgurr
Wind Guard
Barlovento
Anemos-Jacob
IWES

Vestas
REPower
GE
Suzlon
Siemens

NREL
DTU
Lawrence
Livermore
National
Laboratory

Leosphere
Romowind

The group aims to examine ways of improving predictions of wind turbine energy yield in 'real world' conditions.

Openness is a key principal: Proceedings of all meetings publically available at:
http://www.ewea.org/events/workshops/resource-assessment-2013

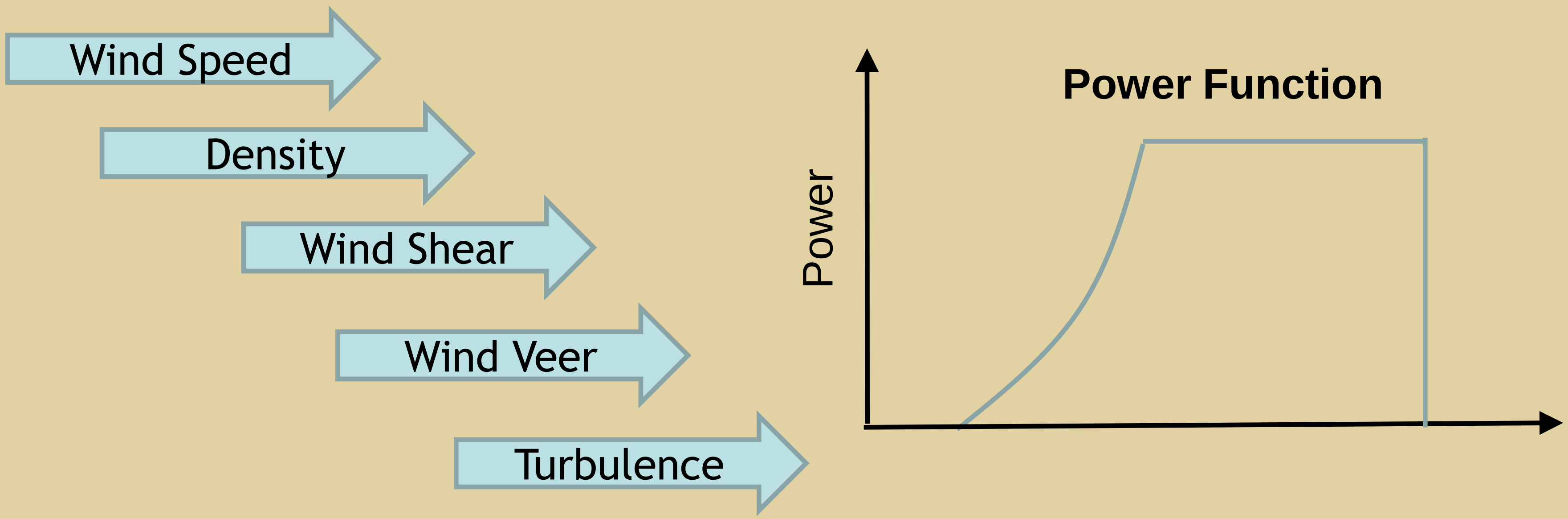
Power Curve Working Group Roadmap

Definition	Solution / Evolution					Conclusion
Meeting 1	**Meeting 2**	**Round Robin 1**	**Meeting 3**	**Round Robin 2**	**Meeting 4**	**Final Meeting**
Define what's the problem we are trying to solve.	Identify possible solutions	Trial solutions	Feedback on solutions. Compare experiences & lessons leant. Identify refined and/or alternative solutions	Trial refined solutions	Feedback on refined solutions. Is problem is solved? Should problem be redefined? Iterate solutions as required…	Finalise conclusions Publication of journal paper by working group. Publication of guideline document.
Publically disseminate presentations and minutes						
Dec 2012	Mar 2013	Apr - May 2013	May 2013	Jun – Sep 2013	Dec 2013	Jun 2014

Current Status

Time

- The power function of a wind turbine is dependent on **wind speed, density, vertical wind shear, vertical wind veer, turbulence intensity, directional variation and inflow angle**.



- From the above parameters; **wind speed, density, vertical wind shear, vertical wind veer and turbulence intensity** are thought to be of primary importance.

Corrections should be applied for ‘real world’ conditions which are different to those for which a power curve is representative. These corrections fall into two categories:

Available Energy

Type A: Adjustments made to reflect changes in the energy available for conversion across the rotor in a ten minute period due to ‘non-standard conditions’.

Type B: Adjustments made to reflect changes in the conversion efficiency due to ‘non-standard conditions’.

Turbine Behaviour

It is important to stress that even for sites with relatively ‘extreme’ wind conditions only relatively minor adjustments in overall energy yield are anticipated. These corrections will help the industry further improve the accuracy of its predictions.

- **Proxy methods**: relate production to a parameter which is broadly associated with changes in performances. Acknowledge that the underlying mechanisms may not be identified, but pursue regardless if methods demonstrably improve predictions. e.g. production loss based on low turbulence intensity.

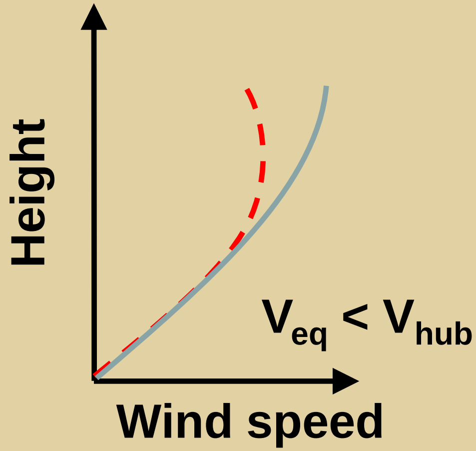
- **Analytical/physical methods**: apply methods based on understanding of underlying physics/statistics. May involve use of additional measurements such as LiDAR e.g. Rotor Equivalent Wind Speed and Turbulence Renormalisation.

- **Schematic methods:** pragmatically simplify problem, but stay reasonably close to the truth e.g. Inner & Outer Range proposal.

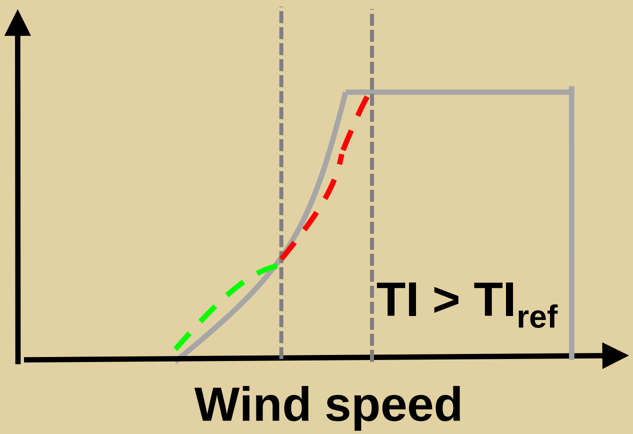
- **Power Curve Experience methods:** classify machine specific performance using power performance data across a broad range of conditions.

- The corrections for wind shear (**equivalent wind speed**) and turbulence intensity (**turbulence renormalisation**) in the current working draft of the IEC Power Performance standard should be considered as candidate methods for incorporation into resource assessment methodologies (**Analytical Type A corrections).**

Equivalent Wind Speed

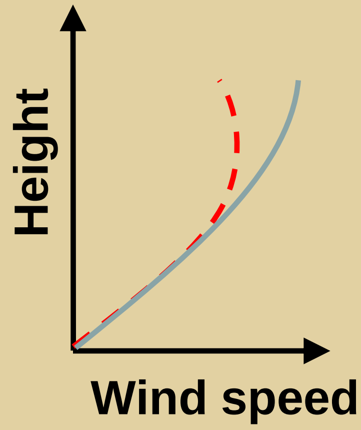


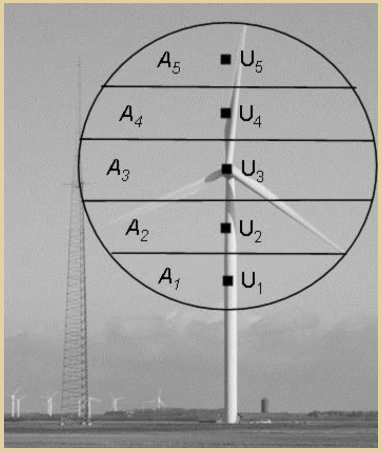
Turbulence Renormalisaton



- These corrections, along with other methods (proxy, analytical, schematic and experience), **are being examined by the working group in a series of round robin exercises**.

- The **use of rotor equivalent wind speed** in wind resource assessment offers the opportunity to correct the wind speed input to the power curve so that it representative of the whole rotor. This approach is an effective way of dealing with the sensitivity of power output to wind shear.





$$V = \sqrt[3]{\frac{1}{A}\int_{H-R}^{H+R}\left(v(z)\cos(\varphi(z))\right)^3 dA}$$

rotor equivalent wind speed

- Tip-height measurements (using remote sensing devices e.g. LiDAR/SoDAR) have a **big role to play in improving wind resource assessment**.

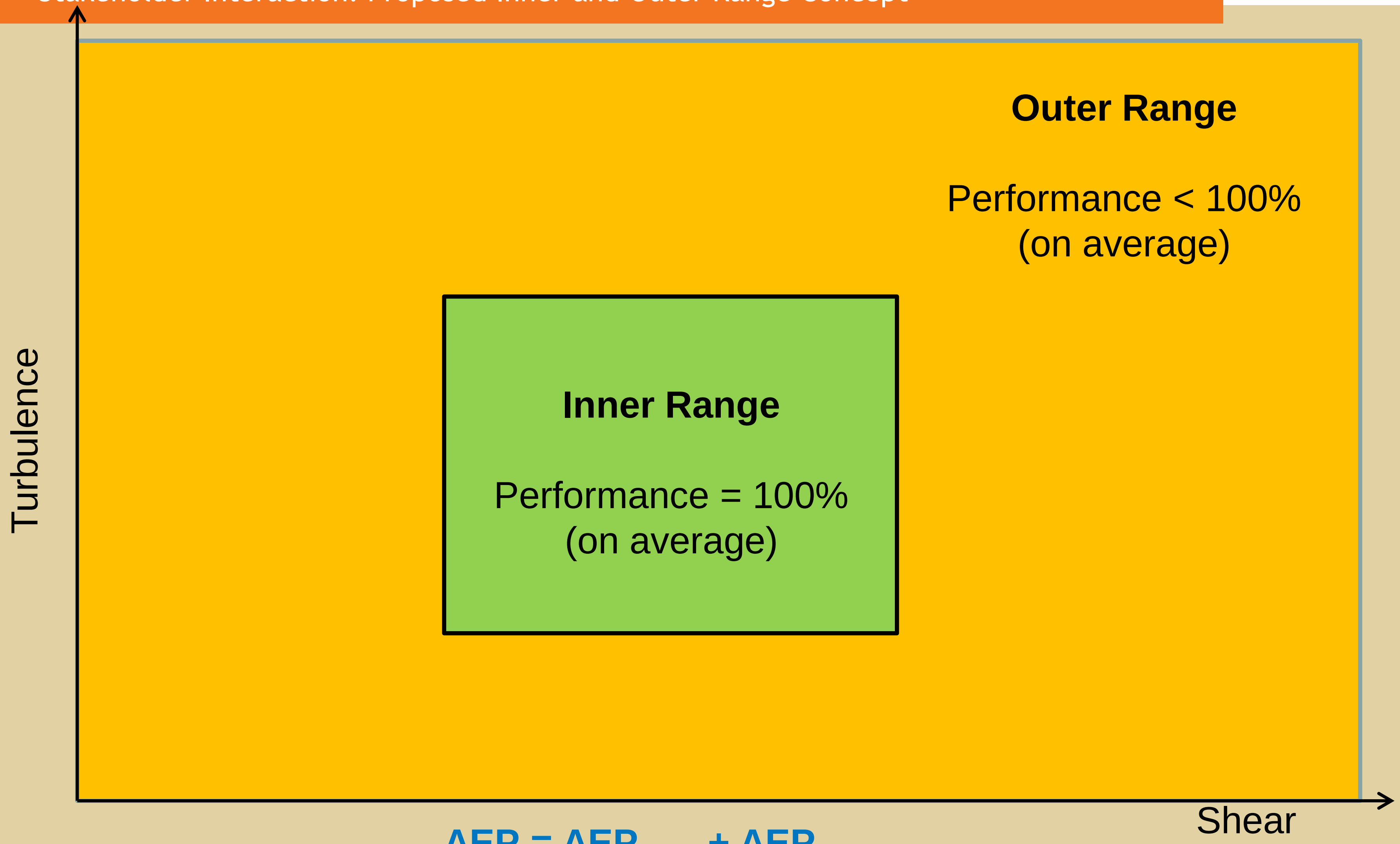
Key Working Group Outcomes: Stakeholder Interaction

- Further collaboration between manufacturers, developers and consultants is required to improve communication of power function information and explore corrections for non-standard conditions.

- There is a need for greater clarity on the range of conditions for which power curves are representative. This will give a clear starting point for considering corrections for ‘non-standard’ conditions.

- **We need to find practical solutions we can all live with!**

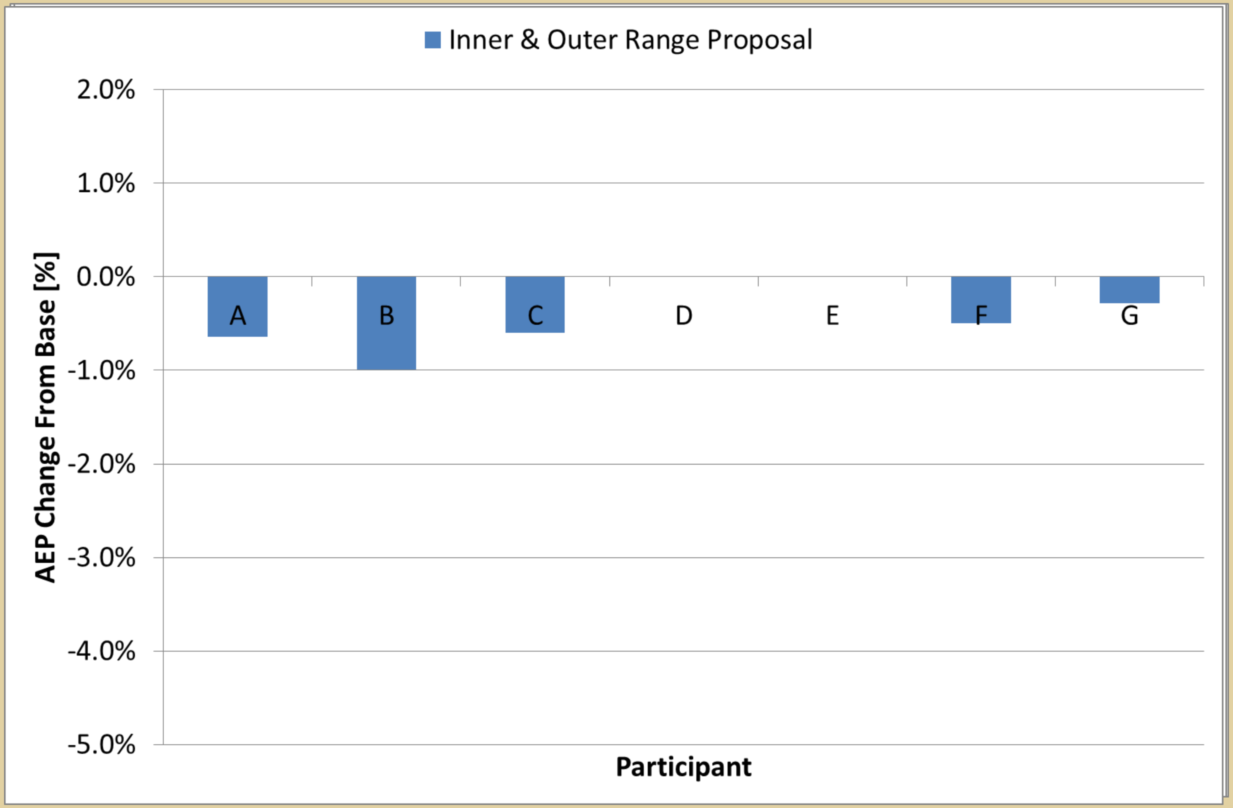
Stakeholder Interaction: Proposed Inner and Outer Range Concept



$$AEP = AEP_{Inner} + AEP_{Outer}$$

Round Robin Exercise

- A round robin exercise was conducted within the working group using a dataset including tip height measurements from in Sweden.



- Real world considerations e.g. working with relatively short LiDAR measurement campaigns with data gaps (source of discrepancy in results)

- Round robin exercise demonstrated some level of consensus on the impact of wind shear and turbulence.
- Some methods were executed with greater consensus than others

  e.g. better agreement on rotor equivalent wind speed than turbulence renormalisation → more work is needed to develop consensus.
- The participants acknowledged that sites are different and that the conclusions drawn from the Swedish site are not universal. **Further round robins are planned to investigate a broader range of sites.**
- Two further data sets have been secured for upcoming round robins and the PCWG are very interested in obtaining additional datasets.
- Participation in the round robins (and the working group in general) is open to anyone who is interested. **Please get in touch!**

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Time →

Conclusions

- The PCWG has been formed to find practical approaches to deal with the issue of turbine performance in real world conditions.

- The PCWG has reached a consensus that the **power function of a wind turbine is dependent on wind speed, density, vertical wind shear, vertical wind veer, turbulence intensity, directional variation and inflow angle**.

- The PCWG is exploring corrections for 'real-world' wind conditions and new methods of stake holder interaction in order to give a more realistic expectation of turbine performance.

- These corrections will help the wind industry further improve/refine the accuracy of its energy yield predictions.

- Further collaboration between manufacturers, developers and consultants is required to improve communication of power function information and explore corrections for real world conditions.

- **This is an issue the industry has the power to solve!**

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power for good