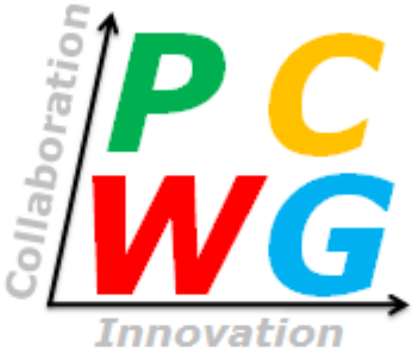
PCWG Update

Glasgow, 8th May 2015

Joint meeting of IEC 61400-12-1, IEC 61400-15 and PCWG



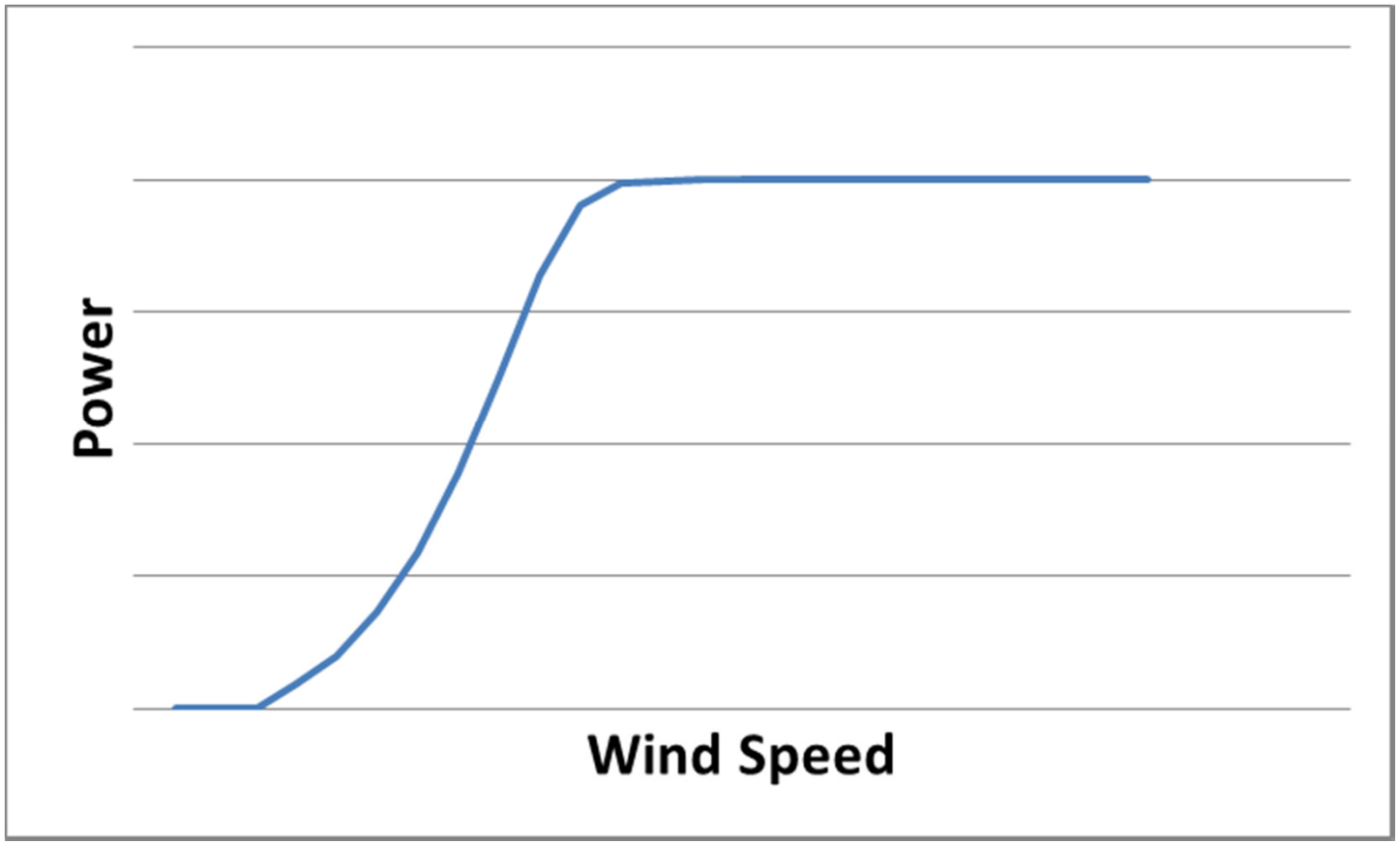
Working Together

- Working together there is a lot we can achieve…

- The Power Curve Working Group (PCWG) aims to bring people together.

An Idealised View of Wind Turbine Behaviour

- In an ideal world the power output of a wind turbine is dependent on hub height wind speed and air density



A Real World View of Wind Conditions

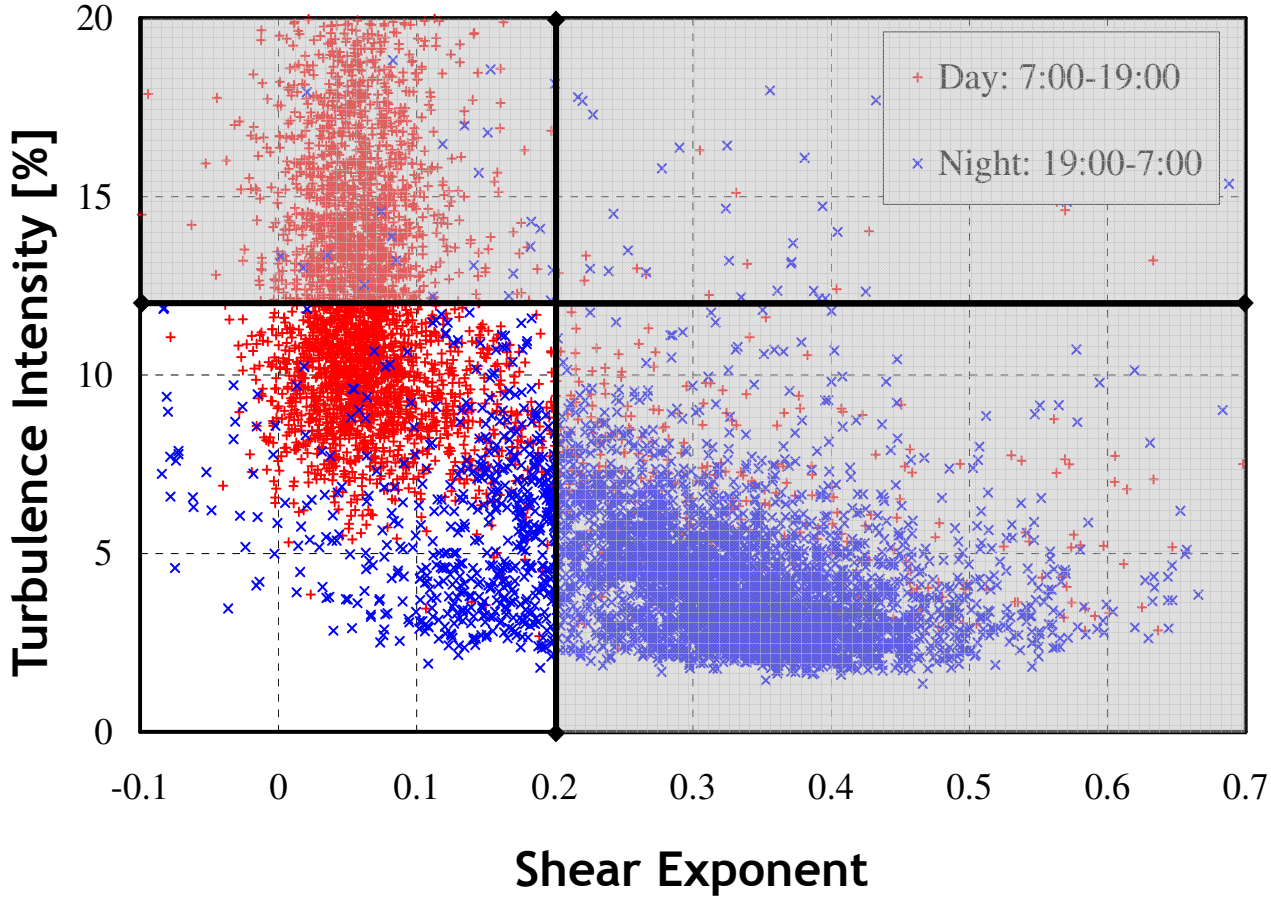


Image from *"One year on, A* review of Working Group progress to date", PCWG Meeting 4th December 2013, Andrew Tindal DNV GL

A Real World View of Wind Turbine Behaviour

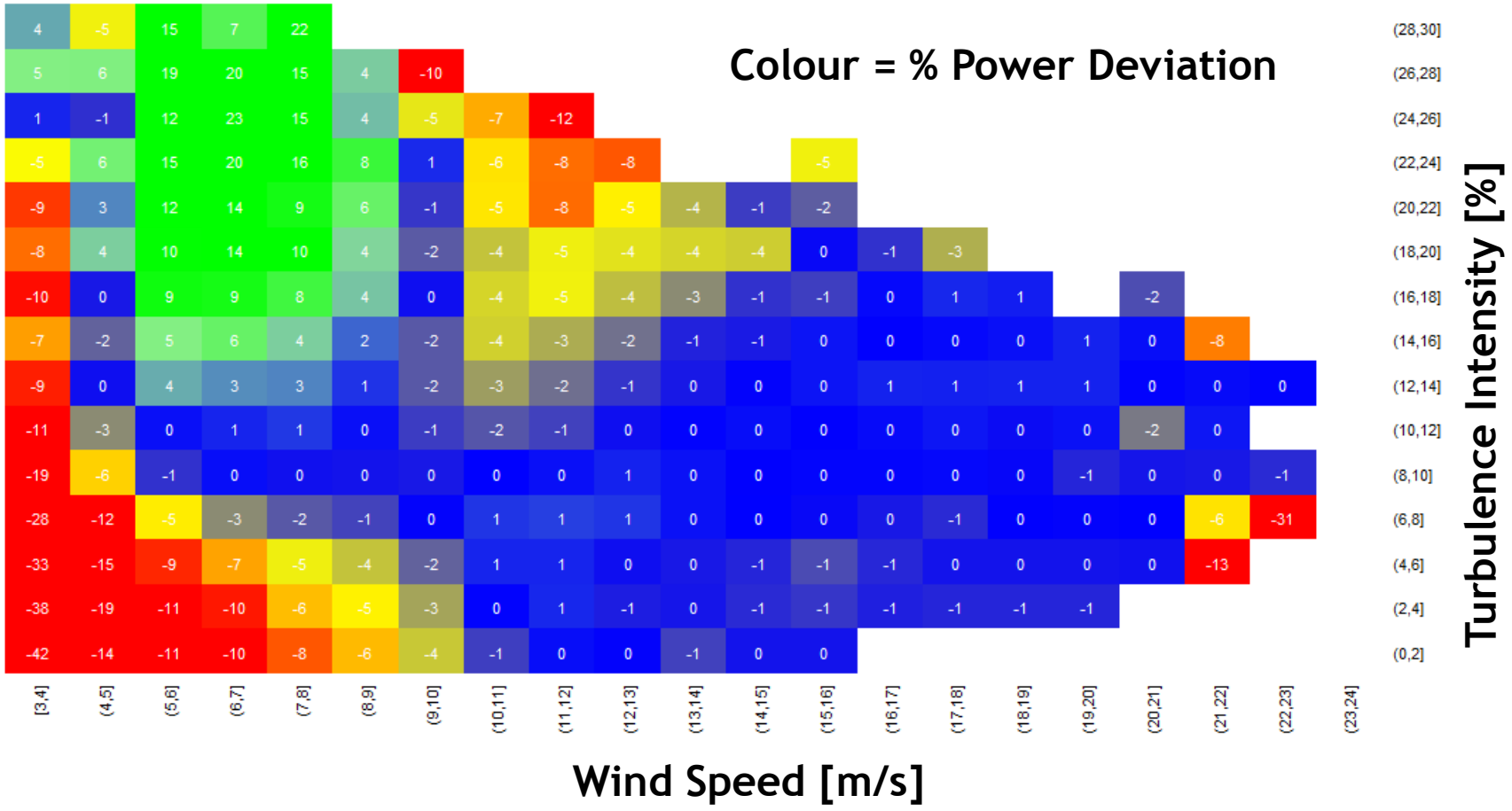


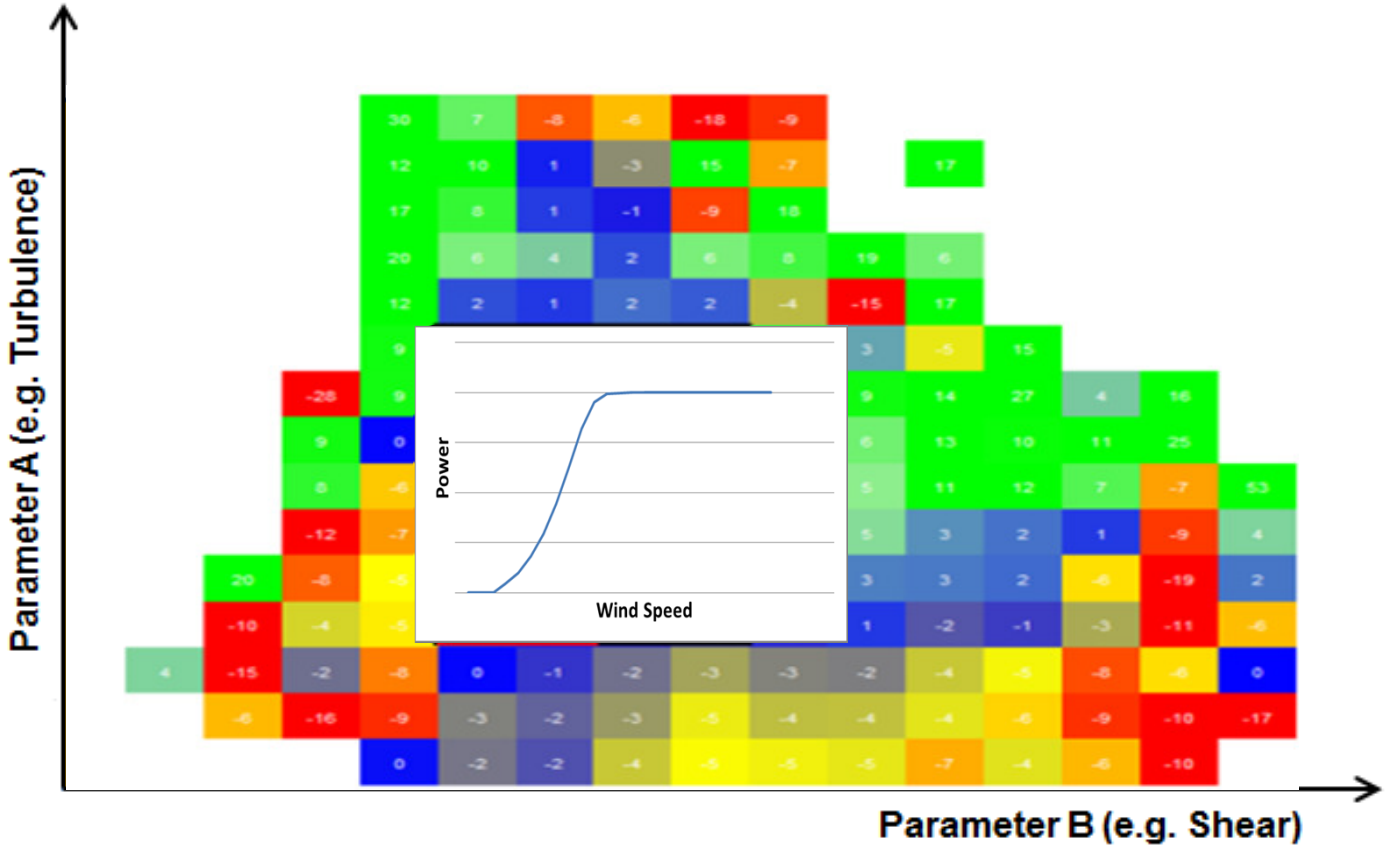
Image from *"Measurements Replace Generic Assumptions"* Tomas Blodau, Head of Wind and Site, Senvion SE, EWEA 2014 Conference, Barcelona

PCWG: Background

- The PCWG was formed in Dec 2012 to find practical approaches to deal with the issue of turbine performance in real world conditions.
- PCWG aims to provide a platform for broad wind industry collaboration.
- The PCWG explores:
  - **Corrections** for 'real-world' wind conditions e.g. high/low turbulence, high/low shear etc.
  - New **methods of stake holder interaction** in order to give a more realistic expectation of turbine performance.
- Ultimately the PCWG aims to further refine the accuracy of its energy yield predictions to **improve investor confidence.**
- With 190 members the group is open to all. Please visit www.pcwg.org or email pcwg@res-ltd.com

Work to Date: Inner/Outer Range Proposal

Public Publication of the **Inner/Outer Range Proposal** (see www.pcwg.org)

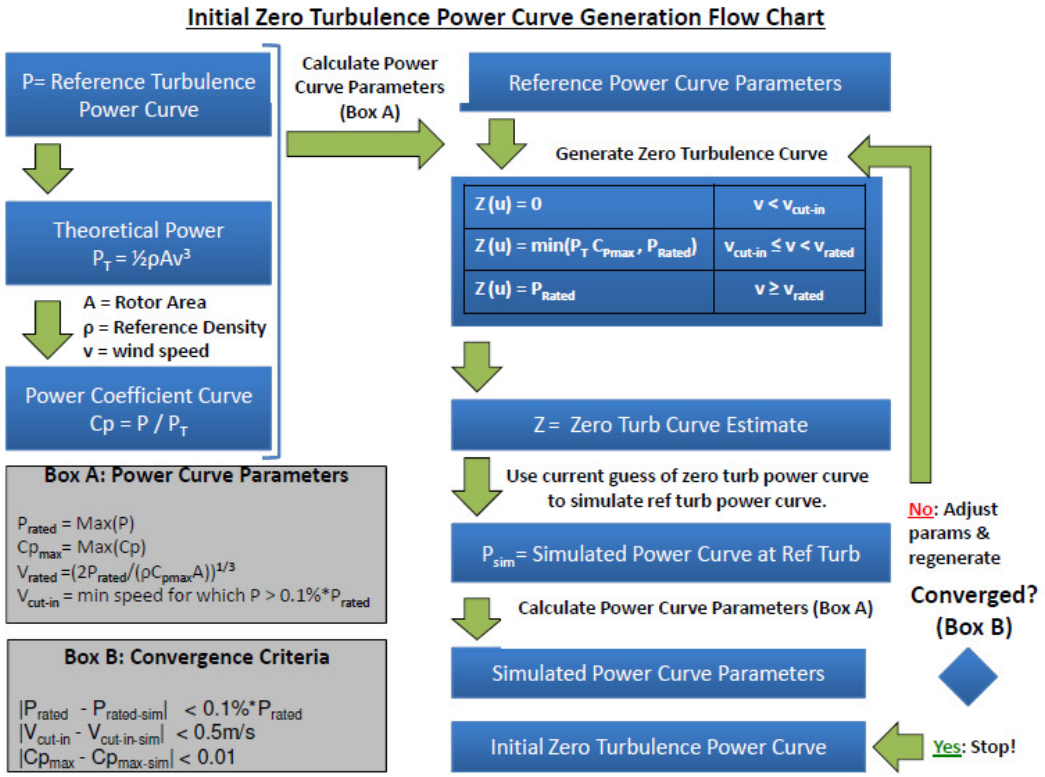


Inner/Outer Range proposal is a schematic concept to assist technical and contractual discussions relating to turbine performance in real world conditions.

Work to Date: Round Robins and Consensus Analysis

Consensus understanding of the Rotor Equivalent Wind Speed (REWS) and Turbulence Correction methods from the DRAFT IEC 61400-12-1 standard:

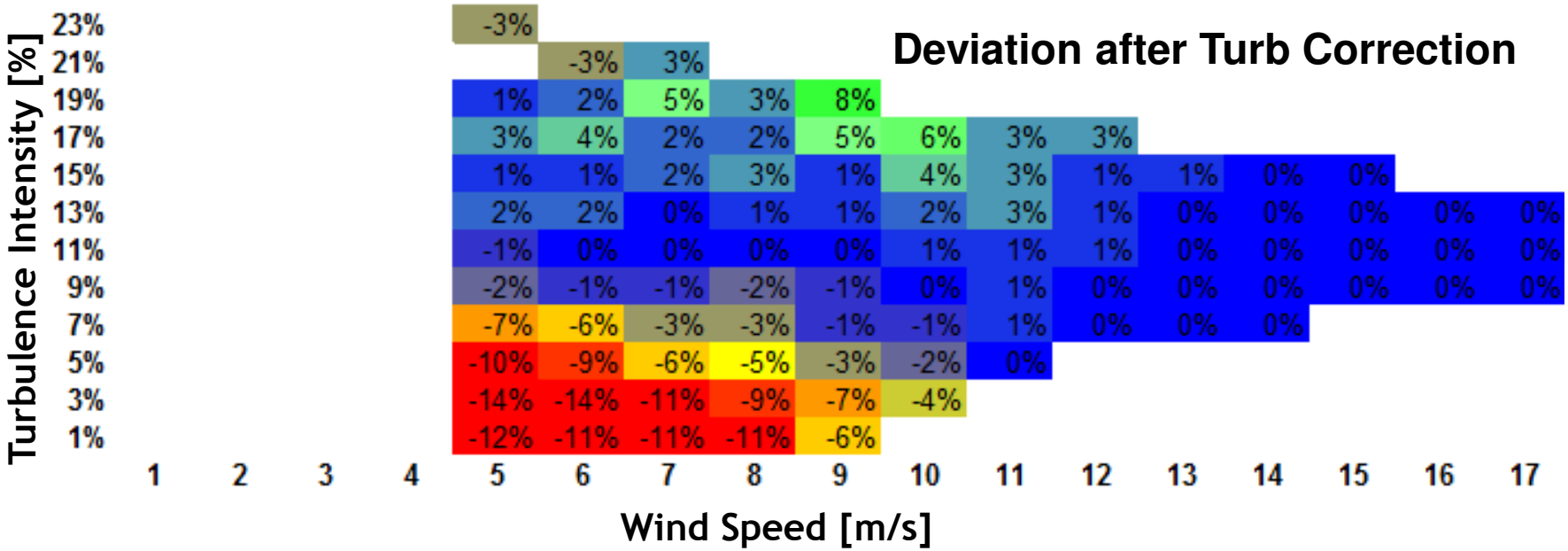
- Round Robin Exercises across three datasets
- Publically available Excel Consensus Analysis (see www.pcwg.org)
- Publically available Documentation (see www.pcwg.org)



Work to date: Evaluaton of IEC 61400-12-1 Methods

- Consensus view that that while helpful, the Rotor Equivalent Wind Speed (REWS) and Turbulence Correction methods (from the Draft IEC 61400-12-1) do not fully describe the real world behaviour of turbines.

- Example Analysis of combined dataset of 5 turbines of the same type



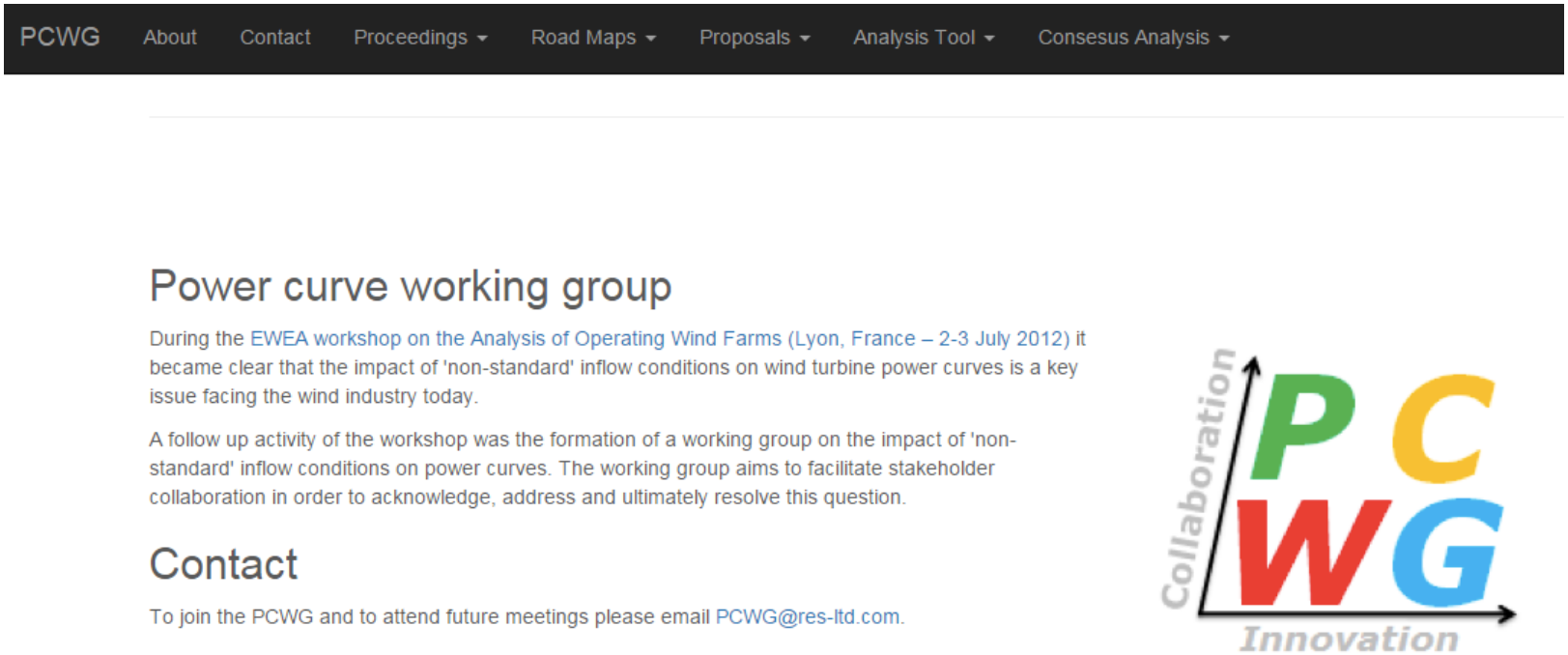
- Rotor Equivalent Wind Speed (REWS) method could not be applied to this particular dataset due to lack of data.

PCWG Website

New PCWG website hosts:

- Historic proceedings
- Proposals
- Datasets
- Roadmap
- Open Source Analysis Tool

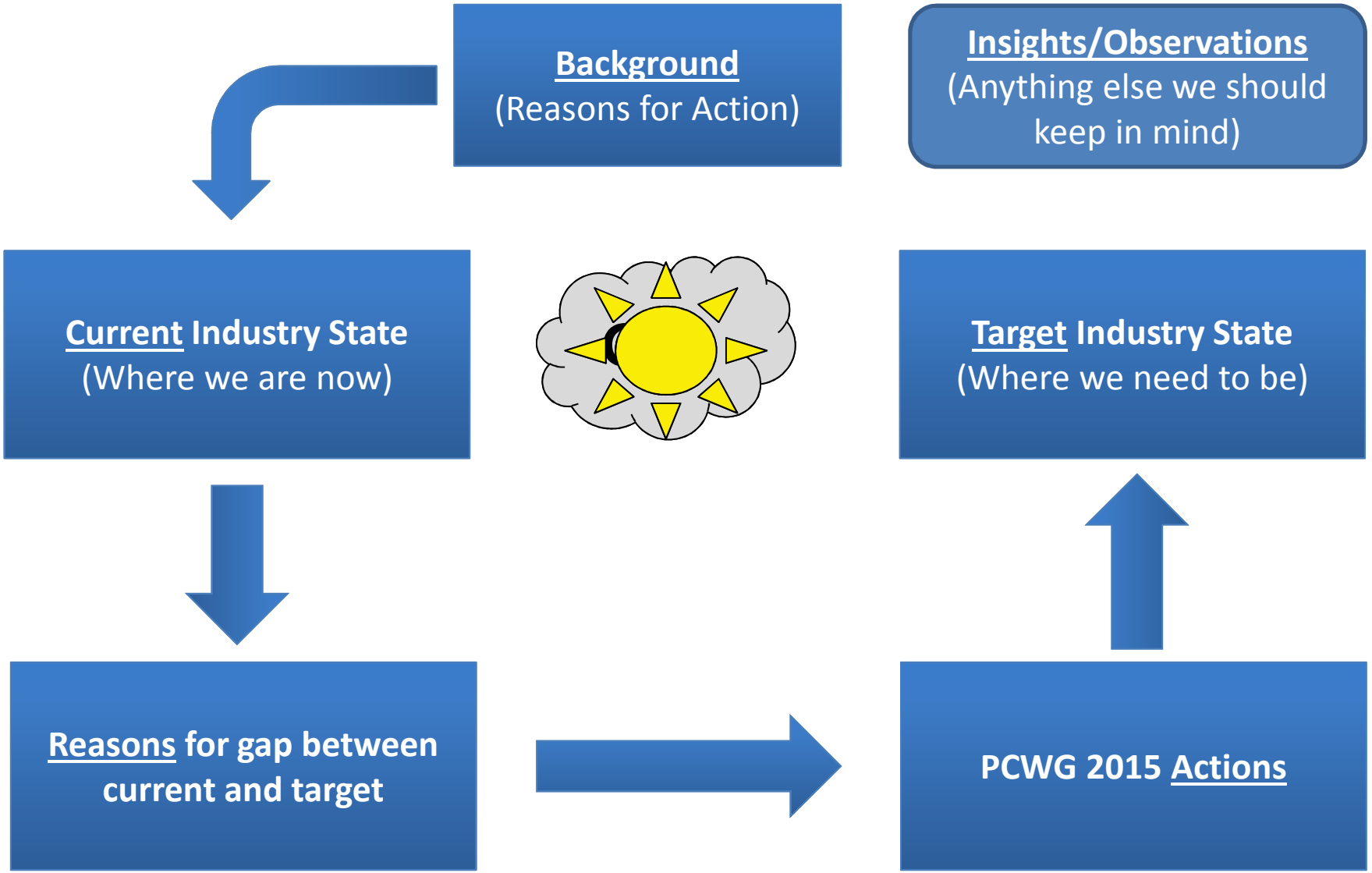
www.pcwg.org



PCWG 2015 Roadmap

Brief Introduction to A3 Report Format

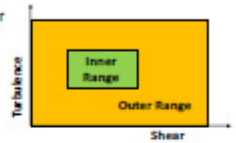
- **The PCWG 2015 Road Map uses the A3 Report Format.**



Power Curve Working Group 2015 Roadmap

Background: Reasons For Action

- **Real world wind conditions** are composed of both inner range and outer range wind conditions:
  - **Inner range conditions** refers to moderate shear and moderate turbulence.
  - **Outer range conditions** refers to high turbulence, low turbulence, high shear, low shear etc.



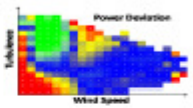
- **Outer range conditions are relatively frequent** and therefore the calculation of turbine power output in outer range conditions is an important consideration in wind energy resource assessment.
- There are **no industry consensus methods** for predicting wind turbine power output in outer range conditions for the purposes of resource assessment.
- **Power performance tests and associated warranties** are **normally limited to** a relatively narrow range of idealised conditions i.e. **inner range conditions.**

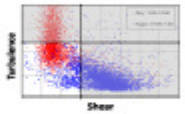
Current Wind Industry State

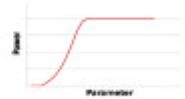
- There are no industry consensus methods for predicting wind turbine power output in outer range conditions for the purposes of resource assessment.
- Power performance tests and associated warranties are normally limited to a relatively narrow range of idealised conditions i.e. inner range conditions.
- The lack of a validated industry consensus methods for predicting power output in outer range conditions (for resource assessment applications) increases the risk perceived by wind energy investors.
- The failure to consider outer range conditions in power performance tests increases the risk perceived by wind energy investors.

Target Wind Industry State

- Well document and validated consensus methods for predicting wind turbine power output in outer range conditions for the purposes of resource assessment.
- Open source benchmarks (e.g. Excel examples) available for all validated consensus methods.
- Open source tools (which comply with benchmarks) available for all validated consensus methods.
- Power performance tests routinely make some consideration of outer range conditions.
- Harmonised communication of power curve information so that corrections for outer range conditions can be unambiguously applied.
- Consensus methods embedded in real world resource assessment industry practice. Reduced resource assessment risk perceived by wind energy investors.
- Reduced power performance risk perceived by wind energy investors.







Reasons for gap between current and target

- REWS and turbulence renormalisation methods are helpful, but do not fully solve the problem.
- There are no industry standard tools for applying existing methods for modelling power output in outer range conditions.
- Several empirical (proxy) methods are available which tie observed turbine performance to key (frequently measured) parameters such as turbulence intensity and lower rotor shear exponent. However, there is a lack of industry consensus regarding which proxy methods are best.
- No objective criteria for evaluating performance of correction methods.
- Minimal data/intelligence sharing between key stakeholders.
- Current power curve documentation can make the application of corrections for outer range conditions difficult e.g. it can be hard to tell if a power curve is defined for hub wind speed, rotor equivalent wind speed or both.
- Currently there is currently no consensus method to extrapolate conclusions at the test turbine to all turbines e.g. extrapolation of shear and turbulence to all turbine locations
- Confusion over contractual and resource assessment contexts inhibits progress on is of turbine performance in non-standard conditions.

PCWG 2015 Actions

- Define trial methods and validate them (including new and novel methods) e.g. REWS, RAWS, site/conditions specific power curves, turbulence renormalisation, power deviation matrix, production by height, modified turbulence renormalisation method.
- Implement PCWG data/intelligence sharing initiate to provide a platform for developing and validating trial correction methods. As part of sharing initiative develop objective criteria/framework for testing corrections for non-standard conditions.
- Develop open source benchmarks (e.g. Excel examples) for applying trial methods so that methods are well understood. Where appropriate perform round robin exercises to develop consensus understanding e.g. Power Curve Deviation Matrix and REWS with Inflow Round Robins
- Develop open source python tools so that trial methods can be applied to many datasets efficiently:
  - Power Curve Deviation Matrix Implemented
  - Rotor Equivalent Wind Speed Considering Inflow Implemented
- Promote application of Inner/Outer range concept for power performance tests by sharing experiences.
- Develop a document to harmonise the communication of power curve information. Document should express requirements for site specific power curves and/or power deviation matrices from a developer/consultant (required outputs) and manufacturer (required inputs) perspective. Document should difference between the resource assessment and contractual contexts.
- Develop methods for applying corrections for non-standard conditions across a wind farm in order to reduce 'by turbine errors' and facilitate the design of better wind farms.

Observations

- No clear consensus method for determining long term representativeness of measured shear, turbulence etc.
- No existing consensus method for modelling turbine performance in non-standard conditions in wake conditions.
- No metric for describing both the energy context and 'bending' of a shear profile.

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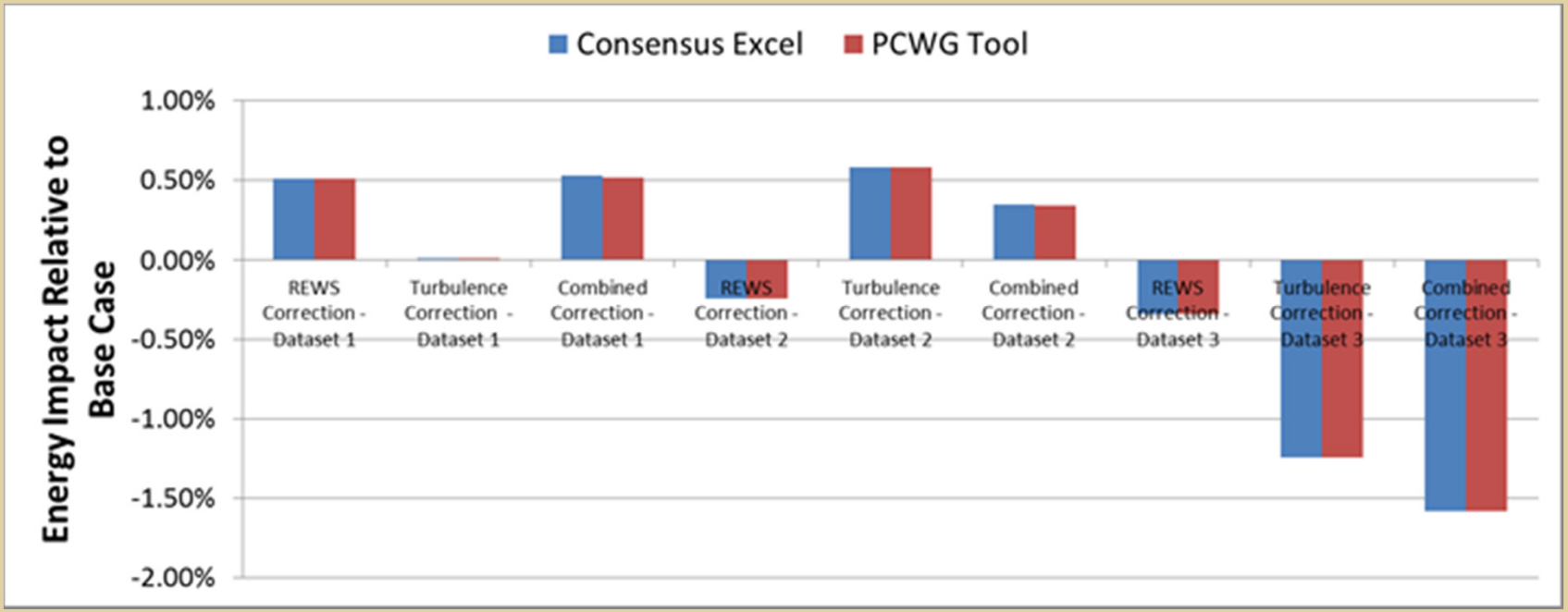
PCWG Open Source Analysis Tool

Purpose/Vision of PCWG Open Source Analysis Tool

- Provide an Open Source Tool to perform IEC Compliant Power Performance Analysis
- Facilitate the work of the PCWG e.g. the PCWG Data Sharing Initiative.
- Open Source: Demonstrate IEC (+other) methods implemented in open source code.
- PCWG is a work in progress, but already it can do a lot!

PCWG Analysis Tool Benchmark vs Round Robin Results



PCWG Open Source Analysis Tool

- The latest release of the (**Version 0.5.3**) of the PCWG Open Source Analysis tool is now available to download.
- The code is provided without warranty under the terms of the MIT software license (see attached for more details). The tool itself can be downloaded at: https://sourceforge.net/projects/pcwg/files
- The tool has been benchmarked against the Excel Consensus Analysis of the working group Round Robin Exercises.
- The tool is open source and working group members are encouraged to contribute. Those interested can access the project source code on GitHub: https://github.com/peterdougstuart/PCWG
- Detailed introduction to tool presented by Alex Clerc during March PCWG Meeting in Hamburg (see proceedings)

Power Curve Working Group

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: www.pcwg.org