DTU Wind Energy

Wind Energy in cold climates
IEA Task 19

December 2016

Final Report EUDP project J.Nr. 64013-0127
December 2016

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Final report EUDP 13-I

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1. Project details

Project title	IEA Task 19 Wind Energy in Cold Climates
Project identification (program abbrev. and file)	64013-0127
Name of the programme which has funded the project	EUDP 13-I
Project managing company/institution (name and address)	DTU Wind Energy Frederiksborgvej 399 4000 Roskilde
Project partners	Vestas Wind Systems A/S
CVR (central business register)	30060946
Date for submission	23-12-2016

2. Short description of project objective and results

The objective of the project is to advance new technologies, stimulate new applications for Danish wind industry, and increase the competitiveness of wind energy in cold climate regions through participation in IEA Task 19. This will include the publication of reports and recommendations, which can be used as guidance for professionals when planning wind farms in cold climates and as the basis for new international standards.

Formålet med projektet er at bidrage til udvikling og udbredelse af ny teknologi og fremme nye anvendelser for dansk vindteknologi. Endvidere fungerer resultaterne (rapporter og anbefalinger) fra IEA Task 19 arbejdet som input til standardiseringsarbejde inden for dette område. Overordnet forøges vindkraftens konkurrencekraft og erstatningen af fossile brændsler med vedvarende energi fremmes.

3. Executive summary

This project made it possible for Denmark to participate in the work of IEA Task 19 – Wind Energy in Cold Climates in the period 2013 to 2016. The Task 19 working period was three calendar years 2013-2015 with a new three-year period 2016-2018. The EUDP project was shifted approximately ½ year allowing time to work on the two main publications of Task 19: The Available technologies report and the Recommended practices report.

The participation included attending meeting and conferences to disseminate information about cold climate issues related to wind energy, and the development of tools and reports to help projects being developed in cold climate regions. In the period 2013-15 nine (9) countries participated:

- Austria
- Belgium
- Denmark
- Finland (operating agent)
- Canada
- China
- Germany
- Sweden
- Switzerland

For the Task 19 period 2016-2018 Norway and UK joined as well.

During the project period the project participants has participated in seven physical Task 19 meetings, and four online meetings, supplemented by informal meetings at conferences focused on cold climate research.

In June 2014 there was a Task 19 meeting in Gaspe, Canada, where Gregory Oxley, Vestas participated and presented a status of the Danish activities. In December 2014 a meeting was hosted by Vestas at their R&D center in Aarhus, Denmark. In February 2015, two members of the project attended the Winterwind conference in Piteå, Sweden. The conference included a session related to the Icewind project, which was chaired by Niels-Erik Clausen, DTU Wind Energy and two presentations by project members relating to work from the Icewind project. In June 2015, a project participant attended the Quebec Wind Energy conference. This conference provided an opportunity to strengthen the international collaboration with the TechnoCentre eolien who hosts this event. On 24-25 June 2015, an IEA task 19 meeting was held in Belgium. Two project participants attended this meeting, which focused on the two reports that will come out from the project at the end of 2015. In December 2015, one project member presented at the Optimising Wind Farms in Cold Climates conference in Helsinki, and the last Task 19 meeting of the period 2013-15 was held in Bad Gastein Austria, where Niels-Erik Clausen participated.

On 26th November 2015 DTU Wind Energy hosted the first National dissemination workshop with 17 partipants. Three wind turbine manufacturers were represented as well as two consultants and one developer. The meeting served to inform the Danish stakeholders working within cold climate applications about the latest achievements and the work of the Task 19 group. Valuable input was received back as input to the next Task 19 working period 2016-18.

The Danish delegation has contributed to 4 sections of the Available Technologies report. The report seeks to provide a clear overview of available solutions and technologies for cold climate wind energy. Furthermore, the Danish project participant Neil Davis has provided significant input language and consistency of both the Available Technologies Report and the Recommended Practices report. Both reports were published in 2016.

4. Project objectives

This project enabled Danish participation in IEA Task 19 – Wind Energy in Cold Climates. This participation included attending meeting and conferences to disseminate information about cold climate issues related to wind energy, and the development of tools and reports to help projects being developed in cold climate regions. As such, the project was largely tied to the structure and priorities of the Task 19 working group. One of the outcomes of this was that there was a larger emphasis placed on WP4 the IEA reporting, and the timing of some of the work packages were shifted fairly significantly.

WP1: Market study: This work package was originally planned to last for most of the project period, but a chance to get a chapter related to cold climate in the BTM world market update study became available late 2012, and the Task 19 working group decided this was an oportunity that could not be missed. This enabled a second updated market study to be carried out during this project as well in 2016.

WP2: Processing/presentation of data and analysis (four tasks):

Task1: Production loss forecasting: Ice on wind turbine blades leads to production losses, however, until now Task 19 has not reported in depth on this phenomenon. Through a number of research projects, among others the Nordic research project Icewind being conducted at DTU Wind Energy, VTT in Finland and at Uppsala University in Sweden state-of-the-art information will be provided to the Task 19 partners.

Task2: Wind tunnel measurement: Experimental investigation of how icing build up on wind turbine blades and meteorological sensors provides important hands-on experience with the icing phenomenon. The presence of ice on these structures is hard to monitor in the field, thus, it is important to investigate it in an icing wind tunnel.

Task3: Ice loading: When ice builds-up on a blade surface it will impact the aerodynamic performance, but also the aeroelastic loadings. The aeroelastic effects are due to changes in shape and weight of the turbine blade. In this task, both of these factors will be considered in order to predict the loads occurring on the turbine. Several icing cases will be used, with different shape and weight. This will be a new area of research for the Task 19 group.

Task4: New ideas: During the duration of the project, new issues related to wind turbines and icing and cold climate applications will be looked at in this task. Examples are new MSc thesis, new research projects, and additional contacts with industry.

WP3: National dissemination: One of the objectives of participating in IEA Task 19 is to disseminate the tools, models and information about cold climate application to the wind industry. In this task, we set up a mailing list with Danish industry to report on the research being reported in Task 19. Furthermore we will disseminate results of the work, especially the Recommended Practices and the State-of-the-Art report, and collect feedback through national events e.g. the annual conference of the Danish Research Consortium for Wind Energy.

WP4: Contribution to IEA reporting: The scope of IEA Wind Task 19 is to gather and disseminate information of wind energy in cold climate, through recommendations and reports, for the use of industry and research dealing with cold climate issues. As a member of the IEA Task 19, our group will contribute to these reports through the dissemination of various tasks in WP2, but also in this work package, by reviewing, editing, and providing feedback to the reports as they are being finalized. This was carried out largely as expected, however, more resources were put into reporting by all IEA Task 19 participants, which took away from some of the other tasks we had planned as mentioned above.

5. Project results and dissemination of results

This project was largely focused on dissemination and collaboration. Therefore, a large part of the results of the project was the attending of meetings, workshops and conferences. In this section we will give brief descriptions of the meetins, workshops, and conferences that were attended by project partipants, the work that was presented, if any, and the outcome of these dissemination tasks.

Task 19 Meetings of the Working Group

Date	Location	Topic of meeting
17-18 October 2013	Beijing+Mianyang, China	Validation of IEA Ice Classification, Offshore sea ice loads
8-9 June 2014 (Québec's Wind Energy Conference 2014)	Gaspé, Québec, Canada	OA change Wallenius -> Lehtomäki. AT report chapter responsibles & Ice induced loads on turbine design and certification
September 2014	Virtual meeting	AT report: first draft content per section
1-2 December 2014	Vestas, Aarhus, Denmark	Validation of IEA Ice Classification, Standardized production loss method & Ice throw risk mitigation
3-4 February 2015 (Winterwind	Piteå, Sweden	Main cold climate challenges

2015)		
24-25 June 2015	Antwerp, Belgium	Ice loads on offshore foundations, Forecasting of wind power and icing & Finalization of RP update
Fall 2015	Virtual meeting	SotA report status
17-18 Dec 2015	Bad Gastein, Austria	Finalization of SotA –report and Task Final report
10 Feb 2016	Aare, Sweden	Kickoff Task 19 period 2016-19 Work program and planning
April 2016	Virtual Meeting	Market study update, IEC work, plan WS#1 for Lender's Technical Advisors @EWEA2016
15-16 June 2016	Bristol, UK	Finalize updated market study, IEA ice class validation, IEC work

WP1 Contribution to market study

The first task of the working group was the assessment of market size for wind turbines in cold climates. The results were divided in status at the end of 2012 and forecasted capacity five years ahead.

Table 1: Total installed capacity in areas with cold climates [Navigant Research 2013]

Cumulative installed capacity by end of 2012 [MW]			Forecasted capacity 2013-17 [MW]		
Low temperature	Light icing: safety risk, some economic risk	Moderate to heavy icing: economic and safety risk	Low temperature	Light icing: safety risk, some economic risk	Moderate to heavy icing: economic and safety risk
18 945	41 079	11 478	20 025	22 083	8 003
Total 69 000[7]			**Total 45 000 – 50 000**		

Note 7: The total capacity is less than the sum of individual capacities because some of the sites have both low temperatures and icing conditions.

The marked study was published by Navigant Research as an attachment to the publication World Market Update 2012 (published in spring 2013). It has since been used extensively by wind energy professionals. In spring 2016 the market study was updated.
By the end of 2015, the global wind capacity operating in cold climates is estimated to 127 GW; however, only a portion of this wind turbine fleet is designed for icing and low temperature conditions. Between 2016-2020, an additional 60 GW of new installations is forecasted (12 GW of annual growth) to the global cold climate market making

it truly a substantial share of total global wind energy installations. The updated market figures were published in WindPower Monthly Magazine August 2016.

WP2 Processing and presentation of data and results

Task1: Production loss forecasting: Icing leads to production losses from wind turbines, however, until recently Task 19 has not reported in depth on this phenomenon. This task was carried out largely as planned and through this project, the research at DTU in this area was disseminated to larger audience, and additional research has been initiated thanks to this dissemination work. The basis was research projects in the Task 19 member counties, among others the Nordic research project Icewind at DTU Wind Energy, VTT in Finland and at Uppsala University in Sweden. Furthermore the Icewind project had partners from Norway and Iceland (not Task 19 members).

Task2: Wind tunnel measurement: Experimental investigation of icing of wind turbine blades and meteorological sensors provides hands-on experience with the icing phenomenon. The presence of ice on these structures is hard to monitor in the field, thus, it is important to investigate it in an icing wind tunnel. Tests were done on an airfoil section to investigate the effect of ice on aerodynamics at different temperatures and angles of attack. One of the objectives of Task 19 was to develop a sensor classification. Due to the increased priority in reporting for the Task 19 working group, the sensor classification part of this work was put on hold during this period. However, there was a masters project at DTU that focused on blade icing using the Force Technology icing wind tunnel. This work was disseminated to the Task 19 working group and presented at Winterwind 2015.

Task 3 Ice loading: When ice builds-up on a blade surface it will impact the aerodynamic performance, as well as the aeroelastic loadings. The aeroelastic effects are due to changes in shape and weight of the turbine blade. In this task, both of these factors was considered in order to predict the loads occurring on the turbine. This will be a new area of research for the Task 19 group, and will provide valuable input to the IEA reporting.

Two different ice types, Rime and Glaze, with NACA 0015 airfoil are investigated at the Climate Wind Tunnel at Force Technology. Aerodynamic characteristics such as lift, drag, and pitching moments, were measured. Also extra weight due to ice was measured. Table 2 shows the list of measurement cases.

Table. 2. NACA0015 test conditions for setting

	Accretion time(min)	Angle of attack(deg)	Chord(m)	Air speed (m/s)	Air temp. (°C)	LWC (g/m³)	MVD (μm)
rime	60	0	0.3	15	-5	0.4	45
	60	4	0.3	15	-5	0.4	45
	60	8	0.3	15	-5	0.4	45
	60	12	0.3	15	-5	0.4	45
glaze	40	0	0.3	25	-1	0.4	34
	40	4	0.3	25	-1	0.4	34
	40	8	0.3	25	-1	0.4	34
	40	12	0.3	25	-1	0.4	34

Figure 1 shows an experimental result for a glaze ice condition at 4deg angle of attack.

Figure 1: Glaze ice case at 4deg angle of attack

Table 3 shows the lift, drag, pitching moment and weight from the case shown above and figure 2 shows the airfoil shape trajectory with ice.

Table3: measurement condition and results

AoA [°]	V [m/s]	T [°C]	Acc. Time [min]	MVD [μm]	Lift [N]	Drag [N]	Moment [Nm]	Weight [N]
4	25	-1	40	34	146.7	11.47	1.91	42.97

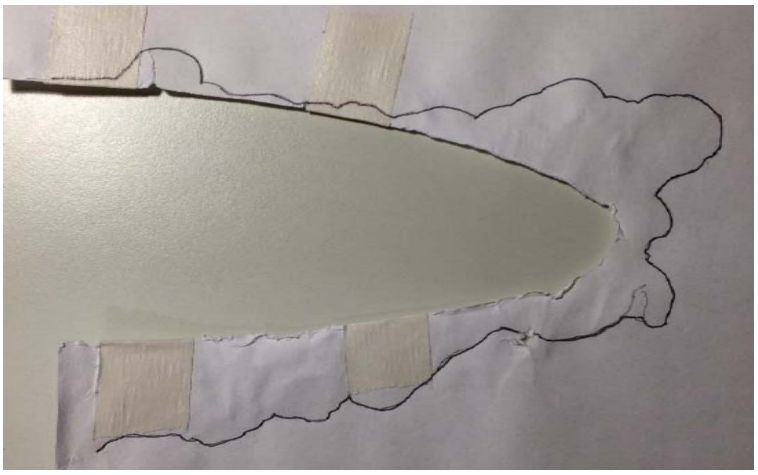

Figure 2: Airfoil trajectory with ice

The obtained information will be compared with the numerical simulation data.

Task4: New ideas: Two MSc projects were carried out: One on modeling ice shedding from wind turbine blades; another on ice build-up on a blade profile. These topics were included in the IEA reporting (WP4). Another idea that came up during the project period was the development of an open source IEA Task 19 Ice Loss code. This was based on a method for detecting ice on a wind turbine using SCADA data. The Danish project members helped in designing and verifying the method, and gave advice on the development of the code.

IWAIS Conference September 2013, St. Johns Canada

The 15th International Workshop on Atmospheric Icing of Structures was held in St. John's Newfoundland and Labrador, Canada. This three-day workshop is held every two years and brings together a diverse group of researchers studying the icing pheonomenon. There was a half-day session focused on Icing in Wind Energy during which three of the Danish project participants presented. In addition, presenations on power line icing, light house icing and hydrophobic structures were presented allowing for cross-diciplinary discussions and collaboration. There were over 55 presenations in total, with more than 70 participants from 13 countries that attended the event. At this conference, models for atmospheric icing were highlighted that had not been used before in wind energy, and these were explored by the Danish delegation after the conference as part of WP2 Task 1.

Project member Niels-Erik Clausen gave presentation at the conference on behalf of the Task 19 working group with the title: *Recommended Practices for Wind Energy in Cold Climates: Resource Assessment and Site Classification*.

Onshore Operations and Maintenance Forum, June 2013 in Hamburg

Project member Neil Davis was invited to give a general talk on icing related issues at the Onshore Operations and Maintenance forum. This forum had over 40 participants, and was largely focused on the maintence of onshore wind farms. Neil's presentation covered the availible technologies and best practices in operating a wind farm in cold climates. The feedback to the talk was quite good, and many of the participants encouraged an icing related forum to be held in the future. This lead to the creation of the Optimising Wind Farms in Cold Climates conference that has been held annually since 2014.

72nd American Helicopter Society Annual Forum and Technology Display, 17-19 May 2016 Palm Beach Florida

AHS conference is an international conference related to the rotorcraft and wind turbines. There are 1200 attendees and approximately 300 presentations in the conference. There were four presentations strongly related to the ice prediction using the CFD and measurements (see the lists below). Two presentations are about developing a rotor icing prediction tool. Both show that the tools are able to predict ice shape accurately during hovering and forward flight conditions under the Rime, Glaze, and Mixed. There was a presentation about the experimental study about Ice shedding during the hovering condition using high-speed camera. From the conference, we expanded our networks and got an opportunity to hear the state-of-the art research activities in rotor blades.

1) Aerodynamic Performance Analysis for Iced Rotor based on New Three-Dimensional Rotor Icing Model (151) Xi Chen, Nanjing University of Aeronautics and Astronautics†*; Qi-jun Zhao, Nanjing University of Aeronautics and Astronautics
2) Rotor Blade Ice Length Prediction of Shed Ice (68) Jared Soltis, Pennsylvania State Universty†*; Jose Palacios, Pennsylvania State Universty
3) Icing of ducted tail rotor based on design of ILX-27 unmanned helicopter (154) Pawel Gula , Institute of Aviation†; Adam Dziubiński, Institute of Aviation*; Piotr Neckarz , PZL Mielec A Sikorsky Company*
4) for Rotorcraft Icing (238) Lakshmi Sankar, Georgia Institute of Technnology†*; Jeewoong Kim, Georgia Institute of Technnology; Andrew Wissink, U.S. Army Aviation Dev Dir - AFDD; Jeremy Bain, Bain Aero LLC; Richard Kreeger, NASA Glenn Research Center

Wind Power Monthly Optimising Wind Farms in Cold Climates Helsinki 10-11 December 2015

Project member Neil Davis gave a talk on combining model and observational data to better understand turbine icing, which focused on four outstanding questions. This relied on the Task 19 IceLossMethod and the icing production loss model discussed in WP2 Task 1. The talk was quite well received and there was quite a lot of discussion with industry during the event about the results. The results found and presented in this meeting have been included in an ongoing project with Vestas to improve the ice loss detection method. The rest of IEA Task 19 also had a large presence at this event, and there was good feedback from the more than 80 participants about the 2016-2019 working plan that the Task 19 group had put together.

Wind Power Monthly pre-forum workshop: The bankability of projects in sites affected by cold climates 18th April 2016, Chelsea Football Club, London, UK

Project members Mark Zagar and Neil Davis were approached to organize a preforum workshop focused on cold climate wind energy ahead of the Wind Power Monthly Resource Assessment Workshop. This was a ½ day workshop where five topics were ad-

dressed through introductory presentations by the hosts, followed by three rounds of group discussions which included a sharing of common conclusions and important points. The topics covered all phases of a wind energy project, and touched on the most significant concerns for these sites. As part of the workshop, we collected feedback from the community to help guide the Task 19 work in the future and better understand the challenges that are being faced on real sites.

WP3 National dissemination workshop 26 November 2015 at DTU Wind Energy Risø Campus

On 26th November 2015 DTU Wind Energy hosted the first National dissemination workshop with 17 partipants. Three wind turbine manufacturers were represented as well as two consultants and one developer. The meeting served to inform the Danish stakeholders working within cold climate applications about the latest achievements and the work of the Task 19 group.
There were 4 sessions during the day:
1) Status of IEA task 19
2) Research talks
3) Industry talks
4) Icing issue and challenges

One of the objectives of participating in IEA Task 19 is to disseminate the tools, models and information about cold climate application to the wind industry. In this task, we set up a mailing list with Danish industry to report on the research being reported in Task 19. Furthermore we informed about the results of the work, especially the Recommended Practices and the State-of-the-Art report, and collected feedback.

In total, 13 presentations were presented. The workshop was finished with panel discussion about the cold climate research agenda. From the workshop six very important topics were prioritized; 1) ice detection systems and methods, 2) data for cost/benefit calculations of de-icing, 3) measure icing potential at a site, 4) definitions right of icing event and when to stop for O&M, 5) considering icing loads as a design load case, and 6) method to calculate AEP at cold climate site from model data. Valuable input was received back as input to the next working period 2016-18.

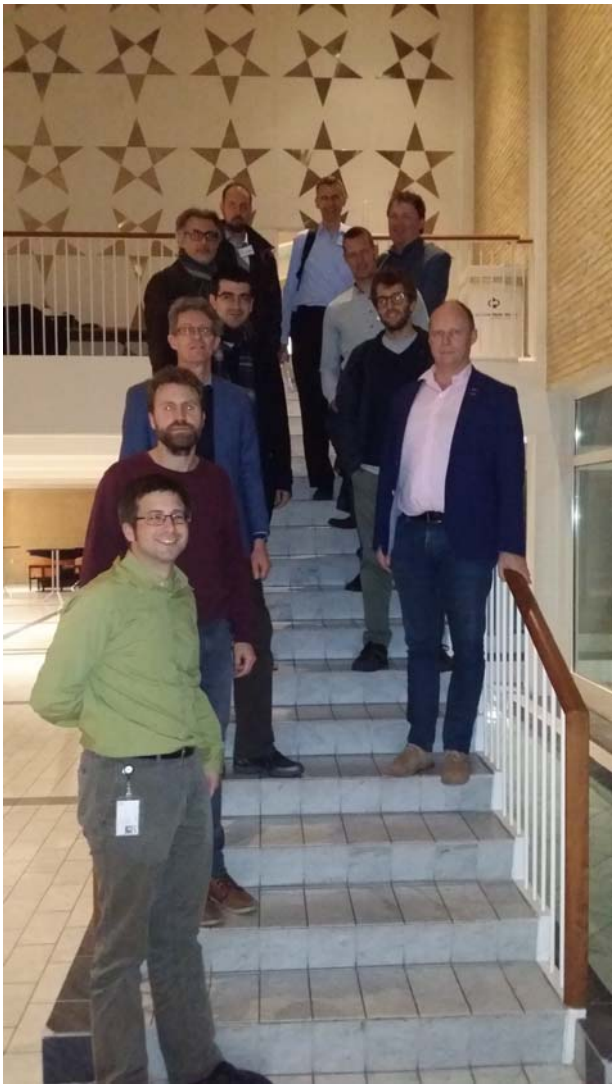

Figure 1: Group photo from the National Dissemination workshop at Risø 26 November 2015

WP4 Contribution to IEA reporting

The two main publications summarising and documenting the work of the working group are the Available technologies report and the Recommended practices report.

Available Technologies Report

The Available Technologies report was the most important publication from IEA Task 19 during this period. It was a complete overhaul of the previous State of the Art report, this was decided to be done to help separate the previous State of the Art report from the Recommended Practices report. The goal of the Availaible technologies report was to provide a reference report that would allow for developers, consultants and engineers to quickly and easily find potential solutions to the challenges found in cold climate wind energy. Each section had a short description of the solution, laying the what, why, and how of the technology, along with a table that gave an overview of the available solution providers and references evaluating or describing the solution.

The Danish participants had a large contribution to this report, as the main authors of 4 sections of the report (Icing Maps, Meteorological models for icing, Empirical ice accretion models, and Ice removal models), and assisting in the writing of 3 other sections (Ice detection, Icing forecasts, and Icing Wind Tunnels). Additionally, Neil Davis a project participant proofread and edited the entire document for language consistency.

Recommended practices report

The recommended practices report had a smaller update than the Available Technologies report, with small updates to sections where new research had come out, and to reference the new Available Technologies report. This report is designed to provide the best recommendations for cold climate wind farms, reduce risks related to cold climate issues, and accelerate the growth of wind energy in cold climates. The document addresses many issues that affect a wind energy project in cold climate locations.

The Danish participants updated Chapter 7 (Energy Yield Calculations), and again Neil Davis carried out the proofreading and edited the entire document for language consistency.

6. Utilization of project results

As the project is mainly a network activity the result of the project is mainly the publications and the software for estimation of ice losses of a wind farm.

From the Task 19 website analytics we have registered 400 downloads of the Available Technologies report (until June 2016) and 28 users of the software to calculate ice losses from a wind farm.

7. Project conclusion and perspective

Based on the result and input at the National dissemination workshop 26 November 2015 with participation of representatives of the Danish Wind Industry it was decided to continue the work of IEA Task 19 for the next three-year period 2016-19. The Danish contribution is funded by EUDP grant Jnr. 64016-0077.

Annex 1 Agenda for Task 19 dissemination meeting

Wind turbines and ice – status of IEA Task 19

Date: 26 November 2015

Venue: DTU Wind Energy, HH Koch meeting room, building 112, Risø Campus

Agenda

10:00-10:10 Welcome, Niels-Erik Clausen, DTU Wind Energy

10:10-11:10 Status of IEA task 19 work

- Available technologies report, Neil Davis, DTU Wind Energy
- Ice detection from SCADA data, Neil Davis, DTU Wind Energy
- Ice throw, Hamid Sarlak Chivaee, DTU Wind Energy

11:10-11:30 Coffee break

11:30-12:30 Research talks

- Icing wind tunnel at FORCE, Holger Koss, DTU BYG
- Project development with focus on cold climate, Niels Baden Rørholm, K2 Management
- Icing detection via vibration based CMS, Alexandros Skrimpas, Brüel & Kjær Vibro

12:30-13:30 Lunch

13:30-14:30 Industry talks (what are the critical issues?)

- Jonathan Peter Carboon, Siemens Wind Power
- Impacts of spatial and temporal icing variability on the planning and operation of wind farms, Mark Žagar, Vestas Wind Systems
- Wind turbines and ice - The developers and owners perspective, Ben Martinez, Vattenfall

14:30 -15:00 Coffee break

15:00 - 15:45 Icing issues and challenges (DTU Wind Energy representatives)

- Ice forecasting & siting – current challenges, Neil Davis
- Ice loading – current status, Torben Larsen
- Scaling of ice measurements, Taeseong Kim
- Deicing – state of the art methodologies and limitations, Taeseong Kim

15:45 -16:50 Wrap up and input to a cold climate research agenda

Panel discussion

16:50-17:00 Close of meeting

Participation in the workshop is free.

Sign up by sending a mail to Diana Kiler diki@dtu.dk latest 20 November. If you are not able to come, send us a mail the day before. There is a no-show fee of 500 DKK.

Annex 2 List of participants at dissemination meeting

List of participants

First name	Last name	Company	E-mail
Jonathan Peter	Carboon	Siemens Wind Power	jonathan.carboon@siemens.com
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