powering change

Renewable Energy Systems

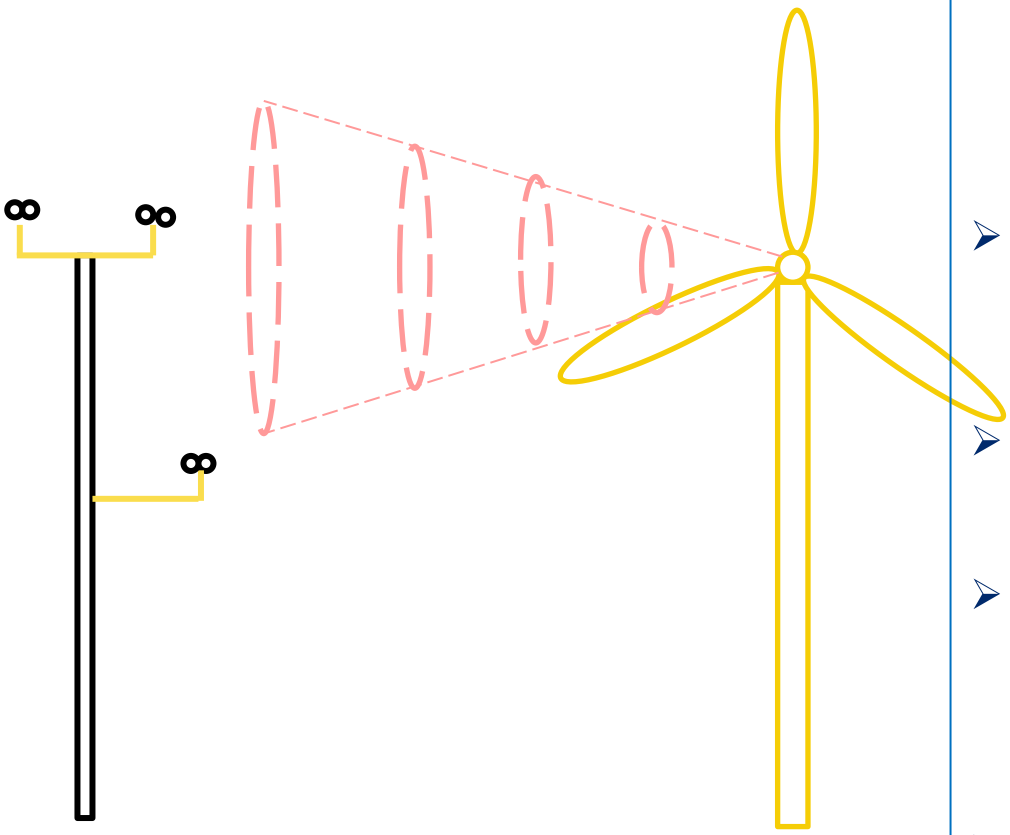
Simon Feeney

Nacelle LiDAR Activities in RES

14th November 2016

UniTTe Workshop – DTU Risø Campus

Why are RES interested in using nacelle LiDAR?



- **RES have undertaken ~85 IEC power curve tests, but changed policy in 2014 to only do tests if customer requests.**
- **Nacelle LiDAR will save £100,000/turbine onshore, almost £200,000 in Sweden**
- **Quicker, more flexible, more information - Shear, inflow, Yaw error**
- **More representative test of actual site conditions – difficult to see any real benefit in contractual warranty test for RES sites.**
- **Relative Power curves – very powerful tool.**
- **Better for complex terrain?**

Project Cyclops

- In 2014 RES decided to buy a ZephIR DM to test the technology on a flat site in England.
- Partnership with ZephIR and Vestas, measured for about 5 months.
- Managed to fully convince ourselves that the LiDAR and met mast approach agreed for this site.
- HH vs. mast y=1x
- REWS vs. LiDAR y=1.003x
- R2=0.999
- Passed the first test!

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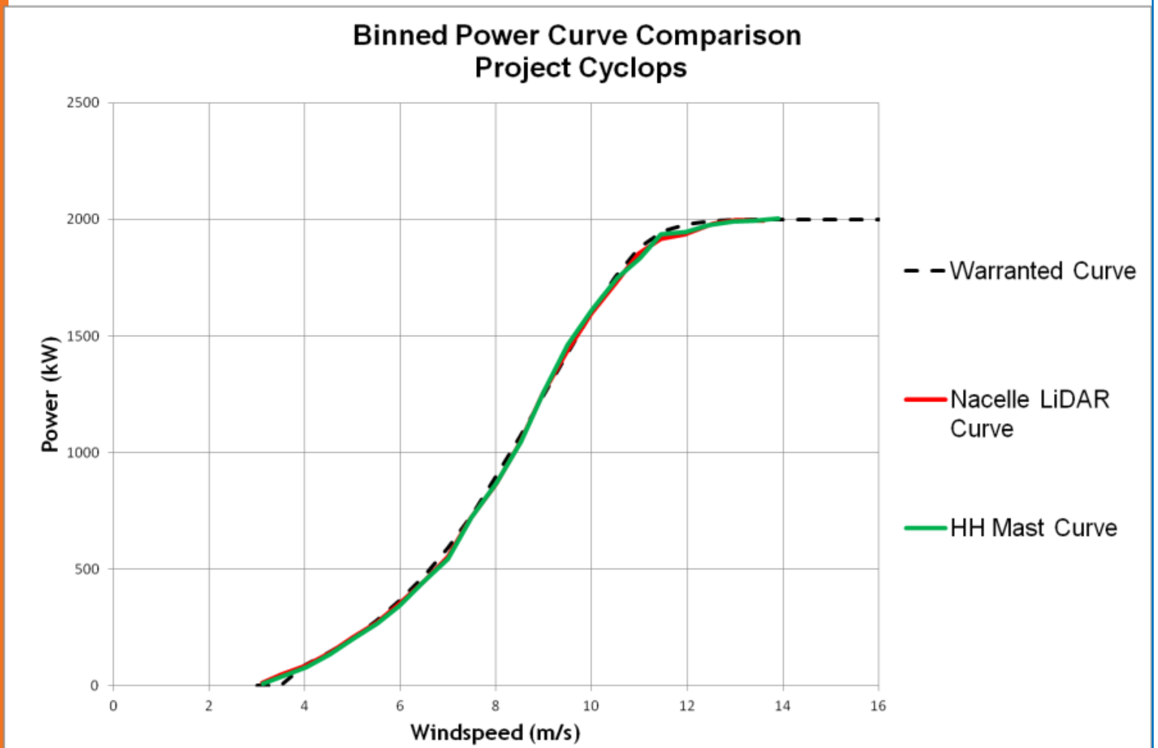

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- **HH vs. mast y=1x**
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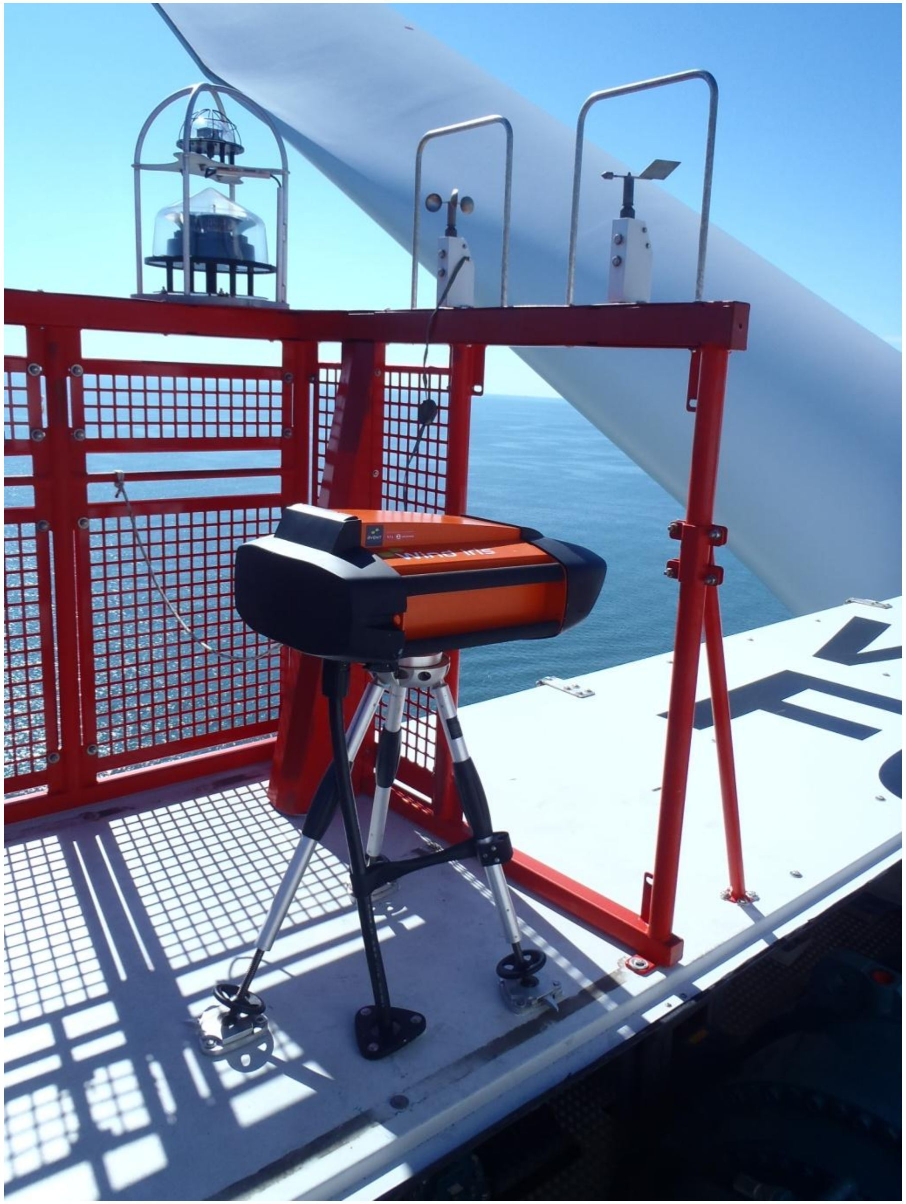
RES Projects



- However nacelle LiDAR not really taken off on RES projects – partly due to change in RES business approach to ownership and partly due to auction systems leading to removal of any non-essential costs.
- Also RES have never really been worried about performance on flat sites.
- More uptake on commercial projects where installation experience and technical capability are desirable
- Some example projects...

Commercial Nacelle LiDAR Projects - Blade Erosion

Example Edge Erosion Before Repair

Nacelle LiDAR Measurement System

- **Client – ORE Catapult**
- **Installation on a single turbine on a Offshore Wind Farm under a commercial contract.**
- **Full results not yet released but LiDAR could detect a 2% change in AEP for a moderately eroded turbine**
- **Uncertainty of test ~ 4.5% but uncertainty on energy delta ~ 0.9% AEP - Shows power of relative power curve testing.**
- **Biggest challenge was to isolate effects of blade repair from changing atmospheric effects.**

Commercial Nacelle LiDAR Projects - OWA

¾ of installed capacity in Europe

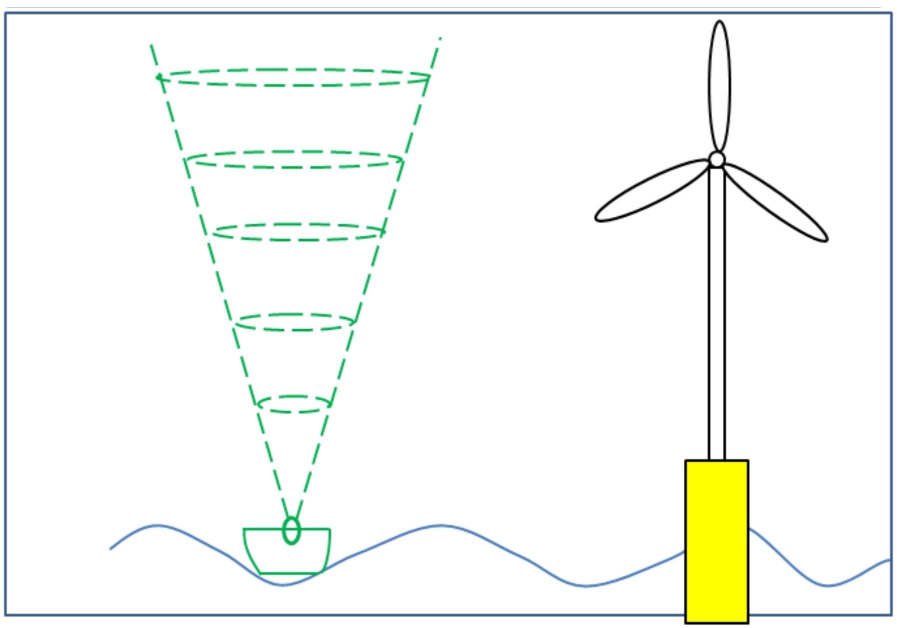
- OWA – UK R&D Group with objective to reduce cost of offshore wind to <£100MWh
- 5 research areas
  - Wakes and Wind Resource
  - Foundations
  - Access
  - Cable Installation
  - Electrical Systems
- £88m programme spend to date
- Research co-funded by UK and Scottish governments

Slides stolen from A Clerc – EWEA Resource Assessment Workshop, Bilbao 2016

Project Overview

- Project comprises detailed analysis of existing LiDAR based power curve datasets submitted by OWA members and RES

- Datasets represent most common approaches offshore:
  - Nacelle mounted LiDAR
  - Transition Piece (TP) mounted scanning LiDAR
  - Floating LiDAR

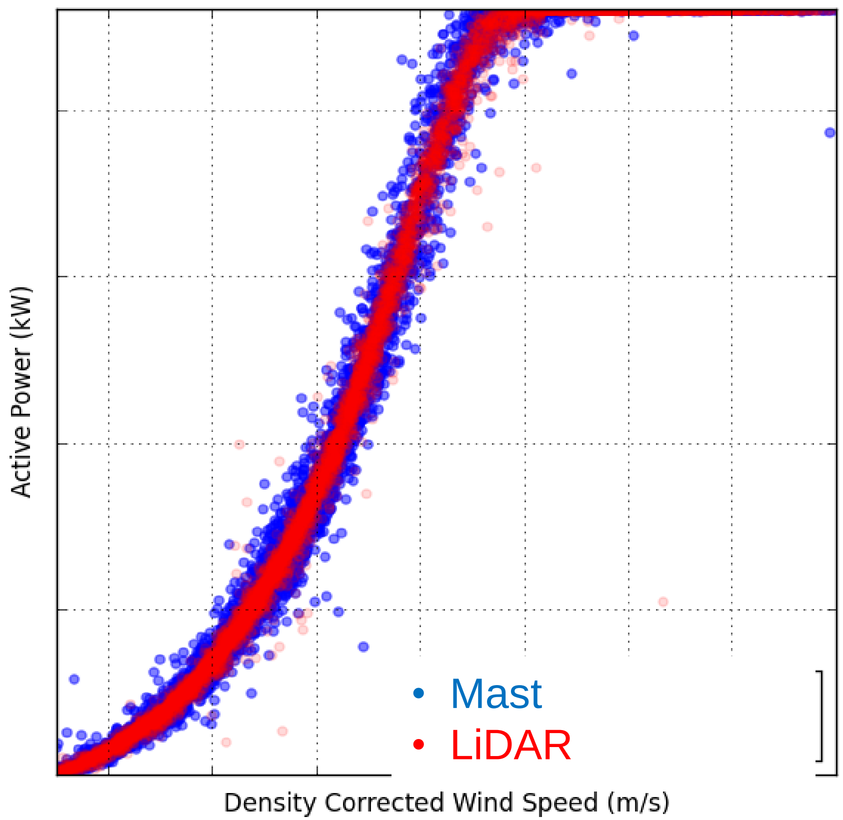


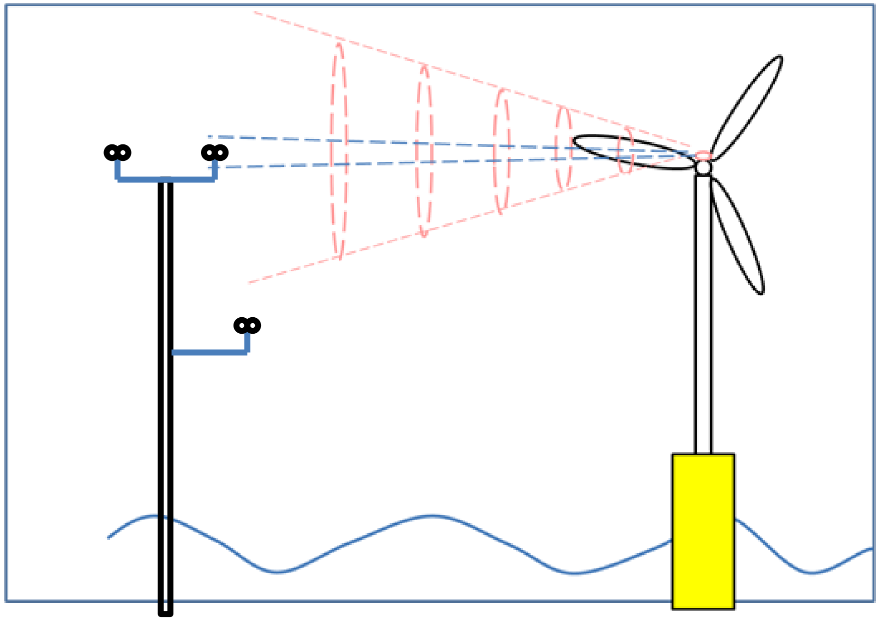
Dataset summary

Technology	Datasets
Nacelle	5 datasets in total, 4 concurrent with masts
Scanning	2 datasets, comparable with each other, but no concurrent mast data
Floating	2 datasets: • One dataset too far from turbine • One dataset too short for quantitative analysis

Power Curve Comparisons

Sample





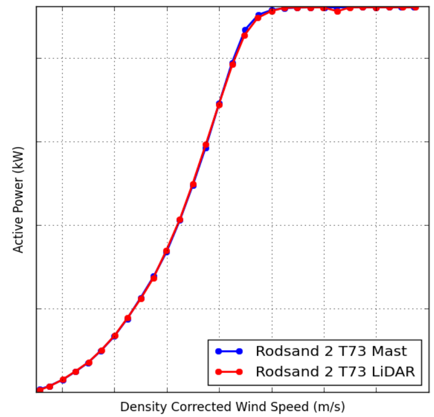
Analysis – Compare LiDAR and Mast

Mast vs Nacelle LiDAR

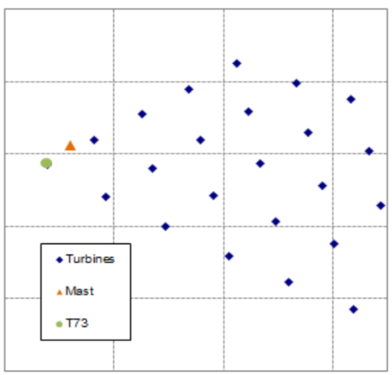
Measurement Device	Measurement Distance	Hours of Valid Data
Mast	3.7D	950
Nacelle LiDAR	2.6D	964

- Offshore
- Mast analysis is IEC compliant
- Mean power curves in close agreement
  - AEP agrees to 0.1%
- Scatter is lower for the nacelle LiDAR measurement

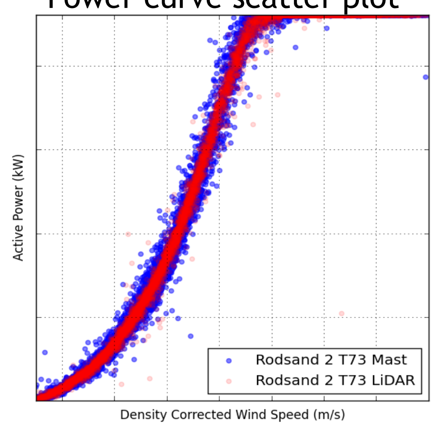
Binned power curves



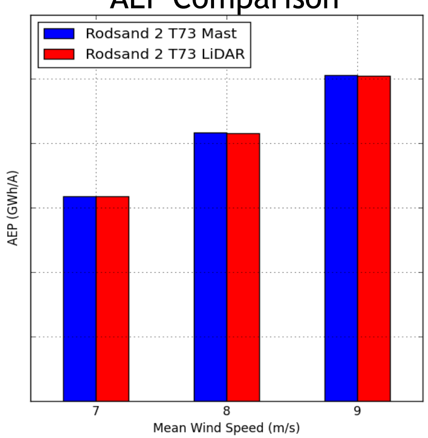
Site setup



Power curve scatter plot

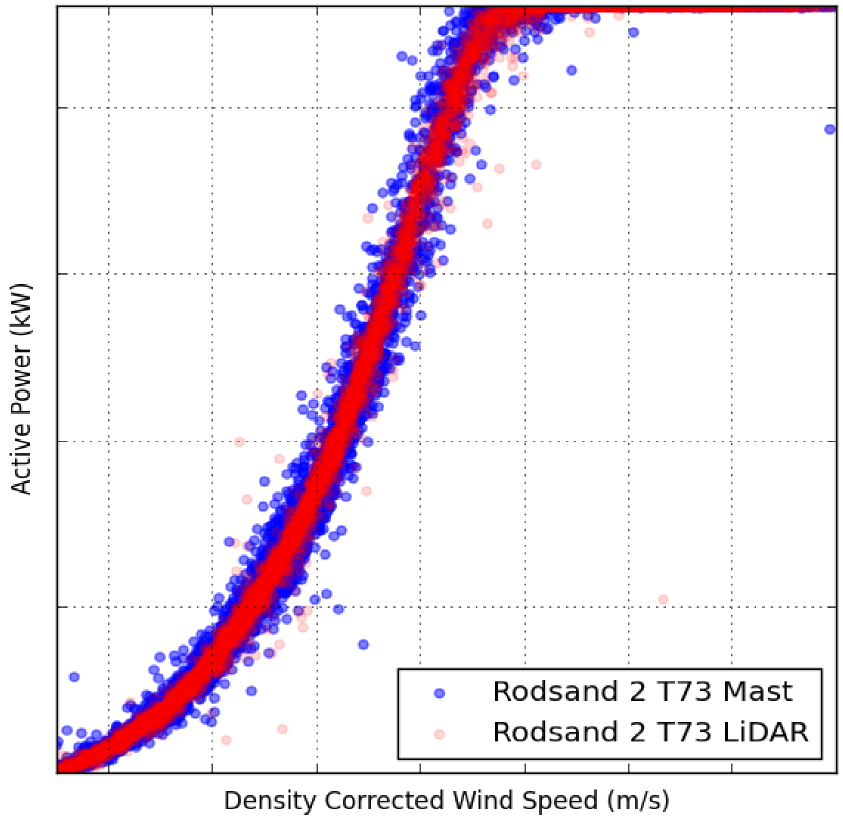


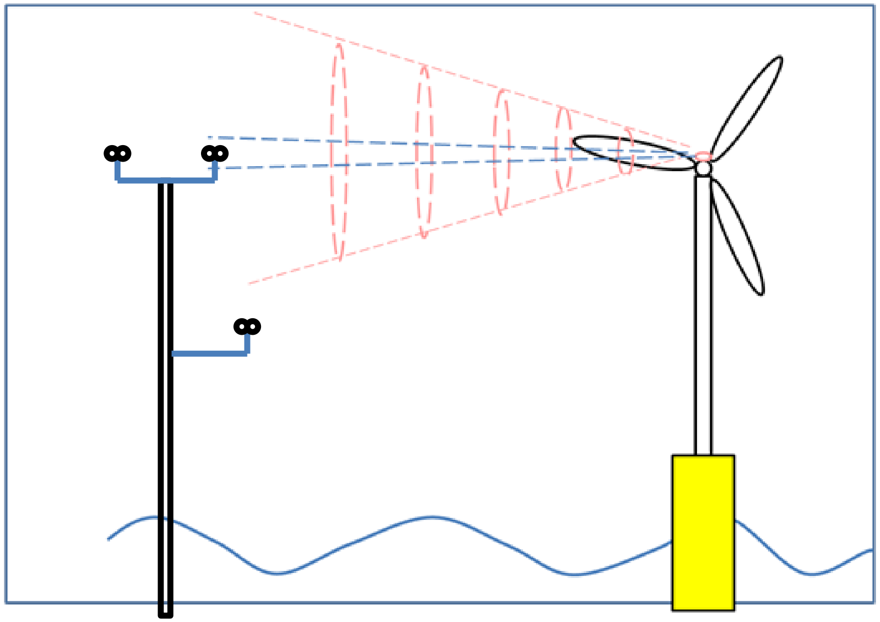
AEP Comparison



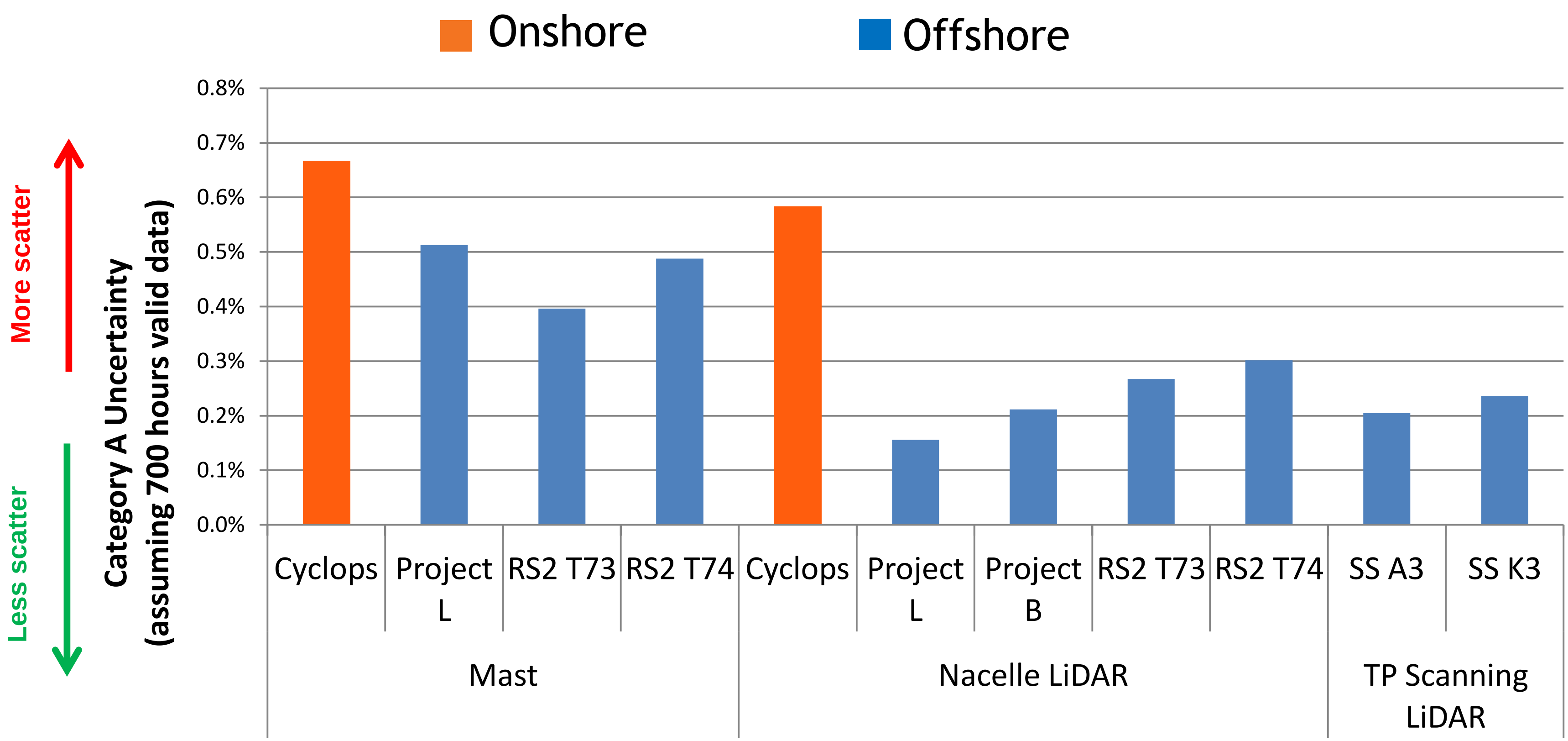
Self-consistency

Do LiDAR power curves have comparable scatter to masts?



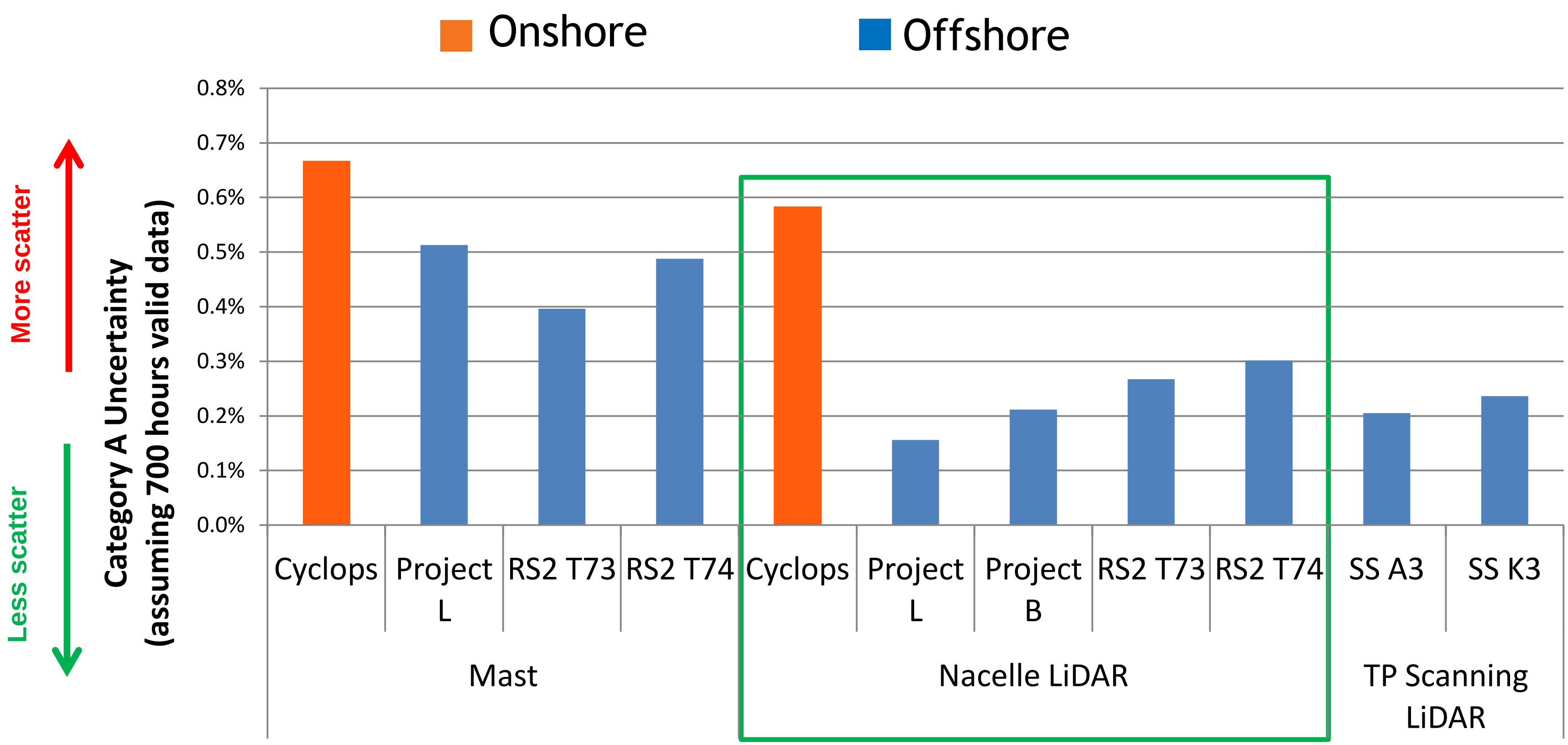


Analysis – Self-Consistency



- Category A Uncertainty quantifies scatter about the mean power curve
- Category A Uncertainty decreases with data count – in the above plot all uncertainties have been corrected to 700 hours valid data for comparison

Analysis – Self-Consistency

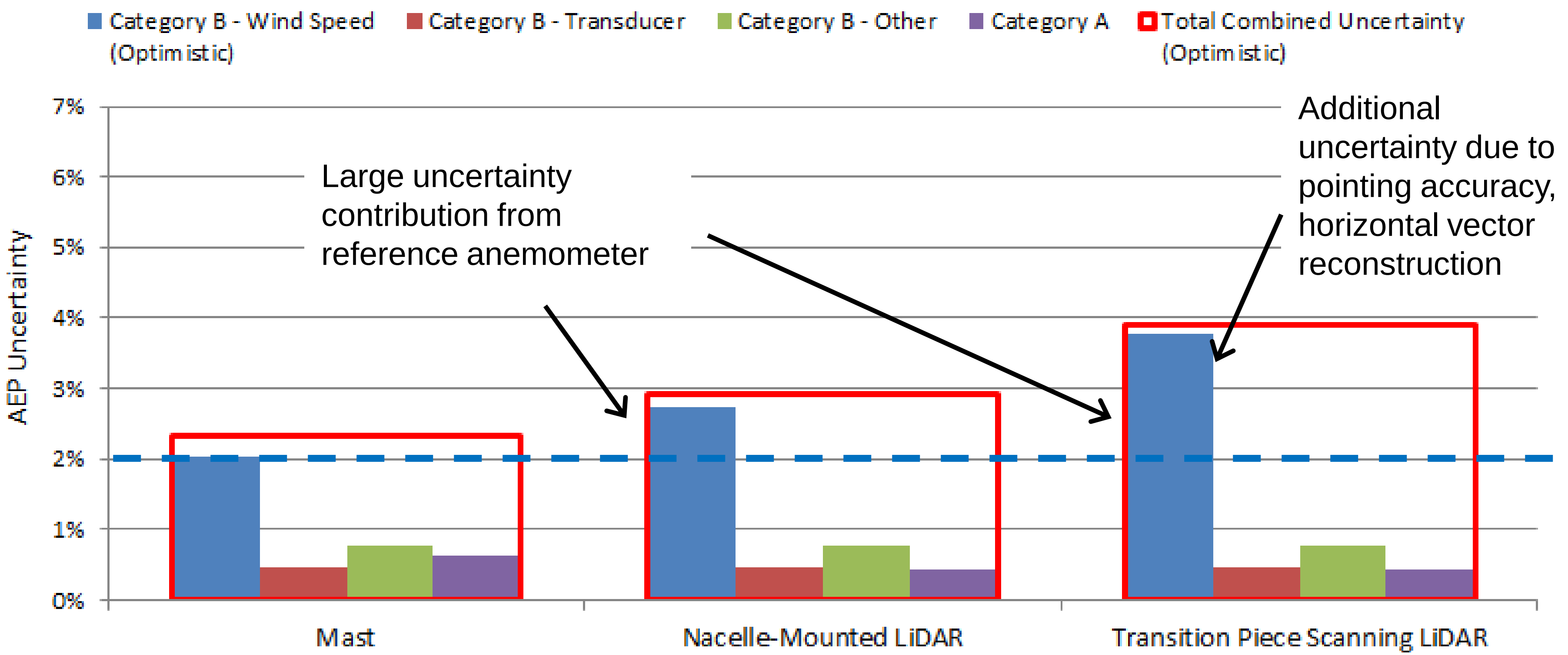


- Highly precise power curve measurement for all nacelle LiDAR datasets
- For each dataset where a comparison can be made, nacelle LiDAR power curve precision is superior to that achieved using masts

Uncertainty Discussion

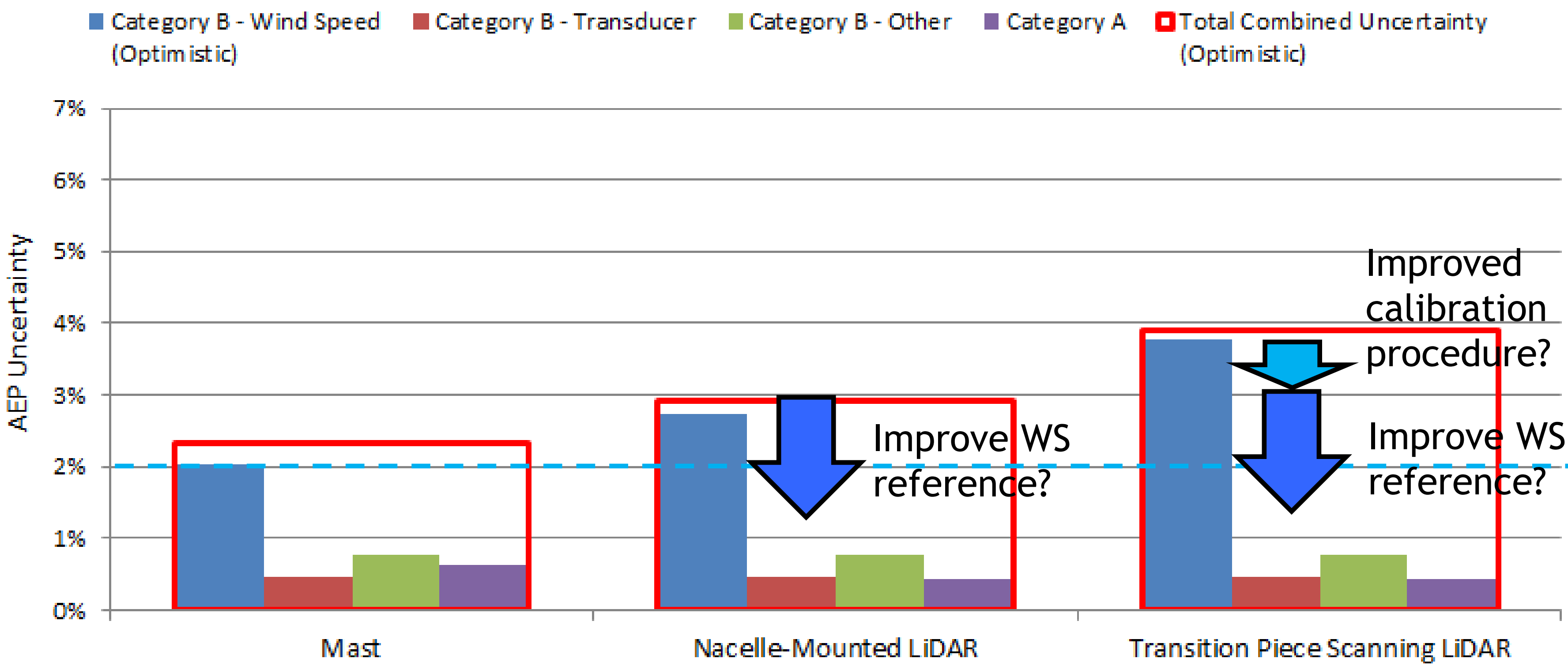
Can LiDARs achieve lower uncertainty than masts?

Illustrative Uncertainties



- LiDAR power curve uncertainties must always be higher than mast power curve uncertainty due to LiDAR wind speed calibration against an anemometer

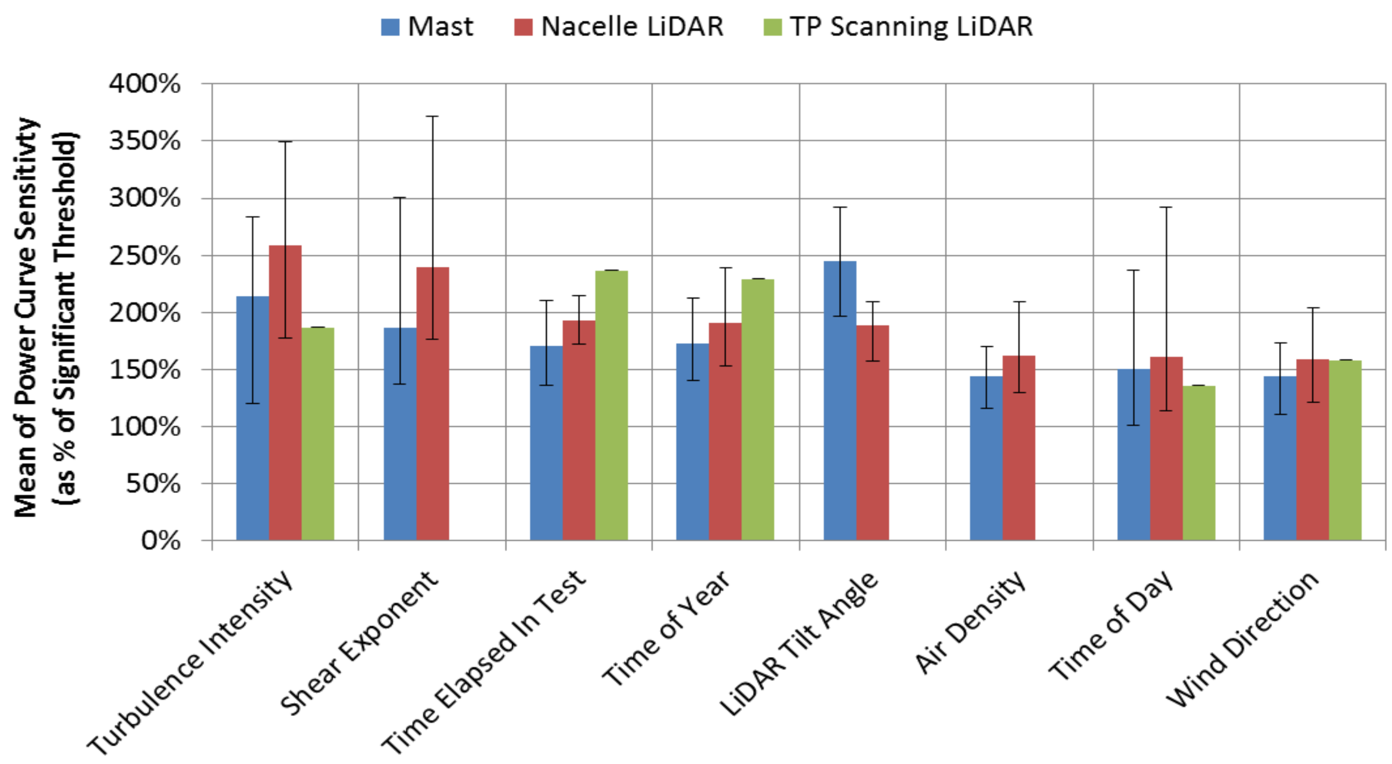
Illustrative Uncertainties



- Key potential for improvement: improve the wind speed reference used in LiDAR calibration
- The relatively high uncertainty assigned to LiDAR measured power curves is strange given their precision and consistently close agreement with masts

Power Curve Sensitivity Analysis

Analysis – Sensitivity

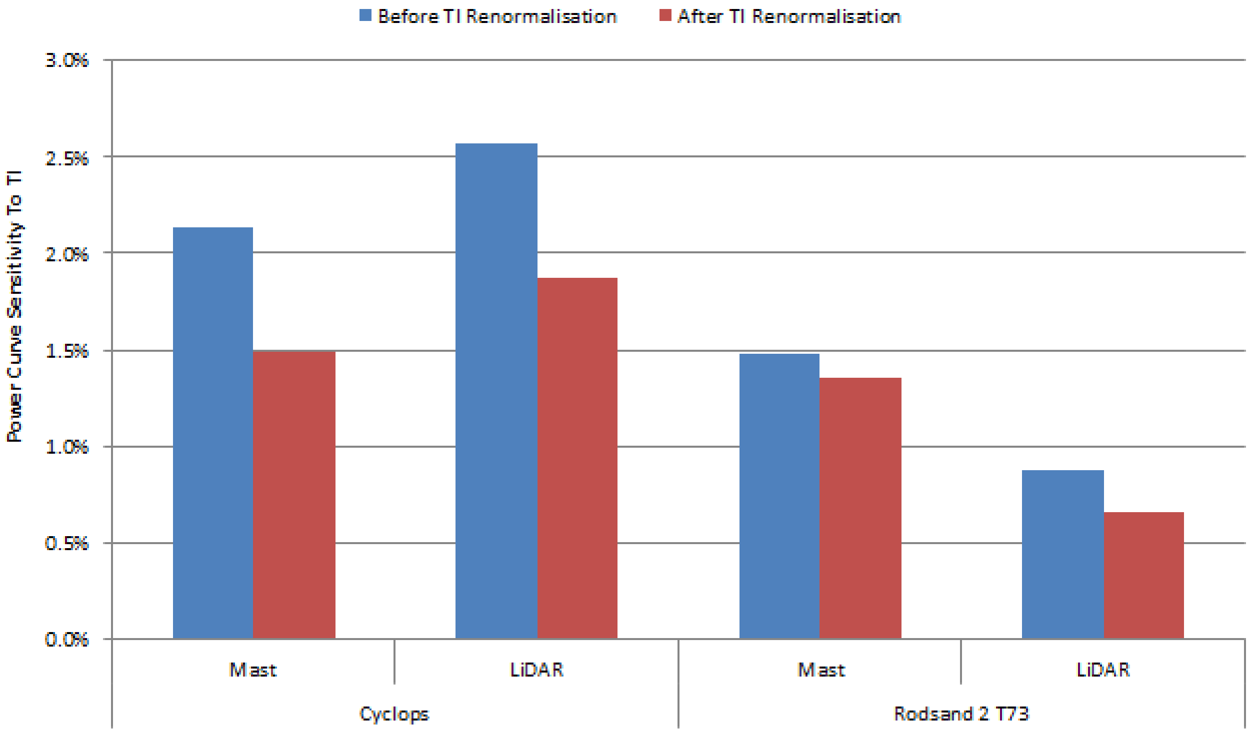


- Nacelle LiDAR and masts show the same sensitivity pattern. Shear and Turbulence are the most significant factors for power curve variation.
- LiDAR Tilt Angle is not associated with significant power curve variation
  - Mast and LiDAR analyses show comparable variation metric (mast slightly higher). The influence is therefore thought to be due to cross correlation with other variables.

Correction Methods

Analysis – Correction Methods

Turbulence Renormalisation



- Using either LiDAR or mast sensitivity of the power curve to TI is reduced through the application of TI renormalisation for both Cyclops and Rødsand 2 T73
- These results imply that TI renormalisation can be applied successfully using LiDAR measured TI signal as long as reference and measured TI are consistent

Finally UniTTE

“Active” partners

Project Coordinator

DTU Wind Energy
Department of Wind Energy

power for good

VATTENFALL

avent
Lidar Technology

ZephIR Lidar
wind speed at light speed

University of Stuttgart
Germany

- **Currently RES fully satisfied that nacelle LiDARs can be used to perform accurate and precise measurements of power curves <u>offshore</u> or for <u>simple terrain.</u>**
- **Understanding how complex terrain will affect the testing process is the next step to really unlock nacelle LiDAR as a useful tool.**
- **Unfortunately there have been some hiccups in the RES complex terrain campaign – To be installed on Thursday hopefully!**

Fingers crossed!

Local date	Thursday, Nov 17								Friday, Nov 18							
Local time	00h	03h	06h	09h	12h	15h	18h	21h	00h	03h	06h	09h	12h	15h	18h	21h
Wind direction																
Wind speed (kts)	12	10	9	9	11	8	7	7	8	8	8	7	5	5	7	9
Wind gusts (max kts)	25	22	20	21	18	20	21	15	19	18	17	12	8	9	15	17
Cloud cover																
Precipitation type			✳													
Precipitation (mm/3h)			0													
Air temperature (°C)	-1	-1	-1	-2	0	-1	-4	-4	-4	-4	-4	-3	0	-2	-3	-3
Air pressure (hPa)	900	897	894	892	891	890	889	889	889	889	889	890	891	892	894	895

Local date	Saturday, Nov 19								Sunday, Nov 20							
Local time	00h	03h	06h	09h	12h	15h	18h	21h	00h	03h	06h	09h	12h	15h	18h	21h
Wind direction																
Wind speed (kts)																


Strategy Sustainable Innovation Safety Operations
Solar Engineering Onshore Analysis Asset
Asset
Technical Construction
Onshore REPUTATION Environmental Development Management
Wind Project
Maintenance
USA
Grid
UK
Ireland
EXPERTISE
Worldwide
Independent
SUSTAINABLE
France
Foundations
HEALTH & SAFETY
Turkey
Reputation
Brilliance Australia
Electrical
Project
Turbines
Engineering
Foundations
Connection
Renewable
DEVELOPMENT
UK
Tidal
France
Canada
End to End
Offshore
LOW CARBON
South Africa
EXPERTISE Scandinavia Diligence
Reliability
Tidal
WAVE
EXPERIENCE Capability
QUALITY
Wind
Blades
Onshore Assessment Sustainable
Grid Environmental
Offshore
Wave
Operations & Maintenance
Strategy Cables DEVELOPMENT
CONSULTANCY Capability
end-to-end Engineering EXPERIENCE
Development
Grid
Energy
Strategy
PROJECT Independent Power Producer
DELIVERY
Tidal
SAFETY
SCADA
Wave
Tidal
Renewable
Management
Cables Data
Energy
Cables
Reliability
Transmission
Grid Energy
SCADA
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