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

Annex 32
Wind lidar systems for wind energy deployment (LIDAR)

Task Description

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Revision history

Date	Scope
September 30th, 2011	- Original document approved by the IEA Wind ExCo
September 20th, 2012	- Small corrections in general project description (Section 1) - Major change in description of sub-tasks. This reflects the result of the kick-off meeting. (Section 3) - Adjustment of distribution of budget share reflecting the change of the responsibility for the technical part of sub-task IV from University of Oldenburg to DTU Wind Energy Department (Section 9) - Update of work plan (Section 4)
September 21st, 2012	- Update of work effort table

April 4th, 2013	- Addition of NREL as partner
	  - Title page
	  - Contact information in Section 8
	  - Budget redistribution in Section 9
	  - Section 11
	- Added reference to the annexed documented "Description of Work packages". (Section 3)

Scope

The Annex 32 - Wind lidar systems for wind energy deployment (LIDAR), under the IEA Wind implementing agreement is dealing with wind lidar systems applied in wind energy. The aim is to address the very fast development of wind lidar technologies and their applicability for more accurate measurement of wind characteristics relevant for a more reliable deployment of wind energy power systems. The purpose is to bring together the present actors in the industry and research community to create synergies in the many R&D activities already on-going in this very promising and new remote sensing based measurement technology.

The drivers for the new IEA Task based on wind lidar technology are:

- Extensive research projects dedicated to the lidar technology have been performed during the last years (see for instance UpWind, NORSEWInD, WindScanner.dk, RAVE-LIDAR, etc.), however a consolidated multi-lateral and international exchange has to date not taken place
- The spread of several new commercial lidar systems with different specifications makes it very difficult for the community to keep up with the advances of this specific technology
- A large number of new applications only possible with remote sensing based wind lidar systems is being developed. However, their real potential cannot be assessed nor exploited without strong work between the research community and the industry

The IEA Task is intended to have four subtasks which have been selected as the most relevant at present. They reflect the great advances in the technology in the last years and the applications which are seen as most promising, but are still in an early stage of development and testing. The planned work involves a first activity of exchange for identification of common working fields and areas where specific research activities should be prioritized. Eventually there is a formulation of common detailed objectives and coordinated research activities in selected areas. In the following activities the working groups join efforts to exchange experience and results of individual or collective activities. The expected outcome is the formulation of guidelines towards evaluation of performance of different systems applied in different selected areas. These act as complementary to documents available in regards to other applications of wind lidar systems. In this respect, it is aimed at the extension of the document draft of best practices being currently under development as outcome of the 59th IEA TEM on "Remote Wind Speed Sensing Techniques".
The topics are also defined to be complimentary to the work being performed at present towards standardization of lidar measurements. For instance, the inclusion of lidar measurements in the IEC 61400-12-1 for power curve could benefit from the evaluation of the procedure included in the current draft Annex L and non-standard procedures. These could be for instance, nacelle-based lidar measurements, nacelle anemometry or dynamic power curve assessment.
The proposed activities build upon the discussions and work already performed in regards to lidar technology during the two IEA Topical Expert Meetings:

- 51st IEA TEM on "State of the art of Remote Wind Speed Sensing Techniques using Sodar, Lidar and Satellites", January 2007, Roskilde, Denmark
- 59th IEA TEM on "Remote Wind Speed Sensing Techniques using SODAR and LIDAR", October 2009, Boulder CO, USA

Despite sodar systems belong to remote sensing as well and were considered alternatives to lidar systems in the mentioned previous IEA Annex XI meetings, sodar techniques will not be considered in this task due to a couple of reasons. Sodar and lidar based techniques differ today not only by the nature of the signals emitted (sound vs. light), but also in their specific applications related to wind energy utilization. For instance, sodar systems are not yet suitable for power curve assessment, are not useful for nacelle-mounted approaches, neither include a scanner system. This present IEA Task will consequently address an intensive and effective investigation of remote sensing measurement techniques based on wind lidars only, with efforts and resources focused on a few but really detailed topics.

1 Introduction

1.1 Development of lidar technology

A great deal of work has been performed in the last years towards verification of lidar systems as replacement of conventional anemometry. This is the basis for the confidence on the technology and the spreading of new ideas regarding to different applications of application of the systems today. One of the first special applications in wind energy was the support of the control system of the wind turbine (Harris 2006). Short afterwards the advantages were recognized and the application spectrum extended to the measurement of boundary layer profiles (Peña 2009), of complex flow fields (Bingöl 2010a-b, Käsler 2010) 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 with extensive use of lidar systems, in particular, UpWind WP6 (EU), NORSEWInD (EU), WindScanner.dk (DK), RAVE-LIDAR (DE) and others.

At present, five manufacturers worldwide provide commercial wind lidar systems, namely Leosphere (FR), Natural Power (GB), Sgurr Energy (GB), Catch-the-Wind (US) and Lockheed Martin (US). In addition there are other systems, which are in development or are used for special application areas in research such as the WindScanner research infrastructure of DTU Wind Energy, the nacelle-based lidar scanner of the University of Stuttgart (DE), the long-range lidar of the DLR – German Aerospace Agency (DE), Mitsubishi Electric Company (JP) among others. These companies and institutes develop their systems sometimes in conjunction with researchers and the wind energy industry. However, it has been recognized that the know-how of the manufacturers and remote sensing scientific community have strong ties linked to optics as well as boundary-layer meteorology and to a lesser extent to the wind energy applications. This means that R&D efforts to implement reliable systems for the wind energy industry should be accompanied by a strong link with the wind turbine manufactures and the wind energy community. The latter can provide useful requirements and suitable specifications of the systems and can foresee new applications of the technology.

It has also been recognized that the development of the wind lidar systems has emerged timely with respect to the development of large wind turbines and large wind farms. The development of large wind energy systems does not correspond with the amount of knowledge of the wind resource. The larger the turbines, the larger are the uncertainties in the assessment of their behaviour under complex inflow conditions. A main issue is the lack of sufficient measurement data of a complete three-dimensional wind field to which a turbine is exposed in the field. Conventional anemometry permits only measurements at a few discrete points. In this respect the remote sensing techniques, and specially the scanning wind lidar systems, offer a big step towards more comprehensive measurements (Mikkelsen 2009).

The great advantages of the lidar systems pose challenges to all actors and especially to the wind energy community. Mainly, the character and retrieval of the measurements is rather different than the conventional and standardized anemometry. There is a change of paradigms due to how the wind resource and wind turbine performance are assessed. For instance, the principle of measurements at a single or at a few points has to be replaced by volumetric or multiple-point measurement perspectives (Lindelöw 2007). This can only be achieved with a gradual understanding and quantification of the real capabilities of the remote sensing based wind lidar systems. Previous work in calibration and certification of ground based measurements has given an insight into the comparability of lidar and conventional measurements. The new IEA Task will provide a platform to dig into open questions, mainly oriented towards the remote sensing wind lidar technology applied in wind energy resource assessment. It gives the opportunity to assess and establish good quality comparisons with respect to conventional meteorological mast based anemometry at the most basic level (single-point). Also, more comprehensive measurements of the boundary -layer wind and turbulence profiles will be addressed and evaluated. Finally wind lidar applications, ground-based and wind turbine integrated, will be evaluated in the fields of power curve assessments as well as load estimation.

1.2 State-of-the-art: today's remote sensing technology for wind speed measurements

In regards to the present state of the technology a summary of the main aspects is given below. This is based on the latest information available from the Topical Expert Meetings and the experience during the research projects in which the proposers of the IEA Task have been involved lately.

- Several commercial and research lidar systems are available. All of these are at the moment based on the coherent detection principle and the majority of the commercial systems available today are built on a pulsed (range-gated) measurement technology. There already exists quite a fair amount of verification data which have been, or are being, measured by high -quality calibrated standard meteorological masts, of heights up to 100 + meters (Courtney 2008. This serves as basis for comparison of wind lidar system performance.
- Ground-based lidar systems offer high correlation of the measured mean wind speed with conventional cup anemometry in flat terrain. This is supported by extensive comparison studies in the last years (Lindelöw 2009).
- Today, there is high confidence on wind lidar measurements performed over flat terrain and fair atmospheric conditions. In complex conditions, however, there are still needs for better site characterizations and corresponding mitigation of errors due to non-homogeneities in the flow fields.
- An outstanding issue is also that lidar and conventional wind anemometry (e.g. cups) measure turbulence differently. This becomes in particular evident when vertical profiles of turbulence measured by lidars are inter-compared with turbulence measured by conventional instrumentation (Courtney 2008, Mann 2008 and Wagner 2009). There is therefore today a pressing need to fully comprehend what lidar-based turbulence actually represent (due to their relative big measurement volumes and variable sampling rate) and to provide practical and reliable recommendations to the wind energy community on how to use lidar based turbulence measurements in practise, including quantification of the uncertainties. Accurate turbulence measurements are important for assessment of site -specific design conditions and wind turbine loads.
- Most of the lidar systems at present have been developed for ground operation as replacement for conventional anemometry. However, new applications such as power curve measurement (Wagner 2008), load estimation (Bischoff 2011) and wind turbine control (Schlipf 2009-2012) make use of less standard approach from the nacelle (Rettenmeier 2010), spinner hub (Mikkelsen 2010), or even blade-integrated.
- New developments are being tested:
  - Nacelle-based systems for power curve measurements and control of wind turbines (Rettenmeier 2011)

- Systems based on multiple synchronized lidar devices for ‘true’ three dimensional measurement (Mikkelsen 2009)
- Lidar measurements inside and in the wakes of wind farms (Trujillo 2011,Käsler 2010)

1.3 State of international collaboration and standardization

IEA Wind Annex XI: 51st Meeting on remote sensing in wind energy, Risø, DK, Jan. 2007

- First experiences with continuous wave (CW) system (ZephIR) have been presented showing high correlations with standard anemometers
- First pulsed lidar system from (Leosphere) presented Extensive verification against conventional cup anemometry has been performed with ground- based systems. A high correlation with meteorological mast wind speed was shown.

IEA Wind Annex XI: 59th Meeting on remote sensing in wind energy, NREL, US, Oct. 2009

- There is high confidence on measurements performed in flat terrain and fair atmospheric conditions. However, there is need of better site characterization.
- Turbulence measurements based on wind lidar remote sensing systems have not been studied extensively.
- Promising concepts for wind lidar assisted wind turbine control have been presented.
- A procedure for dynamical power curve estimation by lidar system has been presented.
- There is a great need of guidelines of recommended practices.

IEC 61400-12-1 Annex L
Proposal for inclusion of ground-based lidar measurements into power curve measurement procedure. Remote sensing, especially lidar, could facilitate standard cup anemometer measurements.

MEASNET – Evaluation of site-specific wind condition Version 1, Nov. 2009
The International Measuring Network of Wind Energy Institutes (MEASNET) gathers several international institutions involved in developing measurements standards to ensure a high quality in wind measurements. In their document “Evaluation of site-specific wind condition”, Annex C – Section II some recommendation concerning calibration, mounting, configuration and testing for lidar measurements are suggested.

National standards
Germany: VDI 3786 Part 14 “Ground-based remote sensing of the wind vector - Doppler wind LIDAR”, Dec. 2001.

2 Objectives and Expected Results

The objectives of the IEA Task are threefold:

1. 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 under different operational and site conditions
2. Continue the development of an “IEA Recommended Practices for Remote Sensing Measurements“ (Action 59th Topical Expert meeting) and refine it during the course of the task in the three areas:
   a) Calibration and classification of lidar devices

b) Procedures for site assessment
c) Procedures for turbine assessment

3. Identify areas for further research and development as well as standardization needs.

The assessment of lidar technologies will aim to:

- Identify technical aspects which differentiate lidar systems with respect to conventional anemometry (errors, accuracy, repeatability)
- Evaluate the performance of lidar systems for resource assessment and prediction of the annual energy production, namely, wind speed, turbulence, stability and boundary -layer characteristics in flat as well as complex terrain, and offshore
- Evaluate lidar-based power curve measurement methods during simple and complex inflow conditions through benchmark studies with new lidar-based measurement techniques and conventional procedures
- Define possible approaches to estimate the inflow conditions related to mechanical loads of wind turbines by means of lidar systems

The competences gained in the new IEA Task will be collected and summarized in an IEA Recommended Practices for LIDAR measurements that will be published in two editions. The first edition expected in 2012 will deal with the standard praxis for the assessment on wind conditions in flat terrain. The second edition will include recommendations to improve lidar-measured wind and turbulence accuracy and will contain recommendations for lidar applications suitable for flat terrain as well as complex flow conditions (to be published in 2014).

3 Approach and Methodologies

The activities of the new IEA Task are divided into four subtasks as presented in *Table 1*. The table presents the scope and the topics in which each subtask will concentrate on. Next, the scope of each subtask and the planned activities are elaborated. The activities described in this section are to be fully defined as the project progresses. An updated and detailed organization of the activities is kept in the annexed documented "Description of Work packages".

Table 1 Scope and contents of the four subtasks

SUBTASK I: Calibration and classification of lidar devices	**SUBTASK II: Procedures for site assessment**	**SUBTASK III: Procedures for turbine assessment**
Terrain: **- flat, complex, offshore**	**Terrain:** **- flat, complex, offshore**	**Terrain:** **- flat, complex, wind farm, offshore**
Lidar placement: **- ground, (floating, nacelle)**	**Lidar placement:** **- ground, floating**	**Lidar placement:** **- nacelle, ground**
Scope: **- CW, pulsed** **- Doppler, non-coherent** **- VAD, (arc scan)**	**Scope:** **- resource & site assessment** **- wind speed, wind rose, turbulence, wind profile/shear, flow inclination**	**Scope:** **- power curves** **- loads**
SUBTASK IV: Data management Scope: platform for data exchange		
Deliverables: **- Expert Group Report input to revision of IEC -12-1 Annex L**	**Deliverables:** **- Review IEA Rec. Practices on Remote Sensing** **- IEA Best Practices on Lidar**	**Deliverables:** **- IEA Best Practices on Lidar or Expert Group Report input to body of -12-1**

Subtask I: Lidar calibration and uncertainty

Introduction

Subtask I will concern itself with coordinating efforts concerning the accuracy of wind lidars and assessing and developing calibration methods and uncertainty budgets based on the concepts presented in IEC61400-12-1 Version 2 CD, Annex L. The work of the sub-task will be made available in expert reports and will hopefully contribute significantly to future revisions of IEC61400-12-1 Annex L.

As lidars become more routinely used in more novel applications such as floating offshore or nacelle-mounted, sub-task 1 will act as a forum to try and form consensus concerning calibration techniques for these new devices. Expert reports will be prepared as appropriate and it is hoped that these will form a useful starting point for future standardization efforts.

Sub-task 1.1 Improving our understanding of lidar calibration

Calibration of ground-based wind lidars in flat terrain is now a well established procedure and is described in some detail in Annex L of the proposed new version of IEC61400-12-1. Quality accredited lidar calibrations are available. However there remain issues that are not fully illuminated and resolved, resulting in an unnecessarily high calibration uncertainty when testing in certain conditions. We have identified two particular areas; testing in high turbulence intensity and testing in sheared flows.

1.1.1 High turbulence intensity

Observations from several sites (Høvsøre, Østerild) have demonstrated apparent over-speeding of the lidars in high ambient turbulence levels. Some preliminary analysis has suggested that the explanation for this behavior lies in the sensitivity of scalar means to different apparent levels of transverse turbulence. Since a cup anemometer and a wind lidar have different sensitivity to the transverse turbulence, the longitudinal scalar mean values can be significantly different. It will be investigated if calibrating using vector mean values can eradicate these differences. Should this change prove to be necessary, the operational consequences for wind lidars, particularly for power performance and wind resource measurements should be thoroughly explored.

1.1.2 Calibrating in sheared-flow

All wind lidar calibrations occur in field conditions where it is impossible to control the wind conditions. In particular the wind shear varies constantly – no two wind shear profiles are ever precisely the same. From our understanding of the physics of lidars, we know that sheared-flows can give rise to wind speed errors since the lidar is performing a non-linear weighting of an often non-linear speed profile. Contemporary lidars make no attempt to mitigate these errors and in our current calibration procedure, these effects are essentially ignored. The intention of this sub-task is to examine alternative ways of describing the speed profile than the traditional power law alpha exponent in the hope that the shear induced errors can be better identified. For example whilst some errors (for example a sensing height error) will essentially depend on the first derivative of speed with height, others (eg. due to asymmetric and non-linear weighting) will be more related to the second derivative. The goal is through more sophisticated profile descriptions, to both reduce the shear induced scatter in our calibrations and provide correction methods for operational measurements.

Sub-task 1.2 Lidar classification and uncertainty
In a manner analogous to cup anemometry, the proposed IEC 61400-12-1 Annex L has presented some concepts for assessing the influence of external parameters on wind lidar measurements and in so doing, has presented a classification scheme for quantifying the uncertainty associated with operating the lidar at a different time and place than when it was calibrated. The method attempts to identify which external parameters are relevant and the sensitivities associated with each of these. An initial exercise has shown only a modest level of success in being able to identify the same sensitivities from measurements from different calibration sites. Sub-task 1.2 will continue the work on classification, incorporating any improvements in the calibration procedure identified from Sub-task 1.1. Although it is recognized to be too late to contribute directly to the current draft of the revised IEC 61400-12-1, it is envisaged that the expert report resulting from this sub-task will be relevant in subsequent revisions.

Sub-task 1.3 Calibration methods for nacelle-mounted lidars
Forward-looking, nacelle-mounted lidars are now available for performing wind turbine power performance measurements. It is probable that many future power performance verifications will be performed using nacelle-mounted lidars since the measurement quality appears comparable to traditional instrumentation and the cost savings, especially offshore are very considerable. As for conventional mast-mounted instrumentation, a traceable calibration and an associated uncertainty budget will be a requirement, especially in any contractual connection. Sub-task 1.3 will function as a forum for achieving a consensus on the measuring techniques and data analysis required to achieve an accepted calibration and uncertainty scheme for nacelle-mounted lidars. The work will be reported in the form of an expert report.

Sub-task 1.4 Calibration techniques for measurements in complex terrain
Working closely with sub-task 2, we will examine the various possibilities for assessing the ability of lidars to measure accurately in complex terrain. Most lidars apply an assumption of horizontal flow homogeneity when calculating the horizontal wind speed. In complex flow, flow curvature will violate this assumption and the lidar will measure with some error. Various techniques have been proposed to minimize these errors. One possibility is to generate a numerical model of the local flow and use this to estimate the magnitude of the measurement error. Some lidars are apparently able to 'identify' the flow complexity and make appropriate corrections without the need for modeling. In either case, some testing methodology is required to assess the accuracy of the final measurements. Since corrections are specific to a given site, it will be necessary to include various terrain types in the testing procedure. Sub-task 1.4 will investigate these issues and report its findings in an expert report.

Sub-task 1.5 Calibration methods for floating lidars
Lidars placed on some floating structure (a buoy or a ship) are set to make a big impact on offshore resource assessment. As water depths increase, the cost of installing masts for resource assessment becomes very large. Floating lidar systems are now becoming available and if they prove to be reliable, such systems will allow offshore resource assessment at much lower costs or in places where it would not previously have been economically feasible. As for nacelle-mounted lidars, sub-task 1.4 can play a role as a forum where calibration techniques and uncertainty concepts can be discussed. Since the technology is slightly less mature than wind lidars or nacelle-mounted lidars we expect this sub-task to first become active in the second half of the 3 year period of the Annex.

Sub-task 1.6 Thinking out of the box – novel ideas for calibrating lidars
Many engineers working with lidar calibrations have often wished they could avoid using cup anemometers as the wind reference measurement. Calibrating wind lidars in sheared flows is

also less than ideal. This sub-task is intended to collect together alternative ideas for lidar calibration techniques and encourage thinking 'out of the box'. One possibility is to investigate whether the line-of-sight wind speed calibration techniques applied to nacelle-mounted lidars have application and advantages for wind lidars.

Timeplan and priorities
The ordering of the tasks represents a rough prioritisering and scheduling. We will start with sub-tasks 1.1 and 1.2 adding 1.3 and 1.4 after some months if resources and interest allow. Sub-task 1.5 is envisaged to start in late 2013. Sub-task 1.6 is regarded as a 'joker' and will start if sufficient interest and relevant ideas can be identified. This may well start as a 'brainstorming' session at an upcoming Annex meeting.

Subtask II: Procedures for site assessment

Introduction
Subtask II dedicates to the coordination of work concerning the proper application of lidar measurements in site assessment activities. The objective is the formulation of best practices measurement of conventional quantities such us mean wind speed, turbulence intensity and wind direction. Additionally, there is an interest in exploring the assessment of non-conventional variables such us wind shear and veer. The work will cover the operation of lidar systems in flat terrain, as well as in complex flow, such as in complex terrain and offshore platform based measurements.
In general wind lidar measurements cannot be handled as the commonly used anemometers based on meteorological masts. All wind lidar systems sample the wind vector over relative large extending measurement volumes; which are in particular extensive along the beam pointing direction, and therefore they "observe" different wind fluctuations than a conventional cup anemometer, mounted on a mast. Several applications of wind data in the wind energy industry rely not only on the mean wind, but also on the turbulence intensity. Typically, this value is directly derived from the statistics (e.g. the standard deviations) of the fluctuations about the mean value from a cup anemometer measurement. In consequence, the turbulence observed by a wind lidar and a conventional anemometer will be different, even for the same deterministic wind. These are issues that could refrain some users from adoption of lidar systems since it affects directly the comparability against conventional systems. This activity will give insight in the present knowledge of this and other issues related to wind lidar measurements.

Sub-task 2.1 RP for Ground-Based Remote Sensing for Wind Resource Assessment in Flat Terrain

The objective of this activity is to promote and assist the reviewing and the release process of the document "Recommended Practices: Ground based remote sensing for wind resource assessment in flat terrain" by a broader audience. These RPs are the result of the work performed in the framework of the Topical Expert Meeting (TEM) 59 on remote sensing coordinated by the IEA Wind – Annex 11. The IEA Wind - Annex 32 will encourage its participants to comment the document. This enlarges the amount of institutes taking part in its formulation process by taking into account their feedback in the last version of the document to be presented to the IEA ExCo. The present time plan is to submit the RPs in the meeting of the ExCo in October 2012.

Sub-task 2.2 RP for Ground-Based Remote Sensing for Wind Resource Assessment in Complex Flow Conditions

The objective of this activity is to develop »IEA Best Practices on resource assessment with lidar in complex flow conditions«. The spatial sampling of wind lidars has an even more significative influence when the sensed flow is not homogeneous, i.e. in forests or at complex terrain. It has been shown that in some applications this can be overcome by processing the data with more complex algorithms than the applied in conventional Velocity-Azimuth-Display (VAD) scanning. Moreover, some others have applied corrections given by computational fluid dynamic (CFD) simulations of the particular topography. With these aids sometimes it is possible to go beyond the flow homogeneity limits given by the conical scan strategy of wind lidar. However, not always the CFD correction is accurate as expected. One of the tasks of this activity is to make an inventory of the present status of procedures of application of wind lidars in complex flow. Additionally there will be a search for reference data and, where possible, there will be an evaluation of the performance given by different typologies of wind lidar approaches, e.g. VAD/DBS scan, CW, Pulsed System, all-sky scanner, CFD correction, applied in complex flows where wind shear and inhomogeneity may affect the accuracy of lidar measurements.
To summarize the results of this activity will be condensed in a document of best practices where the following topics will be exposed.

- Classification of wind lidar approaches in complex flow situations.
- Classification of complex flows considering terrain morphology, meteorological aspects, etc. with relevance for lidar measurements.
- Guidance for the application of wind lidar beyond flat terrain.

Sub-task 2.3 Wind flow parameters

This activity deals with the understanding of the discrepancies on the measurements in flat terrain between conventional anemometry and wind lidars. The main reason for this is due to the spatial and temporal sampling of the standard vertical profilers. A relevant parameter which has been identified to be affected is the turbulence intensity. Different numerical and field studies show a rather complex behaviour of the turbulence intensity measured with wind lidars. The measured quantity differs from the values measured with conventional anemometers. This is mainly explained by the nature of the measurement. The volume interrogated by a wind lidar is in most of the cases much larger than that of a conventional anemometer. On the other hand there is a scanning process needed, when measuring from the ground, which implies the sampling of a large area above the ground based lidar. These two effects combine and give rise to turbulence intensity values different than those measured at a ”single point” with a conventional anemometer. This has been found to be affected by the stratification in the atmospheric boundary layer. The stratification is normally not measured during sitting campaigns and therefore any attempt to take this into account when assessing turbulence intensity is rather difficult. However, as it becomes more relevant, its derivation from standard measurements of the vertical wind profile has to be studied. The work in this activity will concentrate on gathering experiences with turbulence intensity measurement and its factors of influence, concentrating on stratification. This will complement the work done in sub-task 1.1. The following areas are seen of most importance for this task.

- wind speed measurements
- turbulence measurement with ground-based lidar
- correspondence between wind shear and stability
- wind rose and veer
- flow inclination

The results of this activity will be secured in an expert report.

Subtask III: Procedures for turbine assessment

Introduction

Beside site assessment aspects, the lidar technology offers various applications directly linked to the turbine. When using it from ground you can use a lidar for power performance testing according the new IEC 61400-12 standard and its Annex L. In the next step ground-based lidar measurements should be further developed for load estimation regarding a prospective implementation into IEC 61400-13, too.
If you install the lidar on the nacelle / in the spinner you can measure the incoming wind field of the turbine. This information can be used for predictive control strategies, power performance testing and load estimation.
Subtask III comprisesfour smaller tasks, divided in nacelle- and ground-based topics as well as in power performance and load estimation issues. The promising predictive, lidar-assisted turbine control is not directly included in this subtask, due to confidential issues. Nevertheless the wind field reconstruction methods of subtask 3.3. are relevant for all nacelle-based applications to get rid of the “Cyclops dilemma”.

Sub-task 3.1 - Exchange of experience in power performance testing using a ground-based Lidar acc. to 61400-12-1 ed. 2 Annex L

Late research results have demonstrated the need for more comprehensive measurements of the power curve of wind turbines and the induced loads. It has been shown that the wind shear has an important effect in the uncertainty of power curves and becomes more and more important at large wind turbines regarding the loads. Subtask 3.1 aims at evaluating the new IEC 61400-12-2 Ed. 2 standard, which allows using a reference met mast (smaller than hub-height) and a Lidar system. Based on this standard it will be possible to measure the wind speed at hub height or to estimate an equivalent wind speed calculated of measurement points over the swept rotor area.
Even an exchange of measurement data is possible, which could be provided by the participating members. The aim is to use a properly normalized set of data, which could be used to estimate a power curve of e.g. a type of a wind turbine at different standard sites, and to apply different recommended methods. The advantages and disadvantages of the methods could then be exposed. Within this subtask a commitment of measurement institutes and manufacturers is desired.
Sub-task 3.1 will collect the experience of the participants, investigate the experience and report its findings in recommended or best practises and/or revision of main body of the standard

Sub-task 3.2 - Wind field reconstruction nacelle based

The basic wind field reconstruction methods of nacelle-based Lidar measurements are necessary to calulate the wind vectors u,v,w out of the line-of-sight wind speed vector by using assumptions or an estimator. The knowledge of the wind field is necessary for several nacelle-based lidar applications such as Lidar assisted control, power performance testing or load estimation. The work will be reported in the form of an expert report.

Sub-task 3.3 Nacelle-based power performance testing

A very promising approach for on- and offshore power perfomrance testing and validation is to measure the wind field from the nacelle. By using a nacelle-based lidar system, it is possible to measure the incoming wind field the measurement comprises a spacial measurement of the wind speed at discrete points over the swept rotor area thus including also the wind shear. As a result, the power performance testing becomes far more accurate than with any conventional method. The calculation of the so called “rotor effective wind speed” is still part of the ongoing research and it is discussed, which measurement points are relevant and if shear independent approaches are possible. Subtask 3.3 will investigate these issues and record its findings in an expert report.

Subt-task 3.4: Load estimation using a lidar system
The subtask will look at wind measurements by ground and nacelle based lidar systems and their benefit for the load estimation of wind turbines. Refering to this aspect not only the wind speed measurement but also the correct measurement of the turbulence intensity (cf. 2.3) is avery important issue.
Until now the turbulence intensity has to be calculated based on hub height wind speed measurements using standard anemometers. New approaches with ground-based lidar systems seem to be very promising. But also nacelle-based measurements should be taken into account regarding turbulence intensity. Both, ground- and nacelle-based lidar measurements , have the potential to provide additional data to calculate e.g. an equivalent turbulence intensity over the swept rotor area.
Efforts will be spent also in the study of possible lidar-based methods to correlate additional information of the wind field with mechanical loads on the turbine. Particularly, the correlation between the turbulence and wind shear measured by lidar systems and fatigue loads will be investigated. Sub-task 3.4 collects the experience of the participants, investigates the results and reports its findings in the form of an expert report.

Subtask IV: Data management
The previously described subtasks suppose a consistent exchange of data between the Participants in order to achieve positive results. Therefore, Subtask IV is proposed as a cross-assignment in order to establish and coordinate a platform for the exchange of the data. The regulations about the access to the platform and the confidentiality of the data are also considered in this subtask.

DTU Wind Energy will implement a SQL database server that can be used for data transfer tasks. An FTP server is also available when more appropriate. Both servers are accessible from the public internet. Both servers allow appropriate access rules to be established in order to maintain the data security as indicated by the operating agent.

4 Time Schedule with Key Dates

The IEA Task will continue for a period of three years beginning in autumn 2011 and ending in the end of 2014, or resumed at an earlier date, if the Agreement expires or is terminated.

The IEA Task may be further extended for such additional periods as may be determined by two or more Participants, acting in the Executive Committee. Extension shall thereafter only apply to those Participants who agree to the extension.

In the first months of the IEA Task an initial workshop will take place. During this meeting, Participants will share their experience in order to assess the state-of-the-art. Also, the activities concerning the Subtasks will be discussed and assigned. A draft work plan will be extended and will be approved by the Participants within two months (Milestone M1).

Table 1. Time schedule of IEA Task: Wind lidar systems for wind energy deployment

IEA Wind Task 32: LIDAR (Wind lidar systens for wind energy deployment)
Time schedule 20/09/2012

Activity / Milestone	months	2011			2012												2013												2014												2015					
		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
Duration										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
68th ExCo: Expected Task approval		O																																												
Meeting 1: Initial Workshop	1								O																																					
Subtask I: Calibration and classification																																														
M1: Confirmation of participants, agreement on the work plan	2															M1																														
Subtask IV: Data management																																														
M2: Data exchange platform operational, Consortium agreement for data exchange established	3														M2																															
Meeting 2: Progress meeting	6														O																															
Subtask II: Proc. for site assessments																																														
Subtask III: Proc. for turbine assessment																																														
M3: IEA Recommended Practices, 1st ed.	12													M3																																
Meeting 3: Progress meeting	13																					O																								
Meeting 4: Progress meeting	18																										O																			
Meeting 5: Interm. Workshop at ISARS 2014	23																															O														
M4: IEA Rec. Practices, Draft 2nd ed.	24																																M4													
Meeting 6: Progress meeting	28																																				O									
M5: IEA Recommended Practices, 2nd ed.	30																																						M5							
Meeting 7: Final Workshop	36																																												O	
M6: Final report & background reports	36																																												M6	

Every two years, workshops similar to the two previous IEA Topical Expert Meetings on “Remote Wind Speed Sensing Techniques using LIDAR and SODAR”. Ideally these workshops will be organized at the same venue and adjacent to the International Symposium for the Advancement of Boundary Layer Remote Sensing (ISARS) with the intent to favour cross-fertilisation between the lidar and sodar community.

As well, twice a year further meetings will be hold to give the Participants an update about the progress of the Subtasks and, most important, to share cross-relevant results.

The proposed timing of the progress meetings has been scheduled with respect to the edition of the IEA Recommended Practices for LIDAR measurements (Milestones M3 and M5).

The proposed time schedule for the IEA Task is presented in *Table 2*.

5 Reports, Deliverables, and Dissemination of Results

The IEA Task is intended to generate two editions of a community agreed IEA Recommended Practices for LIDAR measurements accompanied by further background information and dissemination of further knowledge acquired.

“IEA Recommended Practices for LIDAR Measurements“, 1st ed., 2012

- based on draft “IEA Recommended Practices for Remote Sensing Measurements“ currently under preparation by working group from the IEA Wind Annex XI: 59th Meeting on remote sensing in wind energy, NREL, US, Oct. 2009
- recommendation for ground-based lidar measurements in standard conical scanning “Velocity Azimuth Display” (VAD) mode for assessment of wind conditions in flat terrain
- referring to MEASNET – Evaluation of site-specific wind condition Version 1, Nov. 2009
- referring to IEC TC88 concerning power curve assessment IEC 61400-12-1

“IEA Recommended Practices for LIDAR Measurements“, 2nd ed., 2014

- recommendations on assessment of precision, calibration, repeatability and operational aspects
- recommendations on assessment of wind conditions over flat terrain and for complex inflow
- recommendations on the estimation of inflow conditions related to mechanical load measurements
- referring to MEASNET – Evaluation of site-specific wind condition Version 1, Nov. 2009
- recommendations on power curve assessment which are optional to IEC 61400-12-1

Background reports prepared by individual Participants

- incl. details of benchmark exercises
- updated documents showing state-of-the-art lidar technologies
- research and development needs for advanced applications

Dissemination of more accessible information for the understanding of lidar measurements and their differences and comparability to conventional measurements
This information will be complied in particular, in regards to:

- wind fluctuations (turbulence)
- measurement of wind shear with ground-based and nacelle-based systems
- application of lidar systems in complex flows

6 Methods of Review and Evaluation of the Work Progress

In the course of the IEA Task the progress will be controlled by the six milestones shown in *Table 3.*

Table 2. Key milestones

Milestone	Subtask	Month
M1: Confirmation of participants, agreement on the work plan	all	7
M2: Data exchange platform operational, Consortium agreement for data exchange established	IV	6
M3: IEA Recommended practices, 1st ed.	all	5
M4: IEA Recommended practices, Draft 2nd ed.	all	24
M5: IEA Recommended practices, 2nd ed.	all	30
M6: Final report & background reports	all	36

The individual progress reports will be edited by each Subtask and the Operating Agent will be responsible to collect them in a single document.

7 Obligations and Responsibilities

Operating Agent
In addition to the responsibilities enumerated in the IEA Wind Agreement

(1) The Operating Agent, as coordinator, is responsible for the results of the entire IEA Task and will report to the Executive Committee.
(2) Upon final approval of the current proposal, the Operating Agents will organize an initial workshop to define in detail the work plan of each subtask and to address the relative assignments to the Participants.
(3) The Operating Agent in conjunction with the subtask coordinators is responsible for the delivery of the first and second edition of the "IEA Lidar recommended Practices for LIDAR measurements"

Participants
The activities planned for this IEA Task is based on the availability of lidar measurements and on a constructive exchange of experience with lidar among the parties. Therefore, in addition to any obligations listed in the IEA Wind Agreement, Participants are required to prove their competence with lidar technique towards the Operating Agent and the subtask coordinators by answering the distributed questionnaires. Moreover, they have to provide data taken in accordance with the prescribed procedure that will be defined in the initial workshop.

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 (*"IEA Recommended Practices for LIDAR Measurements," 1st and 2nd edition*). 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.

The initial workshop and the two intermediate workshops planned adjacent to the International Symposium for the Advancement of Boundary Layer Remote Sensing (ISARS) 2012 and 2014 will be open to other IEA Participants in order to share knowledge across the entire remote sensing community.
Participants will formally join the IEA Task at its activity by signature of the consortium agreement. As a rule the parties interested in becoming a Participant may join one workshop or progress meeting without signature of the consortium agreement once they have proven their competence with lidar technique towards the Operating Agent and the subtask coordinators prior to the meeting.
Further tasks will be defined separately for each Participant at the initial and the following workshops.

8 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 host country shall bear the costs of workshops and meetings convened in conjunction with this Task.
- The total coordination costs of the Operating Agent and the subtask coordinators shall be borne jointly and in equal shares by the Participants.
- Each Participant 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 IEA Task will be centrally managed by the ForWind – University of Oldenburg, Germany (ForWind –OL) and will have three subtask coordinators:

- DTU Wind Energy, Risø Campus, Roskilde, Denmark , to coordinate the Subtask I and IV
- NREL, USA to coordinate the Subtasks II
- Stuttgart Wind Energy (SWE), University of Stuttgart, Germany, to coordinate the Subtask III

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9 Budget Plan

The total costs of the Operating Agent and the subtask coordinators for coordination, management, reporting, and data base maintenance and operation is 57,000 Euro/yr during a projected three year period, and may not exceed this level except by unanimous agreement of the Participants, acting in the ExCo.

Projected expense items of the operating agent and subtask coordinators are as follows (per year):

• Management	4 person-months	Euro/yr.	49,000
• Travel	4 meetings (plenary + ExCo)	Euro/yr.	7,500
• Administrative and misc. expenses		Euro/yr.	500

The person-months will be shared in the following way: 45% for ForWind – OL, 30% for DTU Wind Energy and 25% for SWE. Considering the different hourly rates of the coordinating institutions the budget will be distributed: 40% for ForWind – OL, 38% for DTU Wind Energy and 22% for SWE.

A redistribution of the budget share takes place after February 2013 when NREL takes over the coordination of subtask II. Namely, the person-months will be distributed in the following way: 20% for ForWind – OL, 30% for DTU Wind Energy, 25% for NREL and 25% for SWE. In terms of budget the distribution will be: 20% for ForWind – OL, 34% for DTU Wind Energy, 28% for NREL and 18% for SWE.

The research tasks will be self-financed by institutions or may be covered by on-going projects. *Table 3* provides an estimation of the efforts required in each subtask. This estimation is based on the sum of a base effort, which is essentially independent from the actual number of participants in a certain subtask, and an extra effort, which is proportional to the number of participants. Based on the expression of interest received so far from potential participants a number of participants of at least 15 seems to be realistic. The total required work effort for 15 participants is estimated at 115 person months (*Table 4*). In case of only 10 participants the effort would reduce to approximately 95 person months.

During the kick-off workshop the effort offered by each participant will be established in *Table 4*. This table shows the national effort, that is specifically undertaken in national projects for the task, as well as the related effort, that is undertaken in national (or international) projects related to the task and which is (partly) input for the task.

10 Management of Task

After the initial workshop, the Operating Agent will refine the planning and the contents of the activities and will re-define an action list and the milestones of the project. Intermediate workshops and meetings will be scheduled in order to discuss with the Participant the progress of the subtasks (see time schedule in Section 5, *Table 2*).

The communication of intermediate results will take place through progress and technical reports that will be distributed to all Participants.

The data-exchange among Participants will be coordinated within Subtask IV. In the initial workshop the Participants will discuss what types of data are requested by the other subtasks. Also, the amount of data available will be estimated and possible solutions for the data-management will be proposed.

A consortium agreement will be established to facilitate the exchange of confidential or proprietary data among the Participants.

11 Organisation

The overall management will be undertaken by the Operating Agent, ForWind – University of Oldenburg. As subtask coordinators, DTU Wind Energy will be responsible for Subtask I and IV, NREL will be responsible for coordination of Subtask II and SWE, University of Stuttgart will be responsible for Subtask III.

In the framework of Subtask IV, the data-exchange will be unrestricted only for Participants with experience in lidar measurements and who offer lidar data as well.

For what concerns financing issues, each Participant will bear its own research activity, including travel expenses.

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

Table 3. Estimation of the required work effort for each subtask

Activity		Number of participants involved	Estimated working effort [man months]		
			Basic effort	Extra effort per participant	Total
ST 1: Lidar calibration	*duration [months]: 24*				
Improving our understanding of lidar calibration		5	2,25	0,25	3,5
Lidar classification and uncertainty		5	2	0,25	3,25
Calibration methods for nacelle-mounted lidars		7	2	0,5	5,5
Calibration techniques for measurements in complex terrain		9	2	0,5	6,5
Calibration methods for floating lidars		9	1,5	0,25	3,75
Thinking out of the box – novel ideas for calibrating lidars		7	1	0,25	2,75
Writing deliverables		7	0,25	0,25	2
Total effort of Subtask			11		25,25
ST 2: Procedures for site assessment	*duration [months]: 31*				
RP for Ground-Based Remote Sensing for Wind Resource Assessment in Flat Terrain		10	1	0,1	2
RP for Ground-Based Remote Sensing for Wind Resource Assessment in Complex Flow Conditions		12	7	1	19
Wind flow parameters		9	7	1,5	20,5
Writing deliverables		10	0,25	0,25	2,75
Total effort of Subtask			15,25		44,25
ST 3: Procedures for turbine assessment	*duration [months]: 31*				
Exchange of experience in power performance testing using a ground-based Lidar acc. to 61400-12-1 ed. 2 Annex L		5	2,5	0,5	5
Wind field reconstruction nacelle based		5	2,5	1,5	10
Nacelle-based power performance testing		8	2,5	1,5	14,5
Load estimation using a lidar system		5	2	1	7
Writing deliverables		5	0,5	0,25	1,75
Total effort of Subtask			10		33,25
Subtask 4: Data management	*duration [months]: 35*				
Definition of the file server (data structure, up/download methods, access security)			3		3
Definition of data set criteria			2,25		2,25
System management		15	1	0,25	4,75
Total effort of Subtask			6,25		10
Total effort of entire Task			42,5		112,75

Table 4. Estimation of budget offered by Participants

Country	Participant	Subtask	National effort	Related effort	Total effort
			(Personmonths)		
Denmark	RISØ - DTU				
Finland	VTT				
France	Leosphere				
Germany	Deutsche WindGuard Consulting				
	DEWI				
	DLR – IMF				
	Karlsruhe Institute of Technology				
	ForWind – Univ. of Oldenburg				
	Fraunhofer – IWES				
	GL Garrad & Hassan Deutschland				

	GWU-Umwelttechnik GmbH				
	University of Stuttgart				
	Windtest Grevenbroich				
	Wind-consult				
Greece	CRES				
Japan	AIST – Nat. Institute of Advanced Industrial Science & Technology				
	Mie University				
Korea	Korea Institute of Energy Research				
	POSTECH - Pohang University				
Spain	Acciona				
	CENER				
United Kingdom	Manchester Metropolitan Univ.				
	Natural Power Consultants Ltd				
	Oldbaum Services Ltd				
	SgurrEnergy Ltd				
	University of Salford				
	TUV NEL				
United States	NREL				
	AWS Truewind				
	GL Garrard & Hassan				
	Integrated Environmental Data, LLC				
	NRG - University of Colorado				
	Optical Air Data Systems - Catch the wind Inc.				
Total					

Work effort to be confirmed by participants according to answers to questionnaires sent out after the kick-off meeting.

Preliminary list of participants

"National effort" refers to the effort in person months that is specifically undertaken in national projects for the task

"Related effort" refers to the effort in person months that is undertaken in national (or international) projects related to the task, and which is (partly) input for the task.

12 Information and Intellectual Property

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

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

(c) **Proprietary Information.** The Operating Agent and the Annex 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 the Task. For the purposes of this Annex, proprietary information shall mean information of a confidential nature, such as trade secrets and know-how (for example computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) which is appropriately marked, provided such information:

(1) Is not generally known or publicly available from other sources;
(2) Has not previously been made available by the owner to others without obligation concerning its confidentiality; and
(3) 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.

(d) **Use of Confidential Information.** If a Participant has access to confidential information which would be useful to the Operating Agent in conducting studies, assessments, analyses, 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.

(e) **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 endeavour to make the information available to the Task under reasonable conditions.

(f) **Reports on Work Performed under the Task.** Each Participant and the Operating Agent shall provide reports on 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.

(g) **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.

(h) **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.

(i) **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 Annex Participants, provided however, that the Annex Participants 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.

(j) **Inventors and Authors.** Each Annex Participant will, without prejudice to any rights of inventors or authors under its national laws, take necessary steps to provide the co-operation from its inventors and authors required to carry out the provisions of this paragraph. Each Annex Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the law of its country.

Database. The data provided by the Participants may be used only for activities defined in the mutually agreed work plan of the IEA Task. Participants may not transmit data to external parties without the explicit consent of Operating Agent and the Participant providing the data.

13 List of Potential Participants

The selection of potential Participants listed in *Table 5* is mainly based on the attendance to the two last IEA Topical Expert Meetings. The participation of the companies and institutes in different research projects is not necessarily comprehensive.

Table 5. Participants to the IEA Topical Experts Meetings and other international initiatives

Participant	51th IEA TEM	59th IEA TEM	UpWind WP6	NORSEWInD	National Projects	Windscanner.eu	EERA	Interest in joining Task
Acciona		x						
AIST (Japan)								Y
AWS Truewind		x						Y
CENER		x	x		?	x	x	Y
CRES			x					?
Deutsche WindGuard Consulting GmbH	x							
DEWI		x			x			Y
DLR - IMF	x				x			
ForWind - University of Oldenburg	x	x			x		x	Y
Fraunhofer - IWES				x	x	x	x	Y
Garrard & Hassan Partners	x	x		x				
GL Garrad & Hassan Deutschland	x			x	x			N
GWU-Umwelttechnik GmbH	x							Y
Integrated Environmental Data, LLC	x	x						
Karlsruhe Institute of Technology	x							T
Korea Institute of Energy Research		x						
LEOSPHERE	x		(x)					Y
Manchester Metropolitan University	x							
Mie University								Y
Natural Power Consultants Ltd	x		x					Y
NREL	x	x			x			T
NRG		x						Y
Oldbaum Services Ltd	x			x				Y
Optical Air Data Systems - Catch the wind		x						
POSTECH - Pohang University		x						
QinetiQ	x		x					
Risø DTU	x	x	x	x	x	x	x	Y
SgurrEnergy Ltd	x	x						Y
TUV NEL								Y
University of Stuttgart	x	x	x		x			Y
University of Colorado		x						
University of Salford	x							
VTT	x	x	x					Y

** Y: yes; N: no; T: tentatively; ?: Not known*

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