January 2019

# Minutes
# of the IEA Wind Task 32 Workshop #10 on Turbulence Intensity Measurements with LiDARs - Applications to Loads Verification and Site Suitability

Date: 20th and 21st September 2018
Venue: Ørsted, Gentofte (5 km North of Copenhagen), Denmark
Workshop leader: Ameya Sathe (Ørsted)
Organization team: Eric Simley (NREL), Detlef Stein (Multiversum), David Schlipf (HS Flensburg)

## Minutes

### Day 1

#### Introduction

| | |
|---|---|
| 10:30 | Welcome to Ørsted – Ameya Sathe, Ørsted |

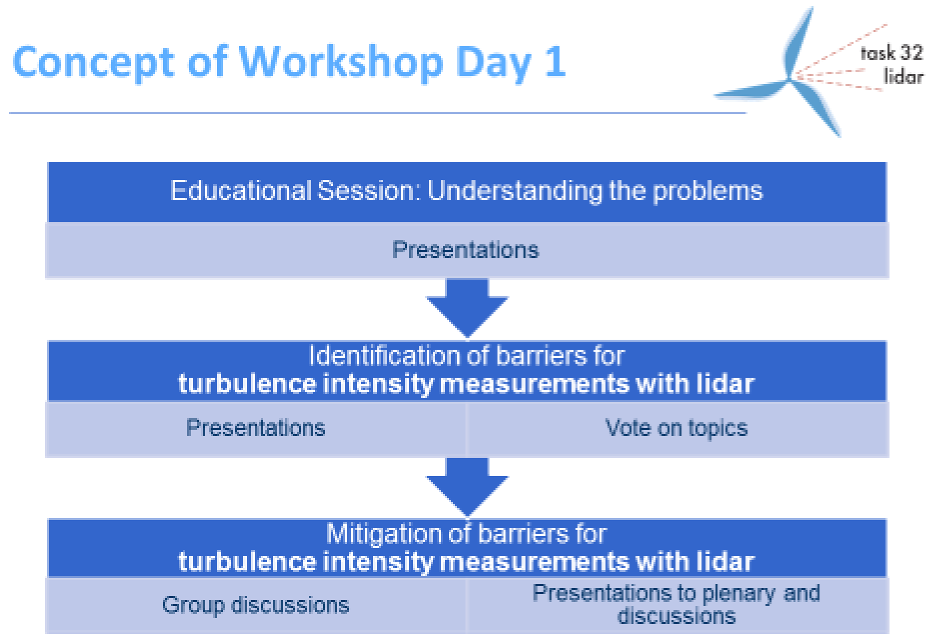
- Ameya welcomed everybody
- Ameya provided the safety information
- Ameya presented the main objectives of the workshop and the program of the two days

| | |
|---|---|
| | Introduction to IEA Wind Task 32 - David Schlipf, HS Flensburg |

- International Energy Agency Wind is a vehicle for member countries to exchange information on the planning and execution of national large-scale wind system projects and to undertake co-operative R&D projects called Tasks.
- Objectives Task 32 (2016-2018):
    - Provide international open platform for exchange of experience
    - Identify and mitigate barriers to the use of lidar for wind energy
- The concept of the workshop and the agenda was presented, see Figure 1.

| | |
|---|---|
| | Presentation round - all |

- All participants presented themselves and the expectations of the workshop based on their stakeholder role



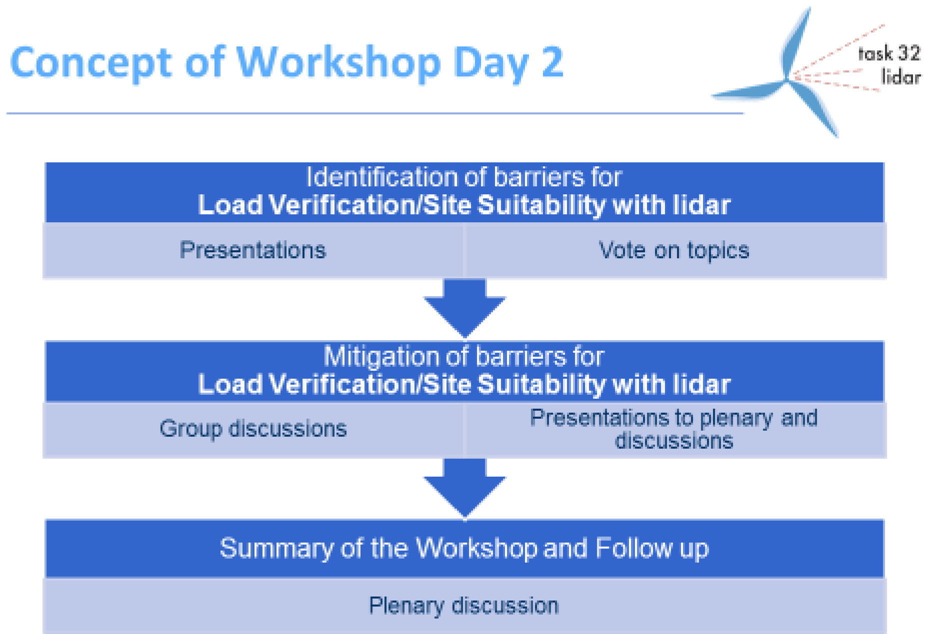




Figure 1: Concept of Workshop # 10 on Turbulence Intensity Measurements with Lidars.

## Educational Session: Understanding the problems

| | |
|---|---|
| 11:15 | Turbulence intensity measurements with lidars - Jakob Mann, DTU Wind energy |

- Presentation

| | |
|---|---|
| 11:45 | Loads verification process - Cameron Brown, Ørsted |

- Presentation

## Identification of barriers for turbulence intensity measurements with lidar

The session was chaired by Eric Simley, NREL.

| | |
|---|---|
| | IEA Task 32 Wind Expert Report on Lidar Turbulence Measurements - Ameya Sathe, Ørsted |

- Presentation
- Report

| | |
|---|---|
| | Turbulence characterization from a forward-looking nacelle lidar - Alfredo Pena, DTU Wind Energy |

- Presentation

| | |
|---|---|
| | TI measurements, CW LiDAR manufacturer's perspective - Scott Wylie, ZephIR LiDAR |

- Presentation

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|---|---|
| | TI sensitivities of DBS and VAD scalar and vector averages - Peter Clive, Woodplc |

- Presentation

## Mitigation of barriers for turbulence intensity measurements with lidar

The session was chaired by Detlef Stein, Multiversum. The following questions were tackled based on the ranking of importance of the problem made by the participants.

### Why is it hard to perform point turbulence intensity measurements with lidar?

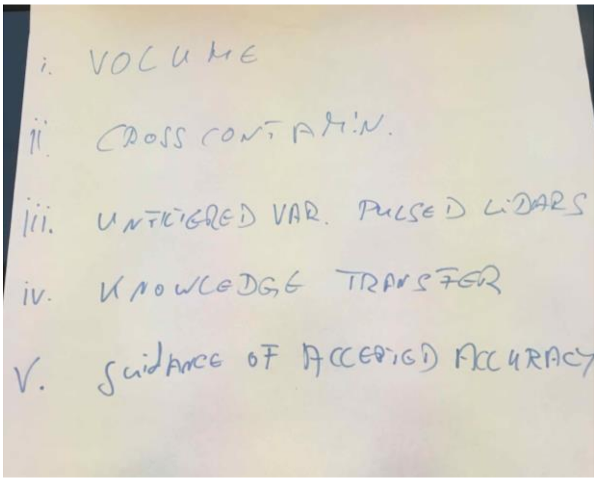
| ID | Barrier | # |
|---|---|---|
| 1 | It is hard to get rid of the **volume measurement**. | 2 |
| 2 | It is hard to get rid of the **cross-contamination** from other velocity components. | 4 |
| 3 | **Sampling rates** might be not high enough. | |
| 4 | Not all lidars provide **Doppler spectra** (needed to get the unfiltered variance). | |
| 5 | **Turbulence models** used for LOS spectra are not trivial / perfect. | |
| 6 | No available **method to get the unfiltered variance for pulsed lidars**. | 4 |
| 7 | Different levels of **knowledge** and understanding, not enough **transfer**. | 3 |
| 8 | There is a **lack of** concrete **guidance** on the **accepted level of accuracy**. | 1 |

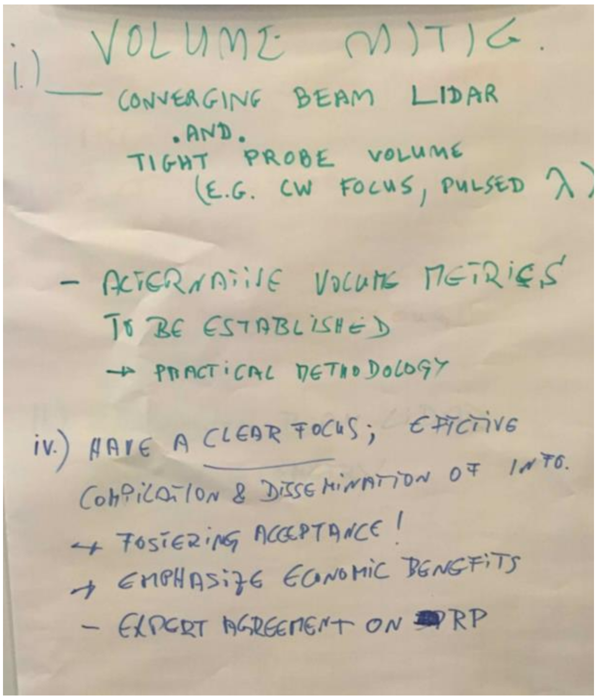
From the figures below, the following summary is made.

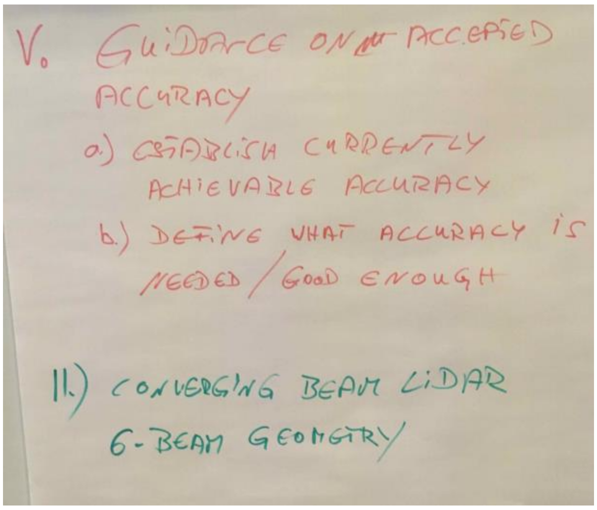
### Why is it hard to perform point turbulence intensity measurements with lidar?

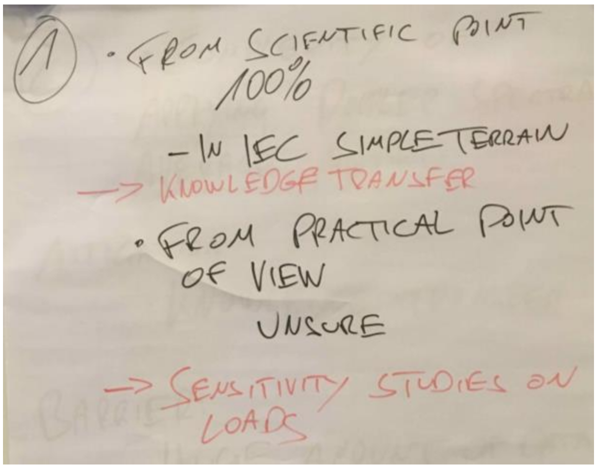
| ID | Mitigation of Barrier | # |
|---|---|---|
| 1 | volume measurement:<br>Converging beams; tight probe volume; alternative volume metrics; apply Doppler spectral averaging method → huge amount of data → device implementation; knowledge transfer; site and turbulence specific transfer function | 2 |
| 2 | cross-contamination:<br>Converging beam; 6-beam geometry | 4 |
| 6 | method to get the unfiltered variance for pulsed lidars:<br>Research review of two Russian methods; investigate pulsed lidar spectrum broadening method | 4 |
| 7 | knowledge transfer:<br>Clear focus; effective compilation & dissemination of info; fostering acceptance; emphasize economic benefits; expert agreement on RP; resolve competition btw. Stakeholders; educate → collaborate → co-create!; dedicated Task 32 workshop | 3 |
| 8 | lack of guidance accepted level of accuracy:<br>Establish currently achievable accuracy; agree on need/good enough accuracy; sensitivity study on loads; define specific purpose e.g. loads verification | 1 |

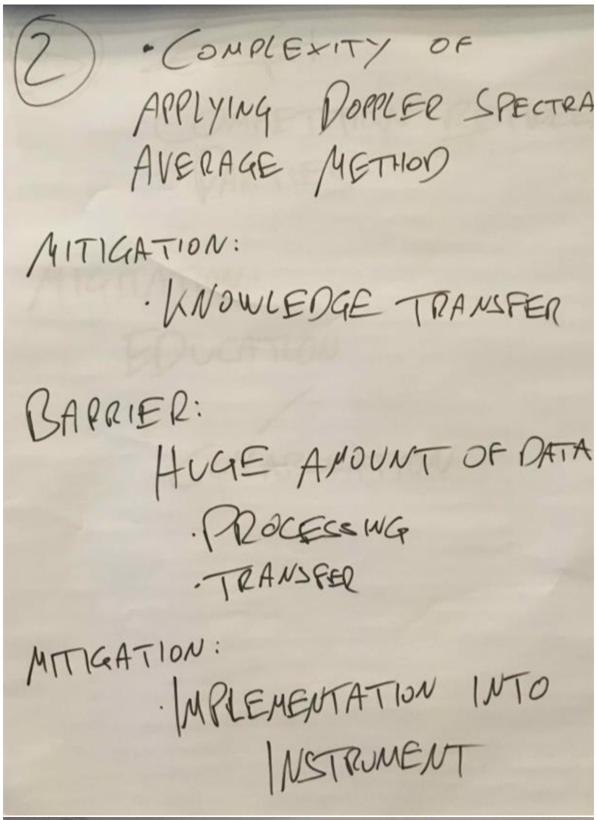
Figures see below.

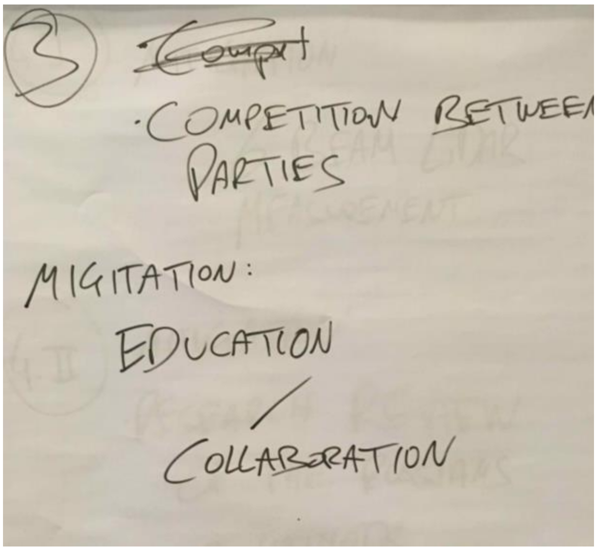

i. VOLUME
ii. CROSS CONTAMIN.
iii. UNTRIGRED VAR. PULSED LIDARS
iv. KNOWLEDGE TRANSFER
V. Guidance of ACCEPTED ACCURACY

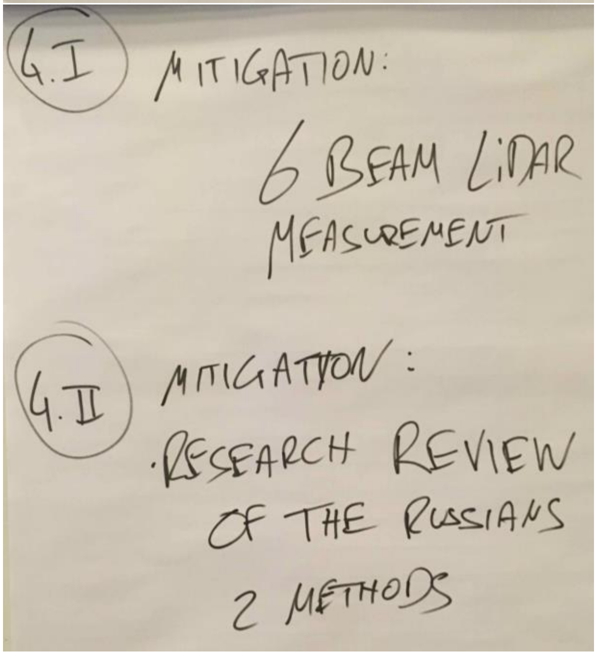

I.) VOLUME MITIG.
— CONVERGING BEAM LIDAR
.AND.
TIGHT PROBE VOLUME
(E.G. CW FOCUS, PULSED λ)
– ALTERNATIVE VOLUME METRICS
TO BE ESTABLISHED
→ PRACTICAL METHODOLOGY
iv.) HAVE A CLEAR FOCUS; EFFECTIVE
COMPILATION & DISSEMINATION OF INFO.
→ FOSTERING ACCEPTANCE!
→ EMPHASIZE ECONOMIC BENEFITS
– EXPERT AGREEMENT ON RP


V. GUIDANCE ON ACCEPTED
ACCURACY
a.) ESTABLISH CURRENTLY
ACHIEVABLE ACCURACY
b.) DEFINE WHAT ACCURACY IS
NEEDED / GOOD ENOUGH
II.) CONVERGING BEAM LIDAR
6-BEAM GEOMETRY


1
· FROM SCIENTIFIC POINT
100%
– IN IEC SIMPLE TERRAIN
→ KNOWLEDGE TRANSFER
· FROM PRACTICAL POINT OF VIEW
UNSURE
→ SENSITIVITY STUDIES ON LOADS


2
· COMPLEXITY OF APPLYING DOPPLER SPECTRA AVERAGE METHOD
MITIGATION:
· KNOWLEDGE TRANSFER
BARRIER:
HUGE AMOUNT OF DATA
· PROCESSING
· TRANSFER
MITIGATION:
· IMPLEMENTATION INTO INSTRUMENT


3
· Compet
· COMPETITION BETWEEN PARTIES
MIGITATION:
EDUCATION
/
COLLABORATION


4.I
MITIGATION:
6 BEAM LIDAR MEASUREMENT
4.II
MITIGATION:
· RESEARCH REVIEW OF THE RUSSIANS
2 METHODS

Hard to get rid of volume measurement

1) Site or turbulence specific transfer function
2) Using unfiltered Doppler Spectrum

Getting Unfiltered Variance from Pulsed Lidars

1) Further investigation of Pulsed lidar Spectrum broadening Variable

Cross Contamination from other Velocity components

1) Multiple lidars measuring Same point
2) One lidar measuring multiple beam direction
   - Assume homogeneity in Measurement volume

Different levels of knowledge/ Not enough knowledge transfer

1) Best practices with input from different stakeholders
2) Meetings like Task 32 Workshop

Lack of concrete guidance on accepted level of accuracy

1) Need to define specific purpose
   - Load validation?

i.) VOLUME MITIG.

CONVERGING BEAM LIDAR
.AND.
TIGHT PROBE VOLUME
(E.G. CW FOCUS, PULSED λ)

- ALTERNATIVE VOLUME METRICS TO BE ESTABLISHED
  → PRACTICAL METHODOLOGY

iv.) HAVE A CLEAR FOCUS; EFFECTIVE COMPILATION & DISSEMINATION OF INFO.

→ FOSTERING ACCEPTANCE!
→ EMPHASIZE ECONOMIC BENEFITS
- EXPERT AGREEMENT ON RP

## Day 2

| | |
|---|---|
| 9:00 | Summary of Day 1 |

The goal of day 1 was to focus on the TI measurements with LiDARs and discuss the barriers that make using LiDARs for TI measurements impossible or very difficult. The barriers on one hand were identified into being technical in nature, such as problem of using large volume measurements and cross contamination of the components of the wind vector, whereas on the other hand, difficulty in disseminating the knowledge and lack of guidance on the accepted level of accuracy were also identified. Focus was primarily on the TI measurements itself, and not much on the applications of TI in wind energy. Mitigation of the barriers were also discussed, where methods to get rid of filtering of turbulence and cross-contamination were put forward.

There was a good mix of presentations, where the industry and academia blended very well to present the respective perspectives on LiDAR TI measurements.

### Identification of barriers for Load Verification/Site Suitability with lidar

The session was chaired by David Schlipf, HS Flensburg.

| | |
|---|---|
| 09:30 | Potential for using floating LiDAR for offshore site assessment - Ben Williams, Carbon Trust |

- Presentation

| | |
|---|---|
| | Turbine Load Assessment: Challenges and Opportunities for Remote Sensing - Zachary Parker, Nordex |

- Presentation

| | |
|---|---|
| | Lidar based load validation: practical experience from the UniTTe project - Nikolay Dimitrov, DTU Wind Energy |

- Presentation

| | |
|---|---|
| | Loads validation using LiDAR TI: Potential and barriers of different correction methods - Jens Riechert, DNVGL |

- Presentation

| | |
|---|---|
| | Alternatives to TI for load estimation (transience statistics) - Peter Clive, Woodplc |

- Presentation

## Mitigation of barriers for Load Verification/Site Suitability measurements with lidar

The session was chaired by Ameya Sathe, Ørsted. The following questions were tackled based on the ranking of importance of the problem made by the participants.

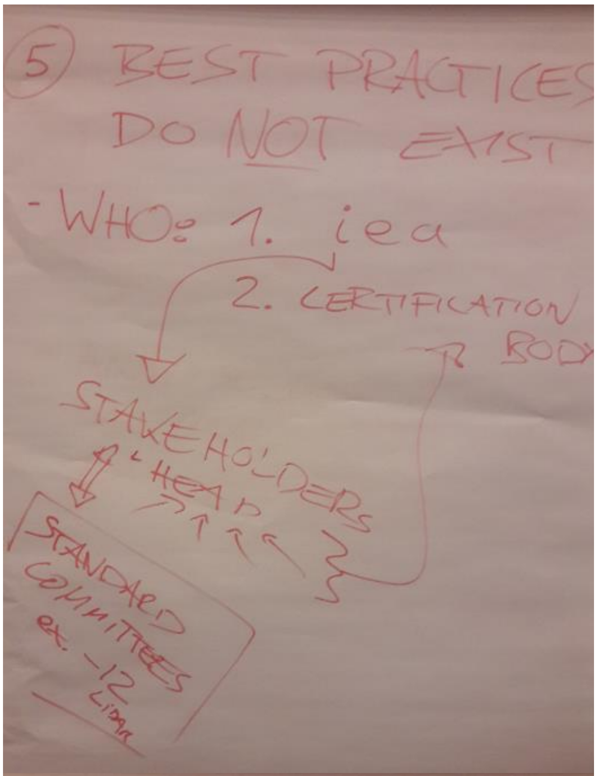
# Why is it hard to perform load verification/site suitability with lidars?

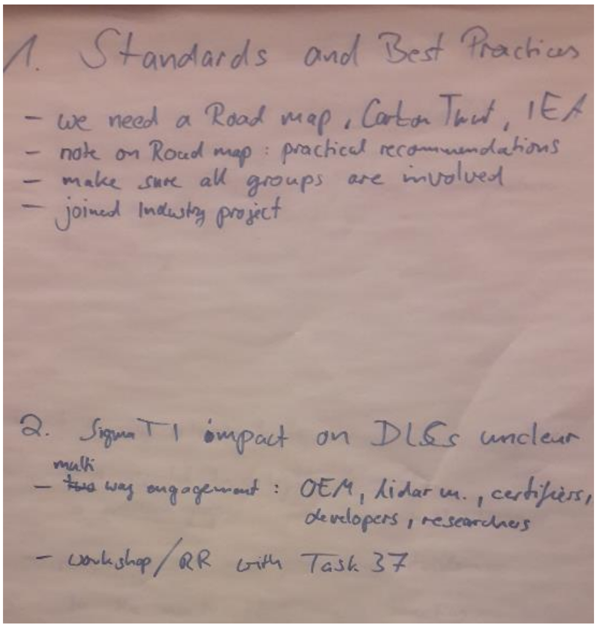
| ID | Barrier | # |
|---|---|---|
| 1 | We can get different TI values with different current lidar devices. | 3 |
| 2 | Raw lidar TI overpredicts loads | |
| 3 | Machine learning models are not perfect, e.g. too site specific for loads, training input needed for correction algorithms, too large scatter | |
| 4 | Industry is reluctant to use other than point TI measurements | 4 |
| 5 | Best practices and standards do not exist for correction methods | 1 |
| 6 | Unsure how to extend turbulence estimation methods to high turbulence, complex sites | |
| 7 | New (Doppler spectral average, spectral fit etc.) methods are very complicated to use in everyday implementation | |
| 8 | Uncertainty in the input TI and its impact on DLCs is unclear | 2 |
| 9 | Turbulence intensity itself is not the best predictor of loads, e.g. may require transient stats, rotor effective TI etc. | |

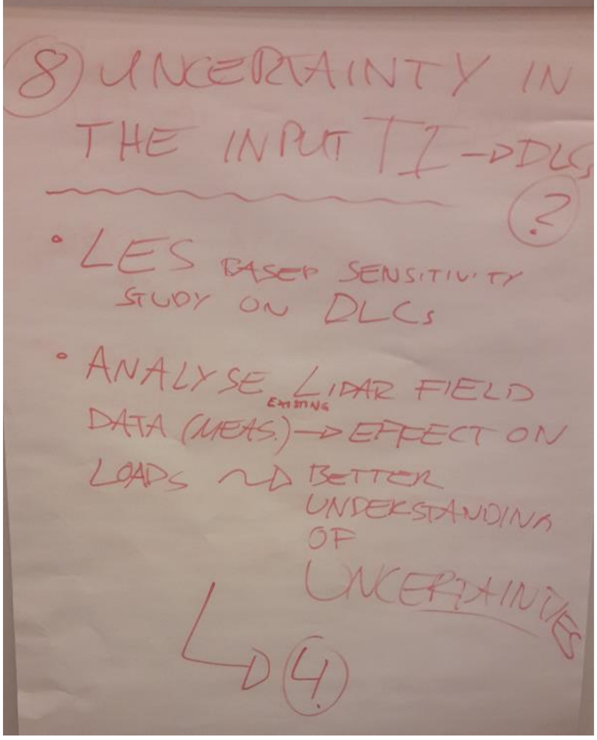
# Why is it hard to perform point turbulence intensity measurements with lidar?

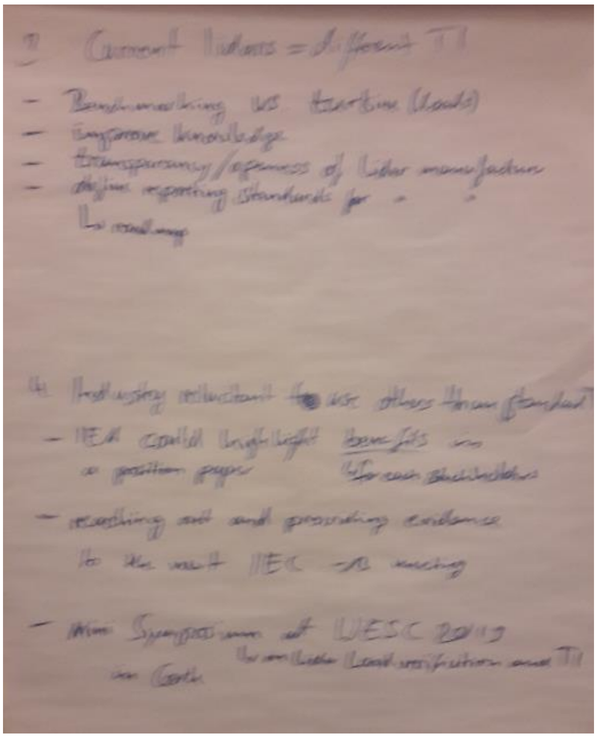
| ID | Mitigation of Barrier | # |
|---|---|---|
| 5 | Best practices and standards:<br>Need a roadmap to write these; Joint Industry Project (JIP), IEA, Carbon Trust can lead the task; All groups need to be involved, i.e. academia, manufacturers, end-users etc. | 1 |
| 8 | Uncertainty in the input TI and its impact on DLCs:<br>Large Eddy Simulation (LES) based sensitivity study on DLCs; Use LiDAR field data and analyze the impact on loads; Sensitivity study using the aero-elastic codes. | 2 |
| 1 | different TI values with different current lidar devices:<br>Define accuracy requirements; establish conditions where accuracy is achieved; establish standard calibration procedure for TI. | 3 |
| 4 | Industry is reluctant to use other than point TI measurements:<br>Provide industry demonstration that LiDARs can provide point TI measurements to sufficient level of accuracy; If ID 5, 8 and 1 are solved, then reluctance will decrease. | 4 |

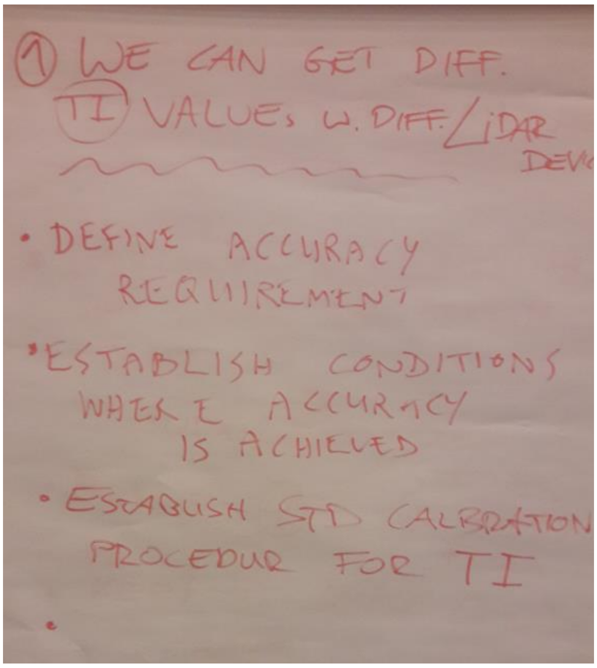
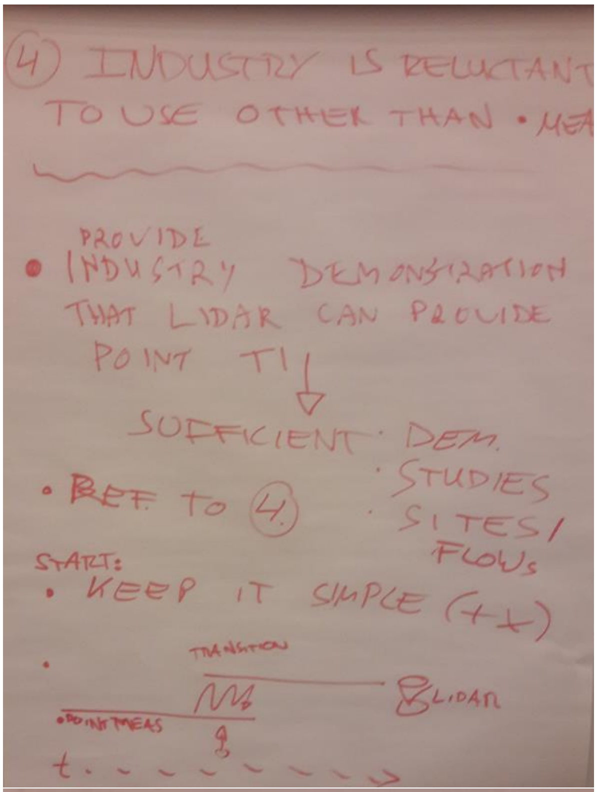
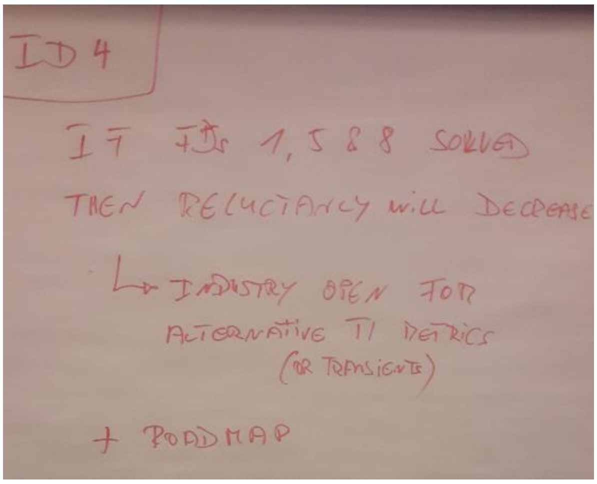
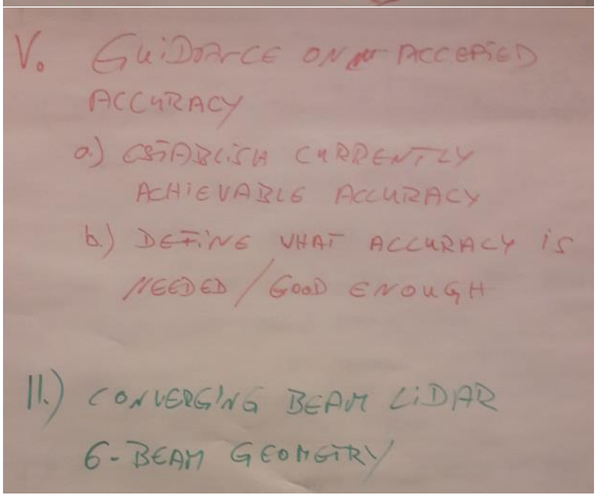
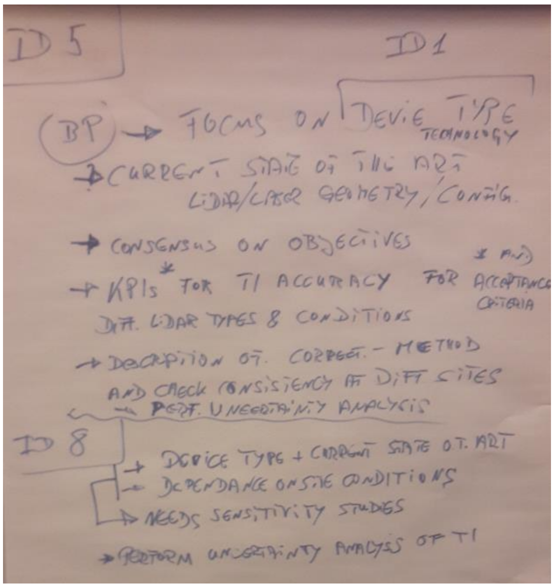
Figures see below.


5) BEST PRACTICES DO NOT EXIST
- WHO: 1. iea
2. CERTIFICATION BODY
STAKEHOLDERS
"HEAD"
STANDARD COMMITTEES
eg. -12
LIDAR


1. Standards and Best Practices
- we need a Road map, Carbon Trust, IEA
- note on Road map: practical recommendations
- make sure all groups are involved
- joined Industry project
2. Sigma TI impact on DLCs unclear
- multi way engagement: OEM, lidar m., certifiers, developers, researchers
- workshop/RR with Task 37


8) UNCERTAINTY IN THE INPUT TI -> DLCs
?
• LES BASED SENSITIVITY STUDY ON DLCs
• ANALYSE EXISTING LIDAR FIELD DATA (MEAS.) -> EFFECT ON LOADS -> BETTER UNDERSTANDING OF UNCERTAINTIES
-> (4)




1 WE CAN GET DIFF. TI VALUES W. DIFF. LIDAR
• DEFINE ACCURACY REQUIREMENT
• ESTABLISH CONDITIONS WHERE ACCURACY IS ACHIEVED
• ESTABLISH STD CALIBRATION PROCEDUR FOR TI

4) INDUSTRY IS RELUCTANT TO USE OTHER THAN • MEA
PROVIDE INDUSTRY DEMONSTRATION THAT LIDAR CAN PROVIDE POINT TI
SUFFICIENT · DEM. · STUDIES · SITES / FLOWS
• REF TO 4.
START:
• KEEP IT SIMPLE (+ +)
TRANSITION
LIDAR
POINT MEAS
t

ID 4
IF 1, 5 & 8 SOLVED
THEN RELUCTANCY WILL DECREASE
INDUSTRY OPEN FOR ALTERNATIVE TI METRICS
(OR TRANSIENTS)
+ ROADMAP

V. GUIDANCE ON ACCEPTED ACCURACY
a) ESTABLISH CURRENTLY ACHIEVABLE ACCURACY
b) DEFINE WHAT ACCURACY IS NEEDED / GOOD ENOUGH
11.) CONVERGING BEAM LIDAR
6-BEAM GEOMETRY

ID 5
ID 1
BP → FOCUS ON DEVICE TYPE TECHNOLOGY
CURRENT STATE OF THE ART
LIDAR/LASER GEOMETRY, CONFIG.
→ CONSENSUS ON OBJECTIVES
→ KPIs * FOR TI ACCURACY FOR DIFF. LIDAR TYPES & CONDITIONS
* AND ACCEPTANCE CRITERIA
→ DESCRIPTION OF CORRECT. - METHOD AND CHECK CONSISTENCY OF DIFF SITES
→ PERF. UNCERTAINTY ANALYSIS
ID 8
→ DEVICE TYPE + CURRENT STATE OF ART
→ DEPENDANCE ON SITE CONDITIONS
→ NEEDS SENSITIVITY STUDIES
→ PERFORM UNCERTAINTY ANALYSIS OF TI

## Summary of the Workshop and Follow up

| | |
|---|---|
| 15:15 | Discussion within the working group about documenting the results of the workshop - all |

The workshop tackled two important issues pertaining to LiDAR TI measurements.

1. Mitigation of barriers for turbulence intensity measurements with lidar, and
2. Mitigation of barriers for Load Verification/Site Suitability measurements with lidar

Many interesting points were discussed, and the focus during the summary session was on the next steps to follow-up on the points raised in this workshop. It was clearly identified that a roadmap to work on the suggested mitigation tasks is required to achieve any meaningful results. Defining such a roadmap requires commitment from the stakeholders in terms of contributing some hours of their work time. It was therefore agreed that disseminating the minutes of the meeting was the first step before sending out any invitations to the stakeholders for defining a roadmap for LiDAR TI measurements. As to who takes the lead in future steps needs to be discussed within the IEA advisory board.

## Participants

| Name | Country | Organization |
|---|---|---|
| Demetrios Zigras | UK | Nordex Acciona Windpower |
| Hans-Jürgen Kirtzel | Germany | Metek GmbH |
| Nikolaj Kruppa | DK | Ørsted |
| Alkistis Papetta | Germany | Fraunhofer IWES |
| Eloise Burnett | UK | Carbon Trust |
| Anantha P. Kidambi Sekar | Germany | ForWind-University of Oldenburg |
| Marte Godvik | Norway | Equinor |
| Pablo Saavedra-Garfias | Norway | Geophysical Institute, University of Bergen |
| Christophe LEPAYSAN | France | EPSILINE |
| Camille Dubreuil | Norway | Equinor |
| Dhruv Dhirendra | Germany | innogy SE |
| REBECA RIVERA LAMATA | Denmark | Ørsted |
| Sebastian Streitz | Sweden | Nordex Sverige AB |
| Jochen Cleve | Denmark | Ørsted |
| Meltem Duran | UK | Ørsted |
| Ameya Sathe | Denmark | Ørsted |
| Detlef Stein | Germany | Stein |
| Sebastian Leithold | Germany | Innogy SE |
| Stephen Etheridge | UK | Innogy |
| Breanne Gellatly | Italy | AXYS Technologies Inc |
| Inga Reinwardt | Germany | HAW Hamburg |
| Andrew Henderson | UK | Orsted |
| Peter Clive | Scotland | Wood - Clean Energy |
| Sara Koller | Switzerland | Meteotest |
| Eric Simley | USA | National Renewable Energy Laboratory |
| David Böckler | Germany | ENERCON |
| Frank Scheurich | Denmark | DNV GL |
| Henrik S Pedersen | Denmark | EMD international A/S |
| Francisco Correoso | Spain | Iberdrola |
| Zachary Parker | Germany | Nordex Energy GmbH |
| Theodore Holtom | United Kingdom | Wind Farm Analytics Ltd |
| Alfredo Peña | Denmark | DTU Wind Energy |
| Nikolai Hille | Germany | DNV GL |
| Nikolay Dimitrov | Denmark | DTU Wind Energy |
| Justin Burstein | Germany | E.ON Climate & Renewables |
| Scott Wylie | UK | ZephIR Lidar |
| Jens Riechert | Germany | DNV GL |
| Rafael Tavares | Germany | DNV GL |
| Stathis Koutoulakos | Netherlands | Nuon/Vattenfall |
| Stefan Goossens | The Netherlands | Vattenfall |
| Adrian How | UK | SSE |
| Jakob Mann | Denmark | DTU Wind Energy |
| David Schlipf | Germany | HS Flensburg |
| Ben Williams | Ireland | DNV GL |
| Björn Schmidt | Germany | Ørsted |
| Cam Brown | Denmark | Ørsted |