International Energy Agency (IEA)

Implementing Agreement for Co-operation in the Research and Development of Wind Energy Systems (IEA Wind)

Task 32 Extension Proposal for ExCo #76, Paris, France

Wind Lidar Systems for Wind Energy Deployment

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Document History

- 11/16/2015: Update Advisory Board

1 Scope

Since May 2012, IEA Task 32 "Wind Lidar Systems for Wind Energy Deployment" provided not only an international open platform for industrial and academic partners to exchange new ideas, experiences, and measurement techniques for lidar in wind energy, but also achieved important results in the form of expert reports, conference papers and recommended practices. The purpose of Phase 2 of Task 32 is to build on these results and continue providing a forum for the community established in Phase 1. The main objective of Phase 2 is to identify and to mitigate barriers to the use of the lidar technology in wind energy applications. While Task 32 Phase 1 has been addressing a very broad range of topics reaching from calibration and classification over applications to research related questions, the proposed Phase 2 should focus on four specific applications in order to foster the use of lidar in wind energy. Further, important improvements will be made based on the experience from Phase 1 in the meeting strategy, the communication and dissemination and the management structure: The general meetings hold five times for all participants during Phase 1 have been an important forum to build up a community and will be continued in Phase 2. Complementarily, one yearly workshop will be organized for each of the four applications focusing on one specific problem, and with a well-define program and tangible outcome. This will allow a continuous dissemination of results. Further, an additional advisory board of 8-10 subject matter experts will help keep the Task and workshops relevant and useful.

This extension is also a good opportunity to enhance cross-Task collaboration with groups like Task 30 (aero-elastic code comparison), and Task 31 (wind farm modeling).

2 Introduction

This Section will give a short overview of lidar systems in wind energy, describe the advances of the first phase of Task 32, and summarize the main motivation of the proposed extension.

2.1 Development of Wind Lidar Systems for Wind Energy

The traditional method in wind energy to obtain wind speed and direction measurements is to mount cup anemometers and wind vanes on meteorological masts. Although applications of lidar to wind energy were explored in the 1980's, the lidar systems of that time were too large, complex, and expensive to be widely used. With the development of larger wind turbines, met masts became less attractive due to higher costs and less representative due to the measurement in single points. Lidar technology has become more and more popular for site assessment purposes since 2003, coinciding with the development of a new generation of lidar devices based on components from the telecommunications industry. Similar to the site assessment, the use of lidar for power performance measurements was discussed early. In 2006, the possibility to use lidar for wind turbine control was considered, since the knowledge of the incoming wind is valuable information for optimizing energy production and reducing structural loads. Shortly afterwards, the application spectrum was extended to the measurement of boundary layer profiles, of complex flow fields in complex terrain and in wind farms. This rapid development has been created by a great effort of the research community in collaboration with the industry and is reflected in several research projects.

2.2 Description and Results from Phase I

IEA Wind started dealing with lidar in January 2007 during the first topical expert meeting about remote sensing organized within IEA Wind Task 11. A second meeting followed two years later in October 2009. A first draft of recommended practices on remote sensing was compiled based on the content of the workshop. The results of the topical expert meetings prepared a solid ground for a new IEA Wind Task on remote sensing. In this context, the wind energy community identified the need to consolidate the knowledge about wind lidars in order to ease and spread their usage and at the same time to investigate how to exploit the advantages offered by this technology at best. This was the motivation which led to apply for IEA Wind Task 32 "Lidar application for wind energy deployment" in October 2011.

Since its kick-off in May 2012, Task 32 provided an international open platform for regular and continuous exchange of experience and progress from individual research activities and existing measurement projects on the performance of lidar devices and associated measurement techniques under different operational and site conditions. Three subtasks were dedicated to investigate three main areas of interest: calibration and classification of lidar devices, procedures for site assessment, and procedures for turbine assessment. The topics of the subtasks were further divided in twelve smaller work packages. Physical as well as virtual meetings were organized, the exchange of experience was stimulated and comparative exercises were carried out. Important results were reached in the field of floating lidars, ground and nacelle based applications, deployment in complex flows and measurement of turbulence. In particular, a recommended practices document for the use of floating lidar system will be submitted to the Executive Committee soon and a peer-reviewed conference paper on the application of the rotor equivalent approach for wind turbine power performance testing was published. Furthermore, Task 32 provided assistance in the final review of the IEA Wind RP 15 "Application of ground based remote sensing for wind resource assessment" written within Task 11. Eventually, Task 32 was successfully concluded. Good achievements were gathered and standardization needs, areas for further research, and development were identified.

2.3 Motivation for the Extension

The motivation of extending the IEA Task is based on following points:

- The participants expressed their continuing interest in the Task during the last meetings. Additional institutions mentioned that they plan to join the Task in the case of an extension.
- The results of the first phase of the Task demonstrate, that Lidar is becoming a mature technology for wind energy, but still several barriers are present. A questionnaire distributed to the participants during the last meetings showed that new applications not addressed in the first phase such as lidar-assisted control are of major interest for the participants.

An extension of the IEA Task 32 will provide a unique possibility to bring experts together on an international level to work on mitigating the barriers for the use of lidar in the different areas of application.

3 Objectives and Expected Results

The general objective of the Task 32 extension is to identify and mitigate barriers to the use of lidar for following wind energy applications: Site Assessment, Power Performance, Loads and Control, and Complex Flow. These four applications will be addressed individually, since they are on different technology readiness levels, see Figure 1.

Figure 1: Nature of the barriers from the four applications of the lidar technology in wind energy. Is there still some research necessary or is the difficulty in the implementation?

In more detail, specific objectives for the application areas are:

Site Assessment

- Revise the IEA Recommended Practices for ground-based remote sensing for wind resource assessment and the IEA Recommended Practices for floating lidar systems.
- Explore ways to improve lidar systems regarding cost, reliability and accuracy.

Power Performance

- Identify gaps in standards and transferability that may prevent widespread adoption.
- Explore if and how new standards for the use of ground-based lidar systems needs to be adapted for the use of nacelle or spinner-based or floating lidar systems.

Loads and Control

- Explore the benefits of lidar-assisted control for the cost of wind energy.
- Give recommendations on how to improve lidar systems for control application.
- Initiate guidelines on how to use lidar in the load verification process of wind turbines.

Complex Flow

- Understand the needs of measurements of complex flow in wind energy and describe the limitations of lidar systems to provide recommendations for adjustments.
- Find metrics to compare flow simulations and lidar field measurements.

Overall Objectives

- Provide an international open platform for regular and continuous exchange of experience and progress from individual research activities and existing measurement projects on the performance of lidar devices and associated measurement techniques.
- Interconnect and leverage experience from several international research projects.
- Identify areas for further research and development as well as standardization needs.
- Continue to collect and summarize competences gained in IEA Recommended Practices and Expert Reports.

Expected Results for the Extension of IEA Task 32

Three workshops will be held for each of the applications and reports will summarize how the objectives have been accomplished, including the revision of two IEA Recommended Practices. It is expected, that the extension will further strengthen the international exchange of knowledge, experience, and ideas and will further foster the use of lidars in wind energy.

4 Approach and Methodologies

In order to approach the new objectives described in the previous section, two important changes are proposed for the extension of Task 32:

1. **Meeting strategy**: Additionally to the general meetings to be held annually, dedicated workshops with a tangible outcome will be organized to focus on specific barriers of the lidar technology in each of the four applications.
2. **Management structure**: As with any IEA Task the Operating Agent will be responsible for the management of the Task. In addition, an Advisory Board with key experts from academia and industry will assist the Operating Agent to align the workshop topics to actual needs and to keep the Task useful for the whole community. The workshops will be organized by Workshop Leaders familiar with the topic and by the Operating Agent.

In this section, more details about the meeting strategy and the management structure will be provided, followed by the description of the barriers and proposed workshops.

4.1 Meeting Strategy for the Extension of Task 32

The following types of meetings are proposed:

- **General meeting**: Yearly meeting of all participants.
- **Advisory Board meetings**: Meeting or telephone conference of experts to advice on workshops and general meeting.
- **Workshops**: Topical meetings of group of experts.

General Meeting

- 2 or 3 day meeting at the end of each year hosted by the OA at a suitable location.
- Time and events for networking will be provided.
- Short presentations and posters including reporting from the workshops, work done related to the task, and general presentations
- Discussion about new workshop topics for the following year of the task.

Advisory Board Meetings

- Kick-off meeting (conference call) to decide on first workshop topics and leaders.
- Conference calls in preparation of general meetings to plan time, place and content.
- After each general meeting (face-to-face) to decide on workshops topics based on the feedback from the general meeting and refining the communication and strategy.
- A tentative meeting agenda will be prepared in advance of every meeting and will be distributed to the Advisory Board well before the meetings by the Operating Agent. The meetings will be documented by approved minutes of the meeting.

Workshops

- 2 to 3 day workshops each year, one for all of the four application areas.
- Workshops will focus on a specific topic related to the objectives given in Section 3.
- Workshops will be organized and hosted by a Workshop Leader (WL) with a very strong interest in the workshop subject, together with the OA. The OA will act as facilitator at the workshop, while the WL will be the moderator.
- Where possible, workshops will link work done by the participants in other projects.

- Workshops will be scheduled around conferences such as EWEA, AWEA or attached to meetings from relevant working groups such as IEA Tasks, IEC 61400-12.
- Workshop goals will be agreed by the WL and OA but in general should be impactful. A general guidance is for the workshop to establish the state of the art in a particular topic / application, identify the barriers to adoption of lidar for that application, work out if those are real, and suggest a path forward to get through them.
- Where at all possible, the path forward should be followed as soon as possible by the workshop participants, with the option for other Task 32 participants to join in.
- Results will have some tangible outcome, for example workshop reports, webinars or a suggestion of a working group. Drafting of the report will start at the workshop and should be finished as soon as possible after the workshop. The outcome will be branded by the host, with participants as coauthors.
- Workshops should represent spread of the lidar community, i.e. by preference they should include academics, developers, consultants, lidar manufacturers, as well as turbine manufacturers. The OA and host will prepare an agenda and work to get the guest list filled. Participants are supposed to provide some position statements prior to the workshop, including expected aims and results of the meeting and have to be willing to commit time to work on the topic after the workshop. If attendees feel the barriers are significant and warrant more work, Task 32 might convene a focused working group for this topic.

4.2 Management Structure for the Extension of Task 32

Following levels of management are proposed:

- **Operating Agent (OA)**: executive body on IEA task level, connection to the ExCo.
- **Workshop Leaders (WL)**: executive body on workshop level.
- **Advisory Board (AB)**: supportive body for decision making.

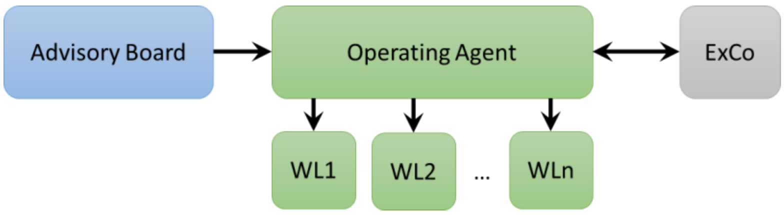

Figure 2: Proposed management structure for the extension of IEA Task 32.

The different bodies of the management structure are described in more detail in the following section.

Operating Agent

The Operating Agent is the executive body on the task level and is acting as the intermediary between the Advisory Board and the IEA Wind Executive Committee (ExCo).

Advisory Board

The Advisory Board is the supportive body for the decision-making of the task. The Advisory Board consists of experts from academia and industry with a strong expertise in at least one of the four considered applications. The Advisory Board meets in face to face meetings and by means of teleconferences to assist the Operating Agent in the decision-making for the general meeting and the workshops. Following persons have already confirmed their participation:

Name	Institution	Sector	Fields of expertise	Focus Application
Julia Gottschall	Fraunhofer IWES	Academia	Floating lidars	Site Assessment
Andy Clifton	NREL	Academia	Wind resource measurements, lidar R&D	Site Assessment
Nicolai Gayle Nygaard	DONG Energy	End user	Wind resource measurements, wake measurements	Site Assessment
Detlef Stein and Erik Tüxen	DNV GL	certification	wind resource measurements, power performance assessment	Site Assessment & Power Performance
Rozenn Wagner	DTU	Academia	Power curves, standards for power performance assessment	Power Performance
Ioannis Antoniou	Siemens Wind Power	Turbine manufacturer	Power curves	Power Performance
Eric Simley	Envision	Turbine manufacturer	Lidar-assisted control, wind evolution	Loads and Control
Dhiraj Arora	Alstom Wind	Turbine manufacturer	Wind turbine control	Loads and Control
Davide Trabucchi	Forwind	Academia	Wake measurements, scanning lidars	Complex Flow
Peter Clive	SgurrEnergy	Consultant	Scanning lidars, standards for power performance assessment	Complex Flow

Table 1: Confirmed members of the Advisory Board for the extension of IEA Task 32.

Workshop Leaders

The workshop leaders are jointly responsible together with the OA for the organization and execution of topic-specific meetings. The workshop leaders are appointed by the OA after a discussion within the Advisory Board after each General Meeting. They might be members of the Advisory Board or any other motivated and experienced participant of the task.

4.3 Barriers and Workshop Proposals for Site Assessment

Site assessment is the process of quantifying the wind and weather conditions on a wind energy site. This is typically done before the wind turbines are installed, but may also occur after. The objective of a site assessment is to quantify the wind speed and direction at multiple heights, and also the temperature, pressure, and precipitation at the site. This information is used to quantify the conditions that the wind turbines operate in and may be used for turbine selection and energy estimates before the site is built. Site assessment takes place both on land and offshore.

The state of the art in site assessment on land varies by country and the stage of plant development. Most developers use lidar to supplement measurements from fixed, 60-80-m tall meteorological (met) towers, particularly to confirm hub-height wind speeds based on vertical extrapolation from lower elevations. Some developers use lidar to confirm the accuracy of their horizontal extrapolation process, where by data from the towers are extrapolated to cover gaps between the met towers. Even fewer developers (representing the true state of the art) have replaced met towers with profiling lidar that are used to measure the wind speed at multiple heights across the potential turbine rotor disk, possibly supplemented by scanning devices. In some cases developers or their consultants may use very specific and focused lidar measurement campaigns to probe regions where models and measurements show high discrepancy. In the majority of cases lidar are not used to measure turbulence, which limits the utility of the data for turbine selection.

Floating lidars (i.e. lidars integrated or placed on top of floating platforms as buoys) were recently introduced as a cost-effective alternative to offshore met masts. Today there are several system suppliers on the market, and four of the developed systems have already reached the 'pre-commercial' maturity stage [1]. The first offshore wind projects have already been planned on the basis of floating-lidar data. Despite this fast integration into current practice, floating lidar technology faces a lot of challenges – as e.g. the harsh offshore conditions, the impact of the buoy motions on the measurements or the need for a sufficient autonomous power supply – that have not yet been fully understood and solved.

Current issues with the use of lidar for site assessment can be broken into three categories. These categories are concerns by end users about cost, accuracy, and reliability.

- Lidars currently cost more than traditional met towers on land but can measure at greater heights above ground. In contrast, the use of floating lidar systems offshore may bring a cost benefit in comparison to the installation of met masts.
- Also, lidar accuracy may be a weak function of environmental conditions and flow conditions, and so there are some industry concerns about accuracy. As well, turbulence intensity measured by lidar is not directly comparable to a cup, meaning that data cannot be used directly for turbine selection.
- Finally, lidars are complex devices and are not always as reliable as met towers, and thus there are concerns about the cost of ownership and missing data impacting results. For offshore application, this weakness is even more critical since the devices are exposed to even more extreme conditions and a failure may result in a longer downtime than on land.

These concerns about cost, accuracy, and reliability have acted as barriers to more widespread adoption of lidar. In Task 32 we will bring together end users, academics, and manufacturers to explore if these issues are valid concerns, and develop roadmaps to mitigate them.

The following activities are proposed as part of the Task 32 extension:

1. Workshop to review and revise the 2013 IEA Recommended Practices for ground-based remote sensing for wind resource assessment. Potential revisions include results from the first phase of Task 32 on turbulence measurements and the recognition of complex flow situations.
2. User group to explore ways to reduce the cost of owning and operating lidar systems.
3. Creation of a store of data on the Task's website of information about onshore and offshore lidar accuracy trials, including any information about sensitivity to operating conditions or flow conditions
4. Workshop on floating lidars and their applications. The activities in WP 1.5 of Task 32 resulted in a first draft 'Recommended Practice' document 'for Floating Lidar Systems'. The workshop will review users' experience with the document, and discuss progress on the topics identified as 'future work' at the end of the Recommended Practice document. Discussions may include e.g. the creation and refinement of a device classification procedure and the discussion of alternative fields of application (besides floating lidars for wind resource assessment). The workshop may suggest a possible revision of the Recommended Practice document if appropriate.

4.4 Barriers and Workshop Proposals for Power Performance Testing

A power performance test is a set of measurements that relates inflow wind conditions to the wind turbine power. Data from the test is often used to create wind turbine power curves, or used to validate computer models of wind turbine performance. Data can also be used to demonstrate the effect of turbine modifications on performance.

The state of the industry in power performance testing is the use of an upwind met tower to allow measurements of wind speed and direction, air temperature, and barometric pressure at hub height. This approach is codified in the international standard IEC 61400-12-1 (2005). The state of the art is starting to diverge from this approach. Instead, remote sensing devices (typically lidar) positioned in place of the met tower are now being used to measure the wind speed at the hub or at multiple heights in the rotor disk. When multiple heights are used this allows the calculation of a rotor-equivalent wind speed (REWS) [2]. A met tower may be used to provide a cross-check on the remote sensing device, or allow scaling of lidar wind speeds to the met tower. The REWS approach was tested in the first phase of Task 32, and found to be more accurate than the traditional hub height measurements [3]. As a result of Task 32 and other investigations, REWS will be included as a method in the forthcoming revision to IEC 61400-12-1. A new technique in power performance testing is the use of nacelle- or spinner-mounted, forward looking lidar that are used to quantify the incoming wind, and then used in the same way as upwind met towers or ground-based lidars.

Power performance testing using either upwind lidar or forward-looking lidar could be cheaper and more accurate than traditional met towers. However, barriers to the adoption of lidar for power performance testing exist additional to those for site assessment:

- A lack of standards. There is no well-publicized chain of recommended practices and standards that define how a lidar for power performance testing can be calibrated, deployed, and analyzed.
- A lack of transferability. In order to move to widespread power performance testing using lidar it is essential to demonstrate that the method is at least as accurate as met towers, or possibly better. However, the lack of open and rigorous studies by unbiased groups that allow comparison of the two methods prevents this comparison.

Specific activities within the extension to mitigate these barriers will include:

1. A workshop to define the state of the art in lidar-based power performance testing, including presentations about applicable studies, cataloguing existing recommended practices and standards, and identifying where gaps in standards or transferability exist that may prevent widespread adoption.
2. A workshop to collect both new and existing results from two-beam, circularly scanning, and multi-beam nacelle lidar applications on site calibration after turbine installation and performance verification in benign terrain. Especially important will be to describe the application and under which conditions it is possible to apply the REWS method. A first layout of the uncertainty of the REWS will be described under the task.
3. A workshop on the application of ground based lidars in complex terrain for performance verification and developments in the correction methods used.

4.5 Barriers and Workshop Proposals for Loads and Control

Wind is the energy source for wind turbines as well as the main disturbance to the wind turbine control system. The control system has to balance competing control objectives: increasing energy yield while reducing structural loads. However, traditional feedback controllers are only able to react to the disturbance caused by the inflowing wind field after it has already impacted the turbine. With recent lidar technology developments, information about incoming disturbances can be made available ahead of their arrival [4]. Lidar-assisted control has become an important research topic in the wind energy and control community.

The use of lidar-assisted controls is currently limited to a few research turbines, but results are promising; during initial field testing a collective pitch feedforward controller was able to reduce the rotor speed variation [5]-[8]. Additionally, control studies relying on simulation suggest that reductions in structural loads and blade pitch actuator effort as well as slight increases in power production can be achieved with lidar preview measurements [9]. However, it is not always straightforward to quantify the reduction of the levelized cost of energy (LCOE) which will arise from these control improvements. One of the long-term research challenges identified by the European Academy of Wind Energy is the transformation into measurable benefit of lidar-assisted control [10]. Therefore, the economic uncertainty of lidar-assisted control is the major perceived barrier, because it is not clear if the benefits are great enough to offset the cost of a lidar system.

Another obstacle to the adoption of lidar-assisted controls is its multi- and interdisciplinary character. A thorough understanding of lidar measurement principles and limitations (e.g., availability, accuracy, signal quality, etc.) is mandatory for providing usable signals to the control system. Also, detailed knowledge about wind turbine dynamics and controls is necessary to determine which signals can be used for preview control. Since lidar and turbine manufacturers typically only know about their own part of the puzzle, current lidar systems are not optimized for wind turbine control applications. The potential mismatch between available lidar technology and the requirements for control purposes can be divided into two categories: lidar systems might not provide the necessary wind speed information for control; or lidar systems could be too complex, and thus costly, to be adopted for wind turbine control.

Further, there are no guidelines in current standards for using lidar-assisted control in the certification of wind turbines. In particular it is not clear, how lidar systems can help to mitigate extreme loads, how the effect of lidar can be included in a realistic simulation of extreme events, and finally how this can be standardized in guidelines.

The following workshop topics are proposed to mitigate the barriers for lidar-assisted control:

1. Optimizing lidar design for wind turbine control applications:
   Discussions, presentations, and exercises at this workshop will focus on determining the wind speed information and system reliability required for different control applications as well as ways to reduce the cost of lidar systems for control purposes. The expected result from this workshop is a report describing the barriers in designing a lidar system for control from the perspective of industry and academia.
2. Integrating lidar-assisted control into the certification process:
   The workshop will be organized together with an IEC working group meeting. The

expected result is a report which describes the open issues and barriers to use lidar-assisted control in simulations for certification.

3. Transformation of improvements in control performance into reduction of LCOE: This workshop is planned to be scheduled together with a meeting of the IEA Task 37, since an overall optimization considering a re-design of the controlled turbine is necessary to estimate the benefits of lidar-assisted control. The expected result of the workshop is a report which describes potential wind turbine design choices made possible by the use of lidar-assisted control that can lead to reductions in LCOE.
4. Lidar control in wind farms:
   Due to the growing interest in wind farm-level control, this extra workshop will address the unique requirements of lidars for detecting wake flows and how the information provided by lidar can be used to optimize wind farm control. A report will state ideas for incorporating lidar measurements into coordinated wind farm control as well as the current barriers and suggestions for how to mitigate them.

In order to discuss the potential use of lidars for load verification of wind turbines, it is first necessary to understand the procedure of load verification thoroughly. The main objective of a load verification campaign is to obtain (IEC/DNV etc.) certification of the prototype turbine. Wind turbines are designed according to the IEC 61400-1/3 standards, where a range of wind conditions are prescribed. A load case matrix is created based on different wind conditions, and several load simulations on different wind turbine components are carried out. Eventually damage equivalent load and fatigue damage are calculated, which provides a basis for dimensioning of the different wind turbine components. Subsequently a prototype turbine is manufactured and is installed at a test site for verification of the actual loads experienced by the turbine as compared to the simulated loads. The load measurements are usually carried out using strain gauges mounted on different wind turbine components, whereas the wind conditions are obtained using meteorological mast anemometry. The instrumentation on the mast usually consists of cup anemometers and wind vanes installed on booms at three heights at some distance in front of the wind turbine. From the time series data of these instruments first- and second-order statistics are estimated; amongst others mean wind speed, wind direction, wind speed profile, and turbulence intensity. Correspondingly statistics of the loads from the measured load time series are estimated. Eventually, the wind and load statistics are plotted are against each other to check the correlation between them. Simultaneously new load simulations are carried out using the measured wind data (instead of the IEC standard wind conditions). The newly simulated loads are then plotted on top of the measured loads, and subsequently verified to check whether the measured loads are smaller than the simulated loads. It is usually observed that the simulated loads do not compare very well with the measured loads, both in terms of accuracy and precision. Two reasons have been attributed to such discrepancy; first is the lack of availability of measurements with high spatial resolution, and the second is the distance between the mast and the turbine. Lidars have the potential to counter both these problems. In particular its use could lead to reducing the amount of material used for constructing certain components, and thereby reducing the cost of a wind turbine. Nevertheless there are some barriers in the use of lidars for load verification.

Lidars are proven to be quite accurate and precise for estimating the first-order statistics such as the mean wind speed, wind direction and the wind profile [11]. However, estimating second-order statistics such as the turbulence intensity from lidar measurements is not yet acceptable. In [12], two barriers in using the ground-based lidar in a VAD scanning mode have been identified; first is the probe volume averaging, and the second is the contamination due to the cross-correlations of different components of the wind vector. The second barrier can be countered to a considerable extent by either using a different scanning configuration and data processing technique (e.g. six-beam, Sathe et al. (2015)), or by using three lidars intersecting at a point. The challenge of probe-volume filtering still remains to be tackled. Besides, due to the physical limitations of the lidars, spatially interspersed measurements cannot be obtained at very high sampling rates. This presents a further challenge in capturing all the relevant turbulence scales that influence the loads on the wind turbine. An alternative to using ground-based lidars is to use nacelle-based lidars. However besides tackling the aforementioned challenges, a robust algorithm is yet to be developed for combining measurements in a vertical plane for estimating second-order statistics.

Different configurations suggested above present different economic challenges. Particularly using three lidar systems would increase the cost of measurements by a factor of three. It is therefore necessary to couple the benefits of using any configuration with the potential reduction in LCOE. A barrier to such coupling is that there is no robust model that provides a link between lidar-assisted load verification and LCOE.

Proposed workshops to tackle the aforementioned barriers:

1. Using ground-based lidars for load verification of wind turbines – Participants will be requested to present some test cases of load verification (preferably on research turbines due to limitations of confidentiality on commercial turbines), where the current problems with using the meteorological mast anemometry will be evident. Simultaneously potential test cases can be presented where the mast anemometry is replaced by lidars (It could also be simulation of lidar measurements). Discussion of the exact requirements of lidar measurements will be carried out that provide a clear perspective of the benefits of using lidars instead of mast anemometry.
2. Using nacelle-based lidars for load verification of wind turbines – The same points as mentioned for the ground-based lidars are also valid for nacelle-based lidars. Depending on the response of the participants the two technologies could be merged into one workshop.
3. Benefits of using lidar-assisted load verification in reducing the LCOE – Such a workshop can be held in combination with the activities of IEA Task 37. Focus will be on identifying the relationship between improved accuracy and precision of load verification using lidars and the impact on LCOE.

4.6 Barriers and Workshop Proposals for Complex Flow

Lidar are potentially very useful tools for the validation of flow models, with or without turbine wakes, in simple or complex flows [13]-[16]. The challenge of measurements in complex flow was explored in the first phase of Task 32, but there was no opportunity to look at how the data were then used. Therefore, Task 32 will look into how measurement methods can be optimized to the data that are required for model validation, and vice-versa.

The development of lidar techniques can be viewed as progress from 1st generation methods, typified by met masts and remote sensing profilers, which acquired datasets from which wind conditions could be extrapolated vertically and horizontally, to 2nd generation devices such as scanning lidars, which acquired datasets from which wind conditions could be inferred in horizontally and vertically disparate locations from the measured line of sight radial velocities and sophisticated flow models as described above, to 3rd generation techniques where wind conditions are directly observed throughout the volume of interest. 3rd generation capabilities are beginning to be exhibited by some systems that combing multiple scanning lidars to implement convergent scan geometries. These allow wind velocity vectors to be fully characterized rather than inferred at arbitrary points within the volume of interest. However, trade-offs between space- and time-resolution are still required as the multiple points necessary for high space resolution would incur a scanning time overhead that reduces the time resolution. Nevertheless, convergent scan geometries have been seen to be the only lidar method to accurately replicate the performance of met masts in relation to the measurement of turbulence intensity (TI) [17].

The further development of well-documented lidar use cases will be undertaken to ensure that lidar methods that are fit-for-purpose can be applied with the consistency on which investor confidence relies [18], including the development of common protocols for recording and describing lidar measurement configurations and scan geometries.

The extension of Task 32 will give the possibility to gather at the same table experts from the lidar and the wind modeling community, in order to precisely define which parameters should be extracted from the lidar measurements and the proper methodology to obtain them. Moreover, the results could provide a valuable support to the joint activity of IEA Wind Task 31 and 30 in which a benchmark of wake and full system simulations on the basis of lidar measurements is attempted. In this regard the following workshops are proposed:

1. Transforming lidar data to a regular Cartesian grid. How should lidar data, which are measured on a polar coordinate grid, be transformed to a Cartesian grid? Test cases based on LES simulations will be proposed and a comparative exercise will be sent to participants before the workshop. The use of an LES simulation will mean that the "true values" of wind speeds and directions are known. A third party will consolidate results. The outcome from the report will be an introduction to the methods used, their cost, and accuracy. Results will allow other people to choose appropriate methods in future.
2. Metrics to compare simulations and lidar measurements. This workshop could be jointly organized with participant of IEA Wind Task 31.

5 Timeline and Key Dates

Beginning on the date the extension of IEA Task 32 is formally initiated, it shall, in principle, continue for a period of three years. The proposed time schedule is presented in Table 2.

year	1				2				3			
quarter	1	2	3	4	1	2	3	4	1	2	3	4
M1 Kick-off-meeting	M											
M2 Homepage operational		M										
M3, M4, M5 General meetings				M				M				M
Workshops		W				W				W		
Advisory Board meetings (face-to-face)				A				A				
Advisory Board meetings (teleconference)		A				A				A		
D1, D2, D3 Annual progress reports				D				D				D
D4, D5, D6 Newsletter			D				D				D	
D7 Revised recommended practices floating lidar					D							
D8 Revised recommended practices ground-based RS									D			

Table 2: Timeline for Phase 2: milestones (M), workshops (W), Advisory Board meetings (A), deliverables (D).

6 Reports and Deliverables

Annual progress reports will give the ExCo an overview of the progress of the project during the annual autumn meeting. A newsletter will be compiled once a year by the OA in order to summarize the most important results from the workshops including photos and overview of publications and industrial advances relevant for the overall task. The newsletter will be distributed to all participants, the ExCo member and a dedicated distribution list complied in consultation with the national ExCo members. The planned deliverables are shown in Table 3.

	Deliverable	Month
D1	First annual progress report	12
D2	Second annual progress report	24
D3	Final report	36
D4	First newsletter	9
D5	Second newsletter	21
D6	Third newsletter	33
D7	Revised Recommended Practices on floating lidar	15
D8	Revised Recommended Practices on ground-based remote sensing	27

Table 3: Deliverables for the extension of IEA Task 32.

Additional media are proposed to foster the internal and external communication:

- **Homepage**: ongoing communication to the general public. Managed by OA. Reports and papers will be uploaded to a document server to increase the visibility.
- **Reports from workshops**: ongoing communication to the wind community. Prepared by the WL assisted by the OA. Format and content will be chosen by workshop participants: technical reports or papers, expert reports or recommended practices.
- **Presentations at major wind energy conferences:** final dissemination of results to the wind community. A full invited session (similar to the American Control Conference) will be pursued and if not possible should be replaced by individual submissions.
- **Advisory Board Minutes:** ongoing internal documentation. Prepared by OA, approved by the Advisory Board, and accessible by all participants.

7 Methods of Review and Evaluation of the Work Progress

The following key milestones are defined for the follow-up of the progress of the project.

	Milestone	Month
M1	Kick-off meeting	1
M2	Homepage operational	6
M3	First general meeting	12
M4	Second general meeting	24
M5	Final general meeting	36

Table 4: Milestones for the extension of IEA Task 32.

8 Obligations and Responsibilities

Tasks and responsibilities of the **Operating Agent** are:

- Act as the single point of contact of the task with the IEA.
- Decision for location, time, and content of general meeting.
- Decisions for workshops topics and nomination of workshop leaders.
- Collecting, reviewing and submitting information on the progress of the task, reports and financial statements to the IEA: Compilation of the annual progress and of the contribution to the Annual IEA Wind Report.
- Supervision on dissemination of results: Responsible for newsletter and homepage.
- Organization of the general meetings and Advisory Board meetings, chairing the meetings, preparing the minutes of the Advisory Board meetings.
- Organization of the workshops in collaboration with the workshop leaders

Tasks and responsibilities of the **Workshop Leaders** are:

- The detailed planning, coordination and documentation of the workshop.
- Cooperation with the OA.
- Dissemination of the workshop results.

Tasks and responsibilities of the **Advisory Board Members** are:

- Advise on decisions for location, time, and content of general meeting.
- Advise on decisions for workshops topics and nomination of workshop leaders.
- Overall progress control against task objectives and recommendations on modifications if deemed necessary.
- Recommendation on Integration of new experts to the board.

Participants will be divided in two categories:

- Active members who can participate to all of the planned activities (meetings, workshops, recommended practices, dissemination of results).
- Observers who can participate to all of the planned activities, except those involving the preparation of the final documents. Since the final documents have to be neutral, lidar manufacturers will be accepted as observers only. However, their contribution is considered of fundamental importance in other task activities.

9 Type of Funding and Proposed Operating Agent

The costs management will be performed similar to other IEA Tasks as "cost shared" where the Participants share the coordination effort of the operating agent.

The funding principles are summarized as follows:

- Each Participant shall bear their own costs for carrying out the scientific work, including reporting and travel expenses.
- The total coordination costs of the Operating Agent shall be borne jointly and in equal shares by the Participants.
- The cost of the workshops and general meetings of this Task will be shared between the host country and the Operating Agent in equal shares.
- Each participant country shall transfer to the Operating Agent their annual share of the costs in accordance with a time schedule to be determined by the Participants, acting in the ExCo.

The Task will be centrally managed by the Stuttgart Wind Energy (SWE), University of Stuttgart, Germany.

The responsible primary investigators are:

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10 Proposed Budget

The total costs of the Operating Agent for coordination, management, reporting, and database maintenance and operation is estimated at 64,900 €/year during a three year period.

Projected expense items of the operating agent are estimated as follows:

• Management: 6 person-months	50,900 €/year
• Travel: 7 meetings (general meeting + 2 ExCo + 4 workshops)	7,500 €/year
• Share of general meetings and workshops organization	6,000 €/year
• Administrative & misc. (website etc.)	500 €/year
Total budget	64,900 €/year

An annual participation fee of 5,900 €/year is proposed based on the assumption of 11 participating countries (see Section 13).

In comparison, the annual budget of Phase 1 of Task 32 accounted for 91,000 € and the annual participation fee was 7,100 € while 9 participants fully committed to Task 32.

11 Management of the Task

The aim of the management activities in the Task is to achieve the scientific objectives as formulated in Section 3 according to the planning and within the budgetary limits.

The monitoring of the project will be carried out by the Operating Agent assisted by the advisory board. In an initial Advisory Board meeting via teleconference, the decision on the workshops topics, time and location as well as on the workshop leaders for the first year will be made based on the proposed topics in Section 4. The Operating Agent will compile a newsletter after each of the four workshops per year to inform all participants about the outcome. Additionally, the results of the workshops and possible working groups from the individual application areas will be presented at the yearly general meeting. The decision on the workshops topics for the following year and the nomination of the workshop leaders will be made based on the feedback at the general meeting and the yearly Advisory Board meeting held after each general meeting. This helps to re-define the approach presented in Section 4 and to keep the workshops close to actual questions of industry and academia. An additional Advisory Board meeting is carried out via a teleconference meeting in preparation of each general meeting.

Dissemination activities will be centralized on the project website. Key conferences and expert meetings will be identified for the presentation of the project's most relevant results.

The Operating Agent will be the single point of contact with the IEA Wind ExCo.

12 Information and Intellectual Property

Executive Committee's Powers. The publication, distribution, handling, protection, and ownership of information and intellectual property arising from activities conducted under this Task, and rules and procedures related thereto shall be determined by the Executive Committee, acting by unanimity, in conformity with the Agreement.

Right to Publish. Subject only to copyright restrictions, the Task Participants shall have the right to publish all information provided to or arising from this Task except proprietary information.

Proprietary Information. The Operating Agent and the Task Participants shall take all necessary measures in accordance with this paragraph, the laws of their respective countries, and international law to protect proprietary information provided to or arising from this Task. For purposes of this Task, proprietary information shall mean information of a confidential nature, such as trade secrets and know-how (for example, computer programs, design procedures and techniques, or wind farm operational data) which is appropriately marked, provided such information: (a) Is not generally known or publicly available from other sources; (b) Has not previously been made available by the owner to others without obligation concerning its confidentiality; and (c) Is not already in the possession of the recipient Participant without obligation concerning its confidentiality. It shall be the responsibility of each Participant supplying proprietary information and of the Operating Agent for arising proprietary information, to identify the information as such and to ensure that it is appropriately marked.

Use of Confidential Information. If a Participant has access to confidential information which would be useful to the Operating Agent in conducting studies, assessments, analysis, or evaluations, such information may be communicated to the Operating Agent but shall not become part of reports or other documentation, nor be communicated to the other Participants except as may be agreed between the Operating Agent and the Participant which supplies such information.

Acquisition of Information for the Task. Each Participant shall inform the other Participants and the Operating Agent of the existence of information that can be of value for the Task, but which is not freely available, and the Participant shall endeavor to make the information available to the Task under reasonable conditions, in which event the Executive Committee may, acting by unanimity, decide to acquire such information.

Reports of Work Performed Under the Task. Each Participant and the Operating Agent shall provide reports of all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations, and other documentation, but excluding proprietary information, to the other Participants. Reports summarizing the work performed and the results thereof shall be prepared by the Operating Agent and forwarded to the Executive Committee.

Arising Inventions. Inventions made or conceived in the course of or under the Task (arising inventions) shall be identified promptly and reported to the Operating Agent. Information regarding inventions on which patent protection is to be obtained shall not be published or publicly disclosed by the Operating Agent or the Participants until a patent application has been filed in any of the countries of the Participants, provided, however, that this restriction on publication or disclosure shall not extend beyond six months from the date of reporting the invention. It shall be the responsibility of the Operating Agent to appropriately mark Task reports that disclose inventions that have not been appropriately protected by the filing of a patent application.

Licensing of Arising Patents. Each Participant shall have the sole right to license its government and nationals of its country designated by it to use patents and patent applications arising from the Task in its country, and the Participants shall notify the other Participants of the terms of such licences. Royalties obtained by such licensing shall be the property of the Participant.

Copyright. The Operating Agent may take appropriate measures necessary to protect copyrightable material generated under the Task. Copyrights obtained shall be held for the benefit of the Task Participants, provided however, that the Task Participant may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee, acting by unanimity.

Inventors and Authors. Each Task Participant will, without prejudice to any rights of inventors or authors under its national laws, take necessary steps to provide the cooperation from its inventors and authors required to carry out the provisions of this paragraph. Each Task Participant will assume the responsibility to pay award or compensation required to be paid to its employees according to the law of its country.

13 List of Potential Participants

Task 32 started with four participant countries (Denmark, Germany, Japan and the US). In the course of the project five other counties joined Task 32 (China, Canada, The Netherlands, Norway and the UK). An overview of Task 32 participants is given in Table 7. Participants include research centres, universities, wind measurement companies, and lidar and wind turbine manufacturers, totalling more than 50 institutions. It is expected that all institutions will continue to participate in an extension of Task 32. Furthermore, institutions from Austria, Belgium, France, Israel, Korea, Switzerland and Sweden have shown firm interest in joining Task 32 and some of them have already started the procedure to express their commitment to Phase II of Task 32. More clearly highlighting activities around topics new to Task 32, such as lidar-assisted control and wake measurement, is expected to attract additional institutions.

Assuming that at least two of the seven interested countries will join the Task, the expected number of countries for the extension of Task 32 is 11.

Country	Partner	Commitment
Austria	Energiewerkstatt	Interested
Belgium	3E	Interested
Canada	AXYS, Technocenter Eolien	Committed (2013)
China	Beijing New Energy Technology Co., China Renewable Energy Engineering Institute, CWEA, Goldwind, Science & Technology Co. Ltd.	Committed (2014)
Denmark	DONG Energy, DTU Wind Energy, Windar, Siemens Wind Power	Committed (2012)
France	Epsiline, Leosphere, Avent Lidar, IFP Energies nouvelles	Interested
Germany	Avent, Deutsche WindGuard, DEWI, ForWind – Oldenburg, Fraunhofer IWES, DNV GL, SWE – University of Stuttgart, GWU, Senvion SE	Committed (2012)
Israel	Pentalum Technologies	Interested
Japan	ITOCHU Techno-Solutions Corp., Mitsubishi Electric Corp., Mie University	Committed (2012)
Korea	Korean Institute Of Energy Research (KIER)	Interested
The Netherlands	ECN	Committed (2014)
Norway	Christian Michelsen Research, Meventus, NORCOWE, University of Bergen	Committed (2013)
Sweden	WindVector AB	Interested
Switzerland	Meteo Swiss, MeteoTest	Interested
United Kingdom	Carbon Trust, Frazer Nash, NEL, RES, Sgurr Energy, SSE, Zephir, Natural Power, Offshore Renewable Energy Catapult LiDAR, DNV GL	Committed (2014)
United States	AWS TrueWind, Envision, Alstom, University of Colorado, Cornell University, National Center for Atmospheric Research (NCAR), NOAA – ESRL, National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL).	Committed (2012)

Table 5: List of potential participants for the extension of IEA Task 32.

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