Application form
ScanFlow project

High-resolution full-scale wind field measurements of the ECN's 2.5 MW aerodynamic research wind turbine using DTU's 3D WindScanner and SpinnerLidar for IRPWind's and EERA's benchmark **(ScanFlow)**

Applicants: DTU and ECN

IRPWIND project – 1st Call for Joint Experiments

Work Programme 2016 February 2016

COMMERCIAL-IN-CONFIDENCE

Table 1 Network Identification:

Research Wind Turbines	**RWT**

A) Proposal Leader details. ***User or Access provider of the Research Infrastructure***

Applicant Full Name	**Charlotte Bay Hasager**
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Other institution details. ***Access provider to the Research Infrastructure***

Institute name	**ECN**
Contact person	**Jan Willem Wagenaar**
Country	**The Netherlands**
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B) Aspect of the proposal related to EERA JP Wind Sub Programme priorities

EERA JPWind Sub Programmes	**(D) Wind Conditions** **(E) Aerodynamics**	**Relevant Networks**	**1. Research Wind Turbines**
Length of the project	**Number of weeks:** **Total project including planning and post-processing 29 weeks hereof experiment campaign 6 weeks.**	**Start date:** **01-06-2016**	**Open Acces to the results all public:** Yes **Level of open access to data:** 100%

C) Project description

TITLE OF THE PROJECT: **ScanFlow**

High-resolution full-scale wind field measurements of the ECN's 2.5 MW aerodynamic research wind turbine using DTU's 3D WindScanner and SpinnerLidar for IRPWind's and EERA's benchmark **(ScanFlow)**

1. Introduction

- Research topics and originality.

We aim to establish a unique turbine power performance and induction zone benchmark experiment by operating a DTU developed high-resolution nacelle integrated 2D SpinnerLidar[1] installed in a research wind turbine at ECN.

Concurrently, three ground-based short-range WindScanner lidars from DTU will be deployed to perform 3D wind velocity field observations. Previous efforts on measuring the inflow induction zone upwind of turbines include the Vestas V27 at Risø [1, 2], the NM80 wind turbine at Tjæreborg [3] and NEG Nordtank 40 at Risø [4, 5] to provide prevision of the inflow in an upwind vertical plane. The scientific progress beyond these previous efforts will now be to achieve data from three vertical planes 10-minute averages of all three wind components. Furthermore we will also observe turbulence along one horizontal transect from 1Hz data. The baseline inflow i.e. when the turbine is not in operation and the induction zone from the operating row of turbines will be observed and quantified by a novel solution. Furthermore the rotor plane equivalent wind speed can be reverse- calculated to wind speed from wind power production at 1 Hz fast production data [6, 7] and compared to WindScanner turbulence observations [8] as well at turbulence data from the meteorological mast. Finally, the inflow observed from lidar is of utmost importance for control of turbines and can be used for load calculation. The innovative aspect of the proposed work, involving detailed 2D and 3D inflow wind scanning is very high.

Recently it has been experimentally demonstrated that a lidar-based feed-forward control can reduce loads and pitch activity by high factors and in certain cases more than by 60%. The impact, technologically as well as economically, achievable from integrating nacelle or spinner lidars for advanced feed-forward wind turbine control is immense: Recently, it has been experimentally demonstrated [9, 10] that lidar- based feed-forward control can reduce tower bending moment loads and pitch activity by factors of 50% to 30% respectively. Prognoses for turbines equipped with lidar-assisted reduction in wind load foresees to be able to prolong the turbine life time by 30 % giving LOE of 6% and in some cases an expected life time extension of as much as + 6 years [11].

The latter study shows that through lidar-assisted improvements in yaw and gust tracking, an installed 2.5 MW turbine face slower turbulence losses and an expected increase in power capture, which in below rated winds would yield a gross AEP increase of 0.6% for the assumed wind speed distribution. Additionally, a decrease in blade and tower fatigue loads (the assumed design life driving loads) are expected to extend the

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[1] Cf. WindScanner.dk and WindScanner.eu

turbine useful life from 20 to 26 years, allowing an additional 30% energy capture over the life of the turbine. Further, a decrease in traditional O&M costs is expected due to fewer component failures as a product of reduced dynamic loads, yet there is also an additional annual O&M cost for maintaining the lidar itself. Because the cost to maintain the lidar is greater than the O&M cost savings due to reduced failures, the annual average O&M cost increases 16% over the base case, cf. reference [11].

Outcome:

The **ScanFlow** project will provide a state-of-the-art inflow dataset useful for evaluation of aerodynamic models ranging from engineering-like up to computational fluid dynamics models [12], models of the inflow [2, 13] and induction zone [1, 14, 15]. A proof-of concept testing of the new advanced software for wind reconstruction using the LINCOM model based on the anti-Cyclop buster methodology program [16] will be applied. The idea of the latter is to extract all three wind components of the inflow in front of the rotor from a single Spinner lidar. The result will be compared with the “true” ground based measurements of the three wind speed components (u,v,w) from the three short-range WindScanner lidars that will measure from the ground.

The benchmark will be available through an open access e-science platform [17, 18], also beyond project time.

- The WindScanner SpinnerLidar from DTU will observe during 6 weeks the inflow approaching the research wind turbine.
- We will establish a raw dataset for the entire campaign.
- The raw data will be transformed into 3D inflow wind velocity fields upwind the rotor plane by methods developed at DTU and compared against 3D short-range WindScanner observations from DTU during few weeks; thereby establish a limited dataset proof-of concept demo.
- The raw and limited processed data set will be open for the IRPWIND consortium, students and all beyond. They can continue to data mine the data set.
- The turbulence will be assessed from an expression combining the rotor equivalent wind speed and the power fluctuations of the wind turbine and will be compared to turbulence observed from the WindScanner and turbulence observed from mast observations.
- Open benchmarks for the IRPWIND community for model evaluation, also accessible beyond project lifetime.

- Work Packages

- WP1 Prepare the WindScanner lidars at DTU for the experiment (June-August 2016) (lead: DTU)
- WP2 DTU visits the ECN field site for installation plan technical details (August 2016) (lead: ECN)
- WP3 Experimental campaign, installation of instruments and continued monitoring of the nacelle-based WindScanner for six weeks, uninstall and ship back (September-October 2016) (lead: ECN)
- WP4 Experimental campaign, installation and continued work on using the three ground-based WindScanners for two weeks, uninstall and ship back (September 2016) (lead: DTU)
- WP5 Post-processing of collected data as proof of concept for three wind components from nacelle-based WindScanner (November 2016) (lead: DTU)
- WP6 Establish public database from wind turbine and WindScanner data and announce it at workshops (December 2016) (lead: ECN)

There will be no management work package paid by the **ScanFlow** project. DTU will ensure timely coordination of all partner activities so the project will be delivered on time and on budget. The Access Agreement and Background and Foreground IRP will be clarified such that optical open access data distribution will be secured. The coordinator (Dr. Hasager) will be assisted by financial and legal administrator (Mrs. Hyllested, also the financial administrator of the overall EERA-IRP programme). Should any major problems occur that cannot be solved by the partners, the Project Officer (PO) will be informed. Risk management will include continued close contacts between DTU and ECN on the experimental work (C. Hasager, DTU and J.W. Wagenaar, ECN). Final reporting and cost statements will be delivered on time.

- Complementarities and Synergy amongst partners

- DTU and ECN are at the forefront of wind energy research in Europe during recent years.
- ECN has the research wind turbine (2.5 MW) at an excellent field site.
- DTU has the most recent WindScanner instrumentation. For this project DTU will use the SpinnerLidar and three short-range ground based lidars.
- DTU and ECN have fine collaboration practices during the last 30 years and both have excellent track-records in wind energy research based on research infrastructure and theoretical work which is most suitable basis for the proposed project to be successful.
- The joint alignment of expertise from the two institutions builds on many previous collaboration activities including the EERA Wind Energy network. The particular relevance of the proposed work aligns sub-programs on wind conditions and aerodynamics that during recent years have got closer interface collaboration in cross-cutting research. This is in part a consequence of increasing computational resources and modelling skills. The numerical models in the so-called modelling chain benefit for instance from integrating actions such as the EERA DTOC project (www.eera-dtoc.eu) [19], the EU project on integration of numerous software for design of offshore wind farms. DTU and ECN will, through alignment of state-of-the-art research infrastructures, provide outstanding new results on the inflow wind field for the benefit of the wind energy community in general because the collected data will be 100% shared. It is believed that the added value in regard to model benchmarking within the scientific and industrial community will benefit European wind energy; from institutions and companies that do not have the means to perform such an experiment to those competing with the capabilities of DTU and ECN.

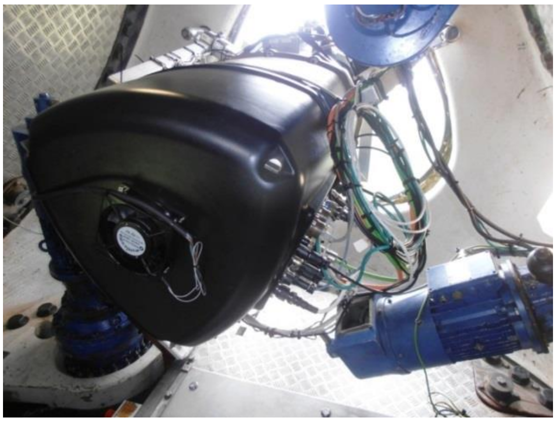
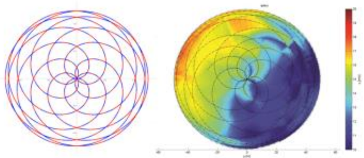
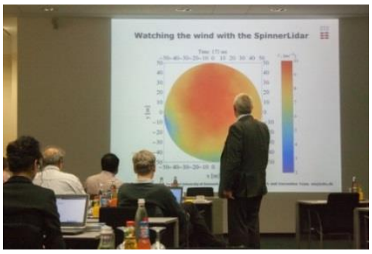


Photo of nacelle-based lidar installed in the spinner of a wind turbine.





Graphics drawing of the scan pattern. Image of results presented. Photo of WindScanner.

- Technological Readiness Level (TRL) of the proposed concept.

  The research wind turbine at ECN is a commercial machine (TRL 9). The TRL level of the research infrastructure is 8 for the WindScanner. It is not commercial but it has the potential. However, this is out of scope at present because DTU strives to have an EU-level research infrastructure, which is already on the EU Roadmap. The proposed measurement concept is TRL 6. The collected data will fulfill data needs for research at TRL 3-6 within the wind conditions, inflow wind fields, induction zone research and aerodynamic research through open access benchmark. The research is expected to progress one TRL level up as a result from the **ScanFlow** project data sharing.

- Description of links to relevant EERA Sub Programmes (SP) and/or IRPWIND Core Projects (CP).

The suggested experiment using the research wind turbine facility at ECN test site [20] in combination with the newly developed WindScanner research infrastructure at DTU combine efforts within WP3 of the IRPWIND core project. The links to the EERA Wind Energy sub-programmes 'Aerodynamics' and 'Wind Conditions' are very strong. In both Sub-programs there is high priority on improved inflow wind fields measurements and modelling. Within '**Aerodynamics**' sub-program new types of data, e.g. from WindScanner, are particularly important for understanding atmospheric flow and aerodynamics for very large rotors. Flow at large wind turbines but without accessible WindScanner data are investigated in the on-going EU AVATAR project as well as EU INNWIND. The current project will link to both of these. Within '**Wind Conditions'** the coupling between meso- and micro-scale models and the progression from siting to loads are very important challenges. At DTU the recently established cross-cutting activity Wind2Loads need data to verify advanced modelling while the proposed **ScanFlow** experiment (on flat land) will be complementary to field data from the New European Wind Atlas (NEWA) ERANET project that has focus on detailed inflow description in complex terrain and coastal areas.

- Description of the experience of both, Users and Access provider in these types of experiments.

ECN Wind Energy Systems is ISO 17025 accredited for power performance, mechanical loads and meteorological measurements. Offshore, ECN maintains a measurement network of wind measurements on various locations [21]. At the test site ECN has executed numerous standardized measurement campaigns for in the framework of wind turbine type certification for manufacturers [22]. Last but not least various research campaigns have been performed on the research wind turbines as for instance the DOWEC, the LTVM and the PROTEST program and more recently the LAWINE and the InnoTip program. ECN Wind turbine test site facilities have been used for all campaigns described above.

DTU Wind Energy is a world-class research institute within theoretical and applied wind energy since the start of wind energy in 1970ies and now has 280 employees. DTU operate the WindScanner.eu instruments, on the roadmap of the EC Infrastructure. This is state-of-the-art new remote sensing wind observation technology. The expertise provides credibility of the planned experiment.

- Definition of Key Performance Indicators, KPIs.

- Obtain 6 weeks measurements with WindScanner SpinnerLidar at ECN wind turbine test field
- Obtain data from three ground-based short-range WindScanner lidars during a two week campaign
- Deliver the wind turbine 10 minute data power production, pitch angle and rotational speed to public database.
- Deliver WindScanner 10 minute data to public database.

2. Description of national projects aligned to the proposed activities in both the sending and the receiving institution

- Description of national projects from the User institution (DTU)

- **UniTTe** http://www.unitte.dk/. UniTTe addresses the question of how best to characterise the wind when measuring the power and loads on modern wind turbines. Current international standards require us to measure the wind from a mast, far in-front of the rotor and at the rotor centre height (hub-height). UniTTe proposes a radical change so that in the future we will measure with a lidar (laser anemometer) mounted on the nacelle, measure quite close to the rotor and measure over a range of heights. Funded by Innovation Fund Denmark.
- **Concert** http://energiforskning.dk/da/project/concert. Concert deals with down-regulation of wind farms and in a system like the Danish one with record high wind power giving as maximum so far 140% of national consumption, this topic is relevant. To estimate what the farm would produce if not downregulated, the PossPOW project developed the 'real-time' power effect curve. This will be further developed in Concert. Funded by PSO ForskEL.
- **POSSPOW** http://www.posspow.vindenergi.dtu.dk/. The project developed a verified way to determine the possible power of a down-regulated offshore wind farm. This includes the reliable estimation of the possible power of a wind power plant based on technology that draws together models including aerodynamic models for wind turbines and wake modelling of large offshore wind farms. Funded by PSO ForskEL.
- **RUNE** project http://www.vindenergi.dtu.dk/english/News/2014/12/The-RUNE-project-Reducing-the-Uncertainty-of-Near-shore-Energy-estimates RUNE aims at reducing the uncertainty of near-shore energy estimates from meso- and micro-scale wind models. The tools are onshore scanning lidars focus on measurement accuracy of free stream atmospheric flow and uncertainty of meso- and microscale models in coastal areas. Funded by PSO ForskEL.
- **Wind2Loads** is an on-going internal DTU project on inflow and engineering modelling for wind turbines.

- Description of national projects from the Access provider institution (ECN)

- **LAWINE** project http://www.tki-windopzee.nl/project/lawine. Lidar Application for WINd farm Effeciency. The LAWINE project improves and demonstrates opportunities for applying Lidar technology. This enables a better assessment of the wind field for planned and existing locations. Partially funded by TKI Wind op Zee.
- **InnoTip** project http://www.tki-windopzee.nl/project/innotip. INNOvative offshore TIPs to improve wind farm yield. The InnoTip project aims to develop and test three innovative blade tips specifically designed for offshore turbines improving the efficiency and energy production. The tips also aim to recover the wake faster. Both effects together should lead to a reduction of 6% of the LCOE. Partially funded by TKI Wind op Zee.
- **Wind op Zee** project http://www.windopzee.net. North Sea wind measurements. ECN's wind energy department was commissioned by the Dutch Ministry of Economic Affairs to conduct a long-term meteorological measuring programme in the Dutch part of the North Sea. The programme involves ECN collecting wind data and making it available to the public and developers of offshore wind farms. The use of more accurate wind data in preparing new offshore wind farms reduces risks and therefore lowers the cost price.

- Foreseen European added value of the joint alignment of both institutions

- **IEA Annex** 32 http://www.forwind.de/IEAAnnex32/ The aim of IEA Wind Annex 32 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 power systems. The purpose is to bring together the present actors in the research community and industry to create synergies in the many R&D activities already on-going in this very promising and new measurement technology. In particular testing of the upcoming new version for IEC 61400-12-1, allowing for the first time the use of ground based lidars for power curve verification, is in the road map for 2016 for the IEA Annex 32 together with the Power Curve Working Group.

- **IEA Annex 31** https://windbench.net/ The WakeBench and WindBench platforms are developed to guide developers and end-users on best practices for using wind flow models based on quality assurance procedures that are mutually recognized by the wind community as standards of good practice.
- **IEA Task 29 Mexnext** http://www.mexnext.org. The main aim of IEA Task 29 Mexnext is to analyze data from the so-called (New) Mexico experiments. Emphasis is put on induction aerodynamics. Thereto PIV flow field measurements around the turbine are combined with measurements of the pressure distributions along the blade. The experiments were carried out on a turbine with a diameter of 4.5 meter which was placed in the largest wind tunnel of Europe, i.e. the LLF facility of the German Dutch Wind Tunnel, DNW. The measurements are compared with results from a large number of calculational codes. Mexnext is coordinated by ECN with DTU as one of the partners. Some results on induction aerodynamics can be found in [23, 24].
- **AVATAR**, http://www.eera-avatar.eu/ AVATAR is a project initiated by the European Energy Research Alliance (EERA), carried out under the FP7 program of the European Union. Its main goal is the development and validation of advanced aerodynamic models (including models for induction), to be used in integral design codes for the next generation of large scale wind turbines (up to 20MW). AVATAR is coordinated by ECN with DTU as one of the partners.
- **MEASNET** http://www.measnet.com. MEASurement NETwork. MEASNET is a co-operation of companies which are engaged in the field of wind energy and want to ensure high quality measurements, uniform interpretation of standards and recommendations as well as interchangeability of results. Both ECN and DTU are founding members of MEASNET. ECN is coordinator of the power performance expert group in which also DTU is very active.
- The expected impact is furthermore to support the **SET-plan priority on Europe "Being n°1 in renewables**"[2] through the action of sustaining technological leadership for reducing costs. Wind energy is the dominant renewable energy in most European countries and improvements in wind power performance is a key topic for industrial and societal needs.

3. Work plan

Gantt Diagram for the project and deliverables and milestones

	June	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Lead**
WP1:Prepare WindScanners	X	X	D1					DTU
WP2: Experiment detail plan			D2					ECN
WP3: Nacelle campaign				X	M2			ECN
WP4: Ground campaign				M1				DTU
WP5: Post-processing data					X	X	D3	DTU
WP6: Database/publication				X	X	M3	D4, D5	ECN

- D1: Nacelle-based and ground-based lidars ready for experiment
- D2: Final experimental plan published
- D3: Report on the experiment and proof of concept

[2] https://setis.ec.europa.eu/newsroom/news/first-agreement-set-plan-actions-1-2-being-n%C2%B01-renewables

- D4: Final workshop with external colleagues from EERA and industry invited
- D5: Final project report
- M1: Collected 2-weeks of three ground-based WindScanner data
- M2: Collected 6-weeks of nacelle-based WindScanner inflow data
- M3: Open database launched

4. Description of the Research Facility where the experiment will be performed

ECN Wind turbine test site facility

The ECN Wind turbine Test site EWTW is an infrastructure that allows for full scale wind turbine and wind farm related research, development and technology.

The test site consists of flat, agricultural terrain with single farm houses and occasionally rows of trees. The site, near Lake Ijsselmeer and near the town Wieringerwerf, is about 50km north of Amsterdam and about 30km east of the ECN offices in Petten. The average wind speed at 80m is 7.5m/s and the main wind direction is South-West.

The site comprises 5 modern, full scale research turbines (Nordex) with a hub height and rotor diameter of 80m and rated power of 2.5MW. The turbines are oriented in a row from West to East, labelled N5 to N9, with a spacing of 3.9 rotor diameters. A fully IEC compliant and 108m high meteorological mast is located directly south of turbines N5 and N6 at a distance of 3.5 and 2.5 rotor diameters, respectively. Wind speed measurements are taken at hub height and around the upper and lower tip heights.

Photo of the wind turbines and met-mast (left) and Google Earth map including turbines, met-masts and in orange indication of WindScanner pattern at the ECN field site.

Wind turbine at ECN field site and in orange indication of WindScanner pattern

About 1.6km south of the research turbine row is a row of 6 prototype locations, also oriented from West to East. These locations are used by turbine manufacturers to develop their prototype turbines. The current turbines have rotor diameters ranging from about 100m to 120m and a rated power ranging from about 2MW to 5MW. 4 fully IEC compliant meteorological masts of over 100m support the development of the prototype turbines.

In between the two rows of turbines a measurement pavilion is located. This pavilion hosts offices for the manufacturers, a dressing room for engineers and a meeting room. In addition, measurement data from the entire test site is gathered, here, using a fiber optical network. On a daily basis these measurement data are transported to the ECN offices in Petten. Data are made available to the relevant community through a dedicated database.

The ECN test site facility offers the opportunity to execute the campaign described in this proposal by making available a research turbine, a meteorological mast, glass fiber network for data gathering and a measurement pavilion for meetings, support personnel etc. The test site facility makes agreement the farm land owners and grants access to the facility. Operation support is offered in setting up and executing the campaign.

The agreements made between all parties, i.e. ECN test site facility, ECN Wind Energy Systems and DTU Wind Energy are elaborated in the 'User Agreement'.

Executing experiments and particularly in the field of wind energy involves several risks. To mitigate these risks the 'User Agreement' specifies what qualification Users of the facility should have. In addition, the test facility uses the 'Emergency Plan EWTW; ECN Wind turbine Testpark Wieringermeer', 2014.

In case the **ScanFlow** project is granted, DTU and ECN will provide within one month proof of any required insurances and the declaration to abide by the rules and regulations of EERA JP WIND related e.g. to confidentiality, intellectual property rules, access rights, dissemination of results etc.

5. Dissemination and Transfer of Knowledge to other IRP and EERA Wind participants

- Explain the Transfer of Knowledge (ToK) and dissemination strategies.

- The dissemination strategy is to produce 100% open access to the benchmarks on inflow conditions. This will include the 10-minute wind turbine information on power production and the collected WindScanner data.
- The Transfer of Knowledge will be through the dedicated web-sites of IRPWIND http://www.irpwind.eu/, WindScanner.eu http://www.windscanner.eu/and WindBench https://windbench.net/ and the EERA Wind Joint Program web site
- Conduct a virtual follow-up meeting inviting all IRPWIND members and EERA members. The aim is to continue the dialogue with scientists across Europe for the benchmark.
- Present the project and launch an invitation to benchmark in IRPWIND and EERA newsletters
- Announce the **ScanFlow** project and preliminary results at conferences:
    - IRPWIND 2016, Amsterdam, 19-20 September 2016 (DTU& ECN on other project budgets)
    - EWEA 2016, Hamburg, 27-30 September 2016 (DTU on other project budget)
    - TORQUE 2016, Munich, 5-7 October 2016 (ECN on other project budget)
- Final workshop at ECN in December 2016.
- The publications will include the EC logo and including a statement: "The work described here has received support from IRPWind, a project that has received funding from the European Union's Seventh Programme for Research, Technological development and Demonstration"

- Final report will include description of the work and major results compared to expected results, KPIs and the advancement of TRL according to the application. Furthermore the future perspectives and research, the open public database and list of publications, done and planned will be provided in the final report such that benefit for the IRPWind and EERA programme will be achieved.
- Beyond project lifetime DTU will ensure further benchmark evaluation and open public peer-reviewed paper (DTU on other project budget)

- Plan of future collaboration with other IRPWind/EERA partners.

- The Sub-program "Wind Conditions" including the New European Wind Atlas (NEWA) http://euwindatlas.eu/ will be using the **ScanFlow** database as well as the Sub-program "Aerodynamics" including the EERA EU-AVATAR project http://www.eera-avatar.eu/ will be using the **ScanFlow** database.

6. Expected results

- Databases, Methodologies and/or Best practices obtained within the project results.

DTU and ECN will publish public open data sharing through the web-sites of IRPWIND http://www.irpwind.eu/, WindScanner.eu http://www.windscanner.eu/and WindBench https://windbench.net/

Database best practice on how to share data will be described with metadata such that subsequent data mining by others will be efficient; thus the value of results are useful for broader use beyond project. Important focus is on the quality test procedures for both data collection and database storage, including formats of the results compliant with the IRPWIND data collection recommendations [25].

- Expected advancement of the Knowledge and Technology after the results are obtained

It is expected that inflow wind conditions at large wind turbine is greatly improved in quantity and quality using new WindScanner lidar and three ground-based lidar technologies. Thereafter research advancement is enabled for future improved understanding of the very detailed near-field flow of large wind turbine.

- Assessment of the Key Performance Indicators, KPIs.

- Obtain 6 weeks measurements with WindScanner SpinnerLidar at ECN wind turbine test field
- Obtain data from three ground-based short-range WindScanner lidars during a two week campaign
- Deliver the wind turbine 10 minute data power production, pitch angle and rotational speed to public database.
- Deliver WindScanner 10 minute data to public database.

7. CVs of relevant persons

- CV's from Charlotte Bay Hasager (coordinator), Torben Mikkelsen, Alfredo Peña and Nikolas Angelou from DTU. Jan Willem Wagenaar, Gerard Schepers, Arno van der Werff, Erwin Johannes Werkhoven from ECN.

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