DTU Wind Energy

Wind Energy in cold climates
IEA Task 19

December 2019

Final Report EUDP project J.Nr. 64016-0077
December 2019

By Niels-Erik Clausen, Neil Davis, Hamid Chivaee, Mark Kelly and Taeseong Kim, DTU Wind Energy

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Final report

1. Project details

Project title	Wind energy in cold climate - IEA Task 19
Project identification (program abbrev. and file)	J. nr. 64016-0077
Name of the programme which has funded the project	EUDP 2016
Project managing company/institution (name and address)	DTU Wind Energy
Project partners	None
CVR (central business register)	30060946
Date for submission	30 December 2019

2. Short description of project objective and results

The objective of the project is to advance new technologies, share state-of-the-art knowledge, 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. In the previous three-year period the project participants participated in a total of ten meetings and conferences.

Formålet med projektet er at bidrage til udvikling og udbredelse af ny teknologi og fremme nye anvendelser for dansk teknologi for vindenergi i koldt klima. Resultaterne (rapporter og anbefalinger) fra IEA Task 19 arbejdet er desuden et vigtigt input til standardiseringsarbejdet inden for dette område. Overordnet bidrager IEA Task 19 gruppens arbejde til at øge vindkraftens konkurrenceevne i koldt klima og derigennem at fremme erstatningen af fossile brændsler med vedvarende energi. I den forløbne 3-års periode 2016-19 har Task 19 gruppens medlemmer deltaget i ti møder og konferencer.

3. Executive summary

The funding through the present EUDP project made it possible for Denmark to participate in the work of IEA Task 19 – Wind Energy in Cold Climates in the period 2016 to 2019. The Task 19 working period was three calendar years 2016-2018 with a new three-year period 2019-2021. The EUDP project did not follow calendar years but was shifted approximately ½ year allowing time to work on the two main publications at the end of the Task 19 period: 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 2016-18 eleven (11) countries participated (in bracket the name of the partner):

- Austria (Energiewerkstatt)
- Belgium (OWI-Lab)
- Canada (Nergica)
- China (Chinese wind power association)
- Denmark (DTU Wind Energy)
- Finland (operating agent is VTT)
- Germany (Fraunhofer IWES)
- Norway (Kjeller Vindteknikk)
- Sweden (WindREN)
- Switzerland (Meteotest)
- UK (DNV-GL)

The project was mainly focused on networking, collaboration and dissemination. Therefore, a large part of the results of the project was preparation for- and attending to meetings, workshops and conferences. In this section, we will give brief descriptions of the meetings, workshops, and conferences that were attended by project participants, and the work that was presented.

During the project period the project participants has participated in five physical Task 19 meetings, and a number of online meetings, supplemented by other meetings related to cold climate applications e.g. at Winterwind and WindEurope conferences. Below is list of the meetings:

<u>London 18 April 2016</u>

Neil Davis participated in the WindPower Monthly event 18th April 2016, at Chelsea Football Club, London, UK as co-chair of the event. The title of the event was “The bankability of projects in sites affected by cold climates”.

Bristol, UK 15-16 June 2016
Niels-Erik Clausen and Neil Davis participated in the regular Task 19 meeting hosted by DNV-GL at their office in Bristol. Among the topics discussed was update of the Market study and review of the recommended practices report.

Oslo 12-13 December 2016
Taeseong Kim participated in the IEA Task 19 meeting hosted by Statkraft. Topics were guidelines for performance evaluation of ice protection systems and blind test of ice maps.

Göteborg, Sweden 3-4 April 2017
Niels-Erik Clausen participated in the Swedish conference "Vindkraft-forskning I focus" hosted by the Swedish Energy Agency, Vindforsk, Stand up for Wind and Swedish wind power technology Centre. The Swedish wind energy market is large and a significant part of it is located in areas with icing a large part of the year and the conference reflected that.

Åre, Sweden Winterwind 5-7 February 2018
Hamid Chivaee participated in the specialised conference on wind energy in cold climates and presented orally the paper: "Numerical simulation of ice throw from horizontal-axis wind turbines".

Andermatt, Switzerland 12-13 February 2018
Taeseong Kim participated in the Task 19 meeting in Switzerland. On the agenda was the ice throw guidelines and going over all ongoing activities of Task 19.

Figure 1. The IEA Task 19 meeting participants in Andermatt

Helsinki, Finland 20-21 September 2018

Niels-Erik Clausen and Hamid Chivaee participated in the Task 19 meeting in Helsinki at VTT office. The group worked on finalizing the deliverables for the previous three-year period: The ice throw guidelines, the Available technologies report and the proposal for extension of the Task 19 group as well as the work plan for the new period.

WESC 2019, Cork, Ireland 17-20 June 2019

A talk entitled "Iced airfoil aerodynamics at low Reynolds numbers" was presented by Hamid Sarlak (DTU Wind Energy) in the Turbine Technology theme at the Wind energy science conference 2019 in Cork at the University college Cork in a session dedicated to icing and wind turbines. Although presence of cold climate topics was not as significant at this conference as the other traditional areas, good discussions at the session and in the breaks made it possible to raise awareness of wind energy in cold climate for a large audience (800 participants).

IWAIS, Reykjavik 23-28 June 2019

Chankyu Son participated at the International workshop of atmospheric icing of structures (IWAIS) 2019 in Reykjavik and gave an oral presentation of the WISE code with the title "Development of Three-Dimensional Icing Simulation Code for Wind Turbines".

On September 3rd & 4th 2019 DTU Wind Energy was hosting the regular IEA Task 19 meeting in Lyngby with 15 participants. In the meeting, the participants updated each other on ice-related activities in their own country and we ran through an update of activities on the Task 19 work plan: Warranty guidelines, Market study and icing forecast fact sheet. The group visited the climate wind tunnel at Force, where icing experiments is carried out.

Figure 2. The IEA Task 19 group at the annual meeting 3-4 September 2019

4. Project objectives

Cold climate areas have gained more focus recently in attempts to reach higher wind energy targets. Wind resources in cold climate areas are often good, and combining these resources with a - typically - low population density makes cold climate areas attractive for wind development. Increased experience, knowledge, and improvements in cold climate technologies have made projects in cold climates more competitive compared to standard, milder climate wind projects.

The objective of this project is to contribute to the development of new cold climate technology and stimulate new applications of Danish wind technology. IEA Task 19 is an international network focused on cold climate issues. Their work will form the basis for new international standards in this area through the publication of recommendations and reports; increasing the competitiveness of wind and accelerating the replacement of fossil fuels. The work is organized in 5 work-packages (WPs): WP0: Coordination; WP1: Update of market study; WP2: Processing/presentation of data and analysis; WP3: National dissemination; and WP4: Contribution to IEA reporting. In the previous Task 19 period (2013-16), a market study of cold climate wind farms was created in collaboration with the BTM world market update

released in 2012. During this period, an updated market study was created and used to increase the interest of the industry, especially the wind turbine manufacturers, in the cold climate market, and to help project developers when discussing financing their projects by giving the cold climate projects a less exotic profile.
The second work-package consists of four tasks covering main research topics for IEA Task 19: ice throw, uncertainty quantification for ice phenomenon, an updated ice detection method using SCADA data, and ice loading. The results will be presented at five Task 19 workshops and form the basis for published guidelines and reports.
The tools, models, and general experience about cold climate wind energy will be disseminated to the Danish wind industry, in WP3, and WP4 will include work on updating the best practices and available technologies reports.

5. Project results and dissemination of results

As outlined above in section 1.4 the project was structured in five work packages: WP0 to WP4. The work in the individual tasks is summarized below:

WP1 - Updated market study for cold climate applications:
At the beginning of the project the market study for wind energy in cold climates was updated.

By the end of 2015, the global wind capacity operating in cold climates was approximately 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 a substantial share of total global wind energy installations. This means that the stimulus for further development of wind power projects and technology in cold climate areas is strong. See figure 3.

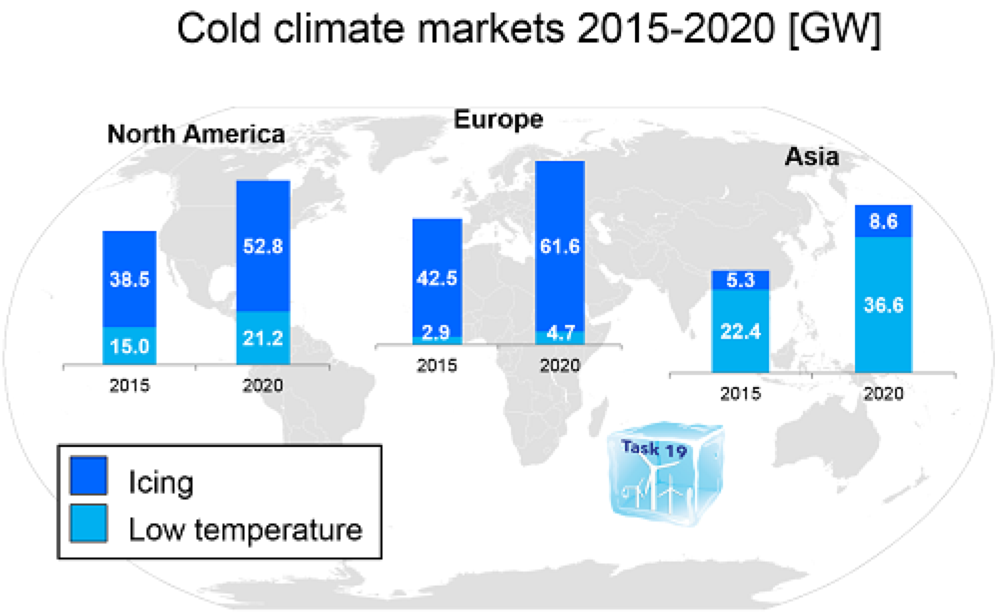


Figure 3. Overview over Global market potential (GW) for cold climate applications. Risk of icing of turbine blades is shown with dark blue, while low temperature climates are shown with light blue.

However, icing and low ambient temperatures pose special challenges for wind energy projects. Icing of wind turbine rotor blades reduces energy yield, may shorten the mechanical life of turbines, and increases safety risk due to potential ice throw. Low temperatures can affect a turbine's mechanical lifetime if they are not taken into account in turbine design by using appropriate materials, oil heating etc..

To meet the increasing demand for cold climate installations, turbine manufacturers have developed technical solutions for low temperatures of their standard turbines. First-generation commercial solutions for de-icing wind turbine blades have also entered the marketplace. R&D activities have been conducted in a number of countries to master the difficulties that atmospheric icing and low temperatures create. These research activities aim to improve the economics of wind power at new areas around the globe. The coming years are important to validate the technology and knowledge, and to analyze the performance of the adapted technologies arising from the wind energy projects going on, as well to develop next generation technology.

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

Task1 - Ice throw

During the project, the existing code at DTU Wind Energy to calculate throw of ice and wind turbine blade fragments was further developed. The code is now integrated with a Monte-Carlo simulation package to perform massive simulations and a new user-friendly interface (GUI) was developed (see Figure 4) and we aim at further developing the code by adding risk assessment elements and making it ready for a future release as an open source toolbox.

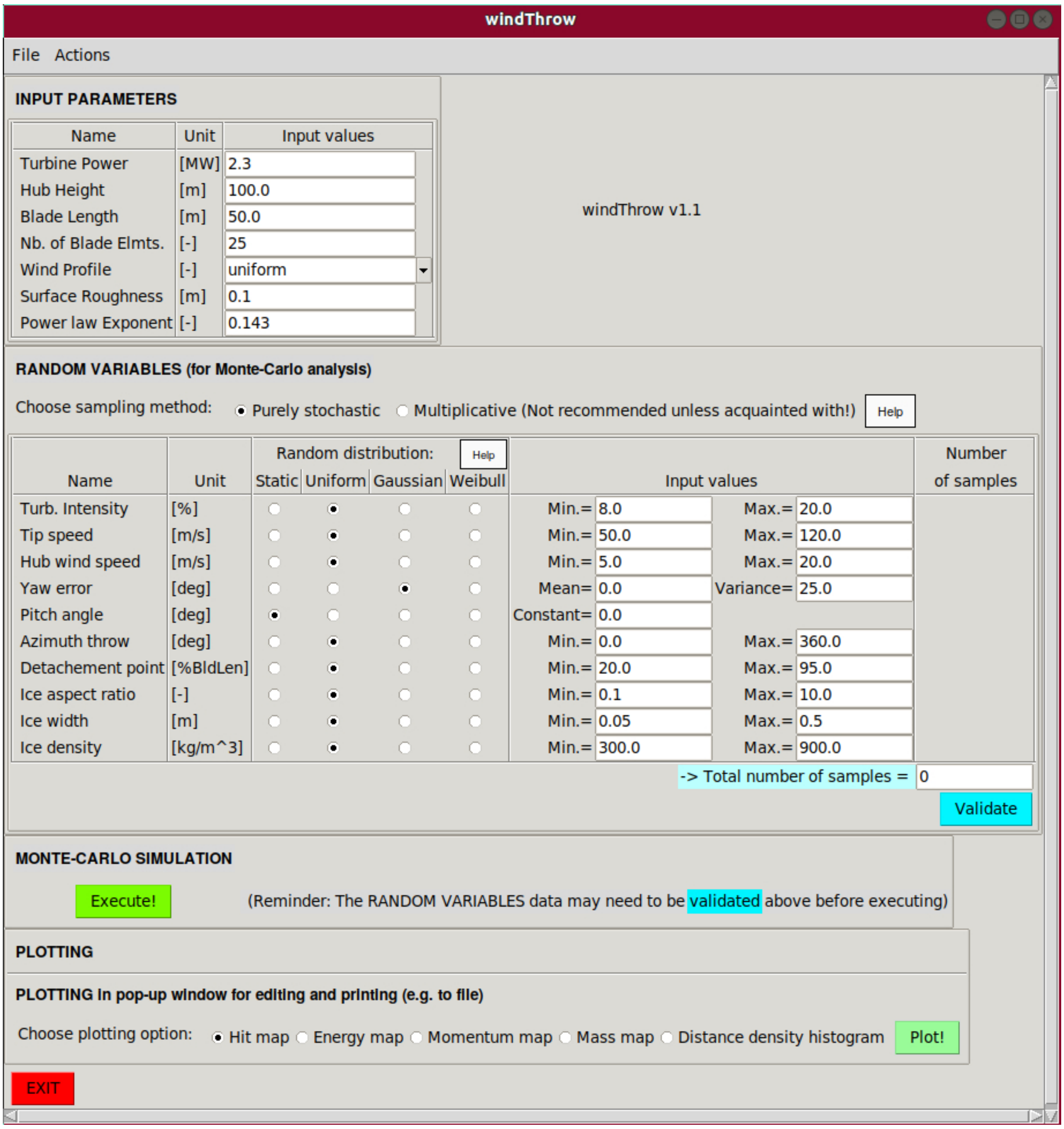


Figure 4. Graphical user Interface (GUI) of Ice-Throw software

Task2 - Probabilistic atmospheric characterization, towards uncertainty quantification

The ideal case is built, whereby statistical characterization and sensitivity analysis of relevant icing related variables and parameters can be carried out; this supports uncertainty quantification (UQ). In order to characterize the uncertainty related to the multivariate icing parameter space it was planned to use data from meso-scale (WRF) runs from the New European wind atlas project (http://www.neweuropeanwindatlas.eu/). However, the analysis of the runs related to icing conditions was delayed beyond the timeline of the present project. Instead, we leveraged our parallel work and experience with uncertainty in wind resources and loads, along with our position in the emerging IEC 61400-15 standard on uncertainty, to both disseminate this knowledge to the industry as well as to impact this new standard—which treats icing as well as uncertainty of measurements of parameters key to icing.

Task3 - Update and validation of open-source T19IceLossCode

During this period, DTU worked with VTT to test and release version 2.2.2 of the Task 19 code to calculate Ice losses. This version included the ability to analyze ice protection systems (IPS), providing both the energy required to run the system, and the production losses during periods where the IPS was working. As part of this release, the code was given the BSD 3-clause license and released on github[1]. Additionally, a simple setup.py file was created to allow users an easier path for installation.

Task4 - Ice loading

Icing simulation: In this task three topics have been investigated: 1) development of 2m long NACA 0012 wing for cold climatic wind tunnel test, 2) development of ice detection method with artificial intelligent technique, and 3) development of a 3D icing shape prediction code.

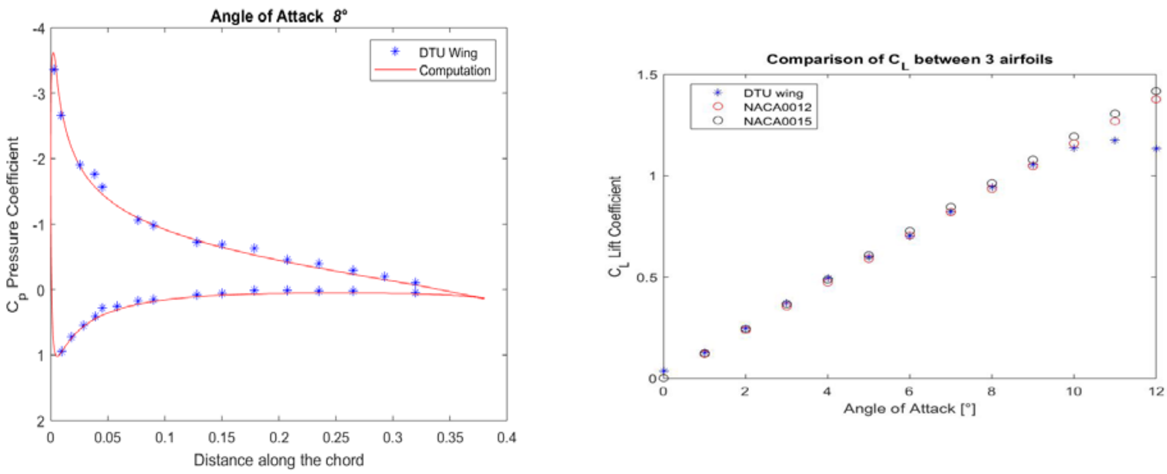
First, a NACA 0012 airfoil-based wing was manufactured for investigating the ice loads under the different ice conditions at the cold climatic wind tunnel. The wing consists of balsa and plywood. It is coated with epoxy and glass fiber to strengthen the wing for the aerodynamic and ice loads in the climate wind tunnel. Inside the wing, 36 pressure tabs are implemented to measure the pressure distributions. The total length of wing is 2m. The pressure distributions, lift, and drag forces are validated with CFD for different angle of attacks.

[1] https://github.com/IEAWind-Task19/T19IceLossMethod

(a) Wing skin and inner structure

(b) After assemble the wing into the climatic wind tunnel

Figure 5. NACA 0012 wing for cold climatic wind tunnel test



(a) Pressure distribution comparison at AoA 8deg.

(b) Lift coefficient comparison between measurement and CFD calculation

Figure 6. Validation the NACA 0012 wing with CFD

Second, a modal based ice detection method with artificial intelligent technique is developed. In this study, the 1st flapwise and 1st edgewise natural frequencies are used as training data. In order to create enough dataset, various added mass cases along 1m hollow aluminum beam are considered. In total, 340 data sets are measured. In this research, Artificial Neural Network (ANN) model is applied to train the data. The beam is divided in 3 different sections, where calibrated weights are placed on the sections. The ANN model is able to predict the ice mass with the least error near the tip ranging from 1% to 15%. Our goal is to train the ANN model for the NACA 0012 wing in real icing conditions in the climate wind tunnel and use further expand the training process using mode shapes.

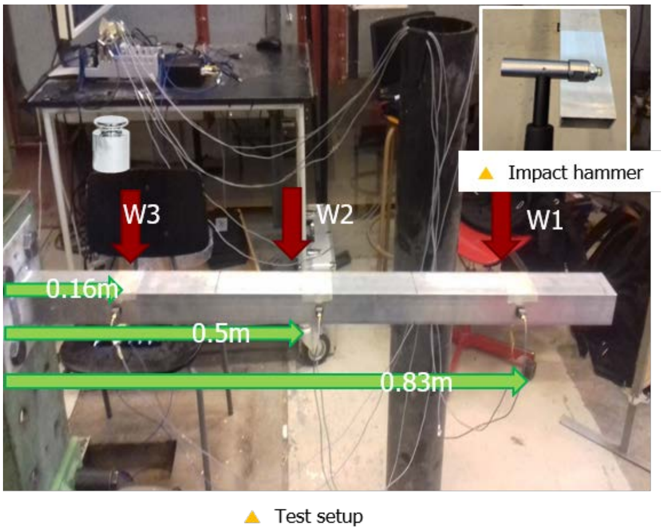
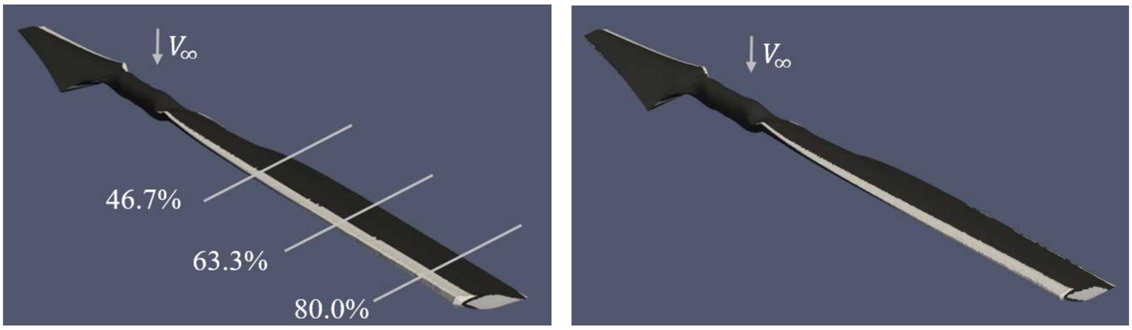


Figure 7: Modal test setup with 1m hollow aluminum beam with 3 sections

Last, the high-fidelity 3D icing simulation code named WISE (Wind turbine Icing Simulation code with performance Evaluation) have been developed. WISE contains four modules: aerodynamic field, droplet field, thermodynamic, and grid-regeneration modules. To consider the rotation of wind turbines, a Moving Reference Frame (MRF) is applied for both aerodynamic and droplet fields. This study discover that the MRF method is essential for the wind turbine icing simulation. For the rime and glaze ice conditions, the icing limits, maximum thickness, and its location are well predicted by WISE compared with FENSAP-ICE while the simulation without MRF method overestimates the icing limits and maximum thickness.



(a) Rimce ice condition (b) Glaze ice codntiion

Figure 8. The ice accretion shapes obtained by WISE on NREL Phase IV

IWAIS is a multidisciplinary conference for atmospheric Icing on structures. The conference is held bi-annually. Materials, mechanical, and chemical engineers as well as meteorologist attended the conference during 23-28 June 2019 in Reykjavik. Fifty-five speakers and nine posters were presented at IWAIS 2019. The conference is multidisciplinary, however most papers are related to either wind turbine icing or icing of power lines.

Chankyu Son participated at IWAIS 2019 and gave an oral presentation of the WISE code with the title “Development of Three-Dimensional Icing Simulation Code for Wind Turbines”.

WP3 - National dissemination

A national workshop was held Thursday 26 September 2019 at DTU Risø Campus. We invited representatives from the wind industry - both manufacturers, developers and consulting companies. At the workshop, DTU presented the status of IEA Task 19’s work on Performance Warranties, the Ice Loss Method update, and the international recommendations for icefall and ice throw risk. In addition, there were four presentations about ongoing research in the cold climate field, a presentation about the inclusion of cold climate related issues in the ongoing IEC standards process, with a particular focus in the IEC61400-15 standard. Finally, we presented the work-plan for the 2019-2022 period of the IEA Task 19 group, and got input from the industry participants on what they would be most interested in learning. The agenda of the meeting is attached as appendix 2.

After the meeting, we were contacted by several industrial players about following up on the items presented in the workshop, with a particular interest in the T19 Ice Loss Code. All documents from the meeting was shared with additional ten persons interested in participating in future meetings. See appendix 3.

Figure 9. National dissemination meeting at Risø 26 September 2019

WP4 - Contribution to IEA reporting

IEA Task 19 released several key documents during the period of this project, this included second editions of the Available Technologies for Wind Energy in Cold Climates, and IEA Wind TCP Task 19 Recommended Practice: Wind energy Projects in Cold Climates, for which DTU provided updates to chapters on ice forecasting, ice mapping, and ice loss modelling.

In addition, two new documents International Recommendations for Ice Fall and Ice Throw Risk Assessments and Performance Warranty Guidelines for Wind Turbines in Icing Climates were published during this period. DTU provided insight into the Ice Throw portion of the International recommendations.

6. Utilization of project results

As the project is mainly a network activity, the results of the project are mainly the publications and the software for estimation of ice losses of a wind farm. Furthermore, results of the ice throw study and the software package will eventually be helpful for the developers, owners as well as researchers who can quantify the risks associated with ice throw in a more accurate way and using detailed aerodynamic models.

7. Project conclusion and perspectives

Based on the interest and input at the National dissemination workshop 26 September 2019 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 2020-22. The Danish contribution is funded by EUDP grant J.nr. 64019-0515.

Annex 1 Relevant links

LINK to IEA Task 19 homepage:
https://community.ieawind.org/task19/home

Annex 2 National dissemination meeting 26 Sept 2019

Cold Climate Wind – status of IEA Task 19

Date: 26 September 2019

Venue: DTU Wind Energy, Poul La Cour meeting room, building 125, Risø Campus

Agenda

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

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

- Performance Warranty Guidelines, Neil Davis, DTU Wind Energy
- Ice detection from SCADA data, Neil Davis, DTU Wind Energy
- International Recommendations for Ice Fall and Ice throw risk, Hamid Sarlak Chivaee, DTU Wind Energy

11:10-11:30 Coffee break

11:30-12:30 Cold Climate related talks

- Development of multi-channel array ice detection sensor, Taeseong Kim, DTU Wind Energy
- Development of WISE (Wind turbine Icing Simulation code with performance Evaluation), Chankyu Son, DTU Wind Energy
- Aspects in experimental simulation of in-cloud icing of structures, Holger Koss, DTU Byg

12:30-13:30 Lunch

13:30-14:30 Cold Climate related talks

- Optical MEMS sensors for real-time wind turbine blade diagnostics and ice detection, Kasper Reck-Nielsen, CEKO Sensors
- Icing in the IEC Wind Energy standards: status and ongoing work, Mark Kelly, DTU Wind Energy
- Aerodynamic Effect of Icing/Rain on Super-Hydrophobic Surfaces, Valery Okulov, DTU Wind Energy

14:30 -15:00 Coffee break

15:00 - 15:45 DTU's cold climate work plan

- Introduction to Task 19 application (10 minutes)
- Discussion

15:45 -16:00 Wrap up, Niels-Erik Clausen DTU Wind Energy

16:00 Close of meeting

Participation in the workshop is free.

Annex 3 List of participants at Nat. dissemination meeting

Cold Climate Wind – status of IEA Task 19

Date: 26 September 2019

Venue: DTU Wind Energy, Poul La Cour meeting room, building 125, Risø Campus

List of participants

- Michael D. Pedersen, European Energy
- Kasper Reck-Nielsen, CEKO sensors
- Neil Davis, DTU Wind Energy
- Taeseong Kim, DTU Wind Energy
- Kostas Karachalios, DTU Wind Energy
- Chankyu Son, DTU Wind Energy
- Valery Okulov; DTU Wind Energy
- Hamid Chivaee, DTU Wind Energy
- Holger Koss, DTU Byg
- Mark Kelly, DTU Wind Energy
- Niels-Erik Clausen, DTU Wind Energy

After the workshop slides were shared with the following in mail sent 14 October 2019:

- Ulrich Stolz, Goldwind Denmark
- Gyde Liane Ohlsen, European Energy
- Leo Raitanen, European Energy
- Finn Daugaard Madsen (SGRE OF INO)Siemens-Gamesa Renewable Energy
- Mark Zagar, Vestas
- Jens Ingemann Madsen, Suzlon
- Tommy Sørensen, Envision Denmark
- Lars landberg, DNV-GL
- Charlotte Bay Hasager, DTU Wind Energy
- Gabriel Zeitouni (gaze@cowi.com)