Integrated Research Programme on Wind Energy

Project acronym: **IRPWIND**
Grant agreement nº 609795
Collaborative project
Start date: 01st March 2014
Duration: 4 years

Evaluation reports on the results of the mobility scheme P3

Work Package WP5 - Deliverable 5.4

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Table of Contents

1. Executive Summary

In this document, we describe and evaluate the activity within WP5 "Mobility of Researchers" for the third period (1/03/2016-28/02/2017) of the IRPWIND.

The document contains:

- A list of the activities within the WP.
- New issues with respect to the two previous years.
- Remarks and future actions. and
- An appendix with the collection of the final reports submitted by the beneficiaries of the grants and their evaluations and new application and their evaluation.

The mobility programme was conceived with the following objectives:

1. To ensure an efficient implementation of the CPs and in general of the research activity in EERA;
2. To facilitate the cooperation between EERA research organizations and the broad scientific community to fill gaps in the ERA in the wind energy sector;
3. To connect relevant National projects/Initiatives to the IRPWIND core projects and generally to the EERA JP Wind Energy Joint Sub Programmes, keeping an eye to future emerging technologies and scientific topics; and
4. To conduct actions oriented to promote the concept of mobility of researchers as brain gain and foresight schemes to enable effective mobility.

Our program, differs from other existing mobility programmes, is innovative in the proposed mobility scheme, born to enforce cooperation within the IRPWIND Partners through established scientist mobilization. Since February 2017, PhD students in the second and third year of their PhD project, are now allowed to apply, after request from the EERA JP WIND research community. The acceptance of PhD student add a new element for experimenting a mixed inclusion program for last year. This could help us in adding elements for analysing better effectiveness of the "brain drain and brain gain" issue.

According to the starting hypothesis, the mobility of researchers funding programme consisted of 39 Grants for a period length of 1 month; 18 Grants for a 3-month period and 16 grants for a 6-month period. A lump sum covers travel expenses from/ to home institution.

Since the start of the third year, the "OPEN CALL" formula was adopted together with flexibility in the choice of the length of the grant period between 4 weeks and 26 weeks. A scheme with periods shorter than one month, between 2 and 4 weeks, have been designed specifically for managers, to allow shorter visits in order to plan new collaboration strategies. Eleven applications have been received through the year.

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Two applications were rejected: the first because the applicant was a PhD student (at that time not yet allowed to apply) and the second because the host institution was not an IRP/EERA Partner.

At the end of the third year, all projects granted during the previous calls (I, II, II and IV) were completed, but two of the IV, and evaluated. An exceptional case has been the permission granted to split a 17 weeks grant into two periods to Dr. Til Kristian Vrana from SINTEF due family reason. The original application was for a period of 17 weeks at IREC. For an emergency in his wife pregnancy he asked the possibility to split the grant in two and instead travel to ECN in the Netherland, since his wife is Dutch. He delivered a report for the work done at IREC and resubmitted an application to a second evaluation. The 4 and 12-13 weeks periods are the most popular, as shown in Figure 1 not including rejected applications, while none of the applicants has chosen more than 17 weeks.

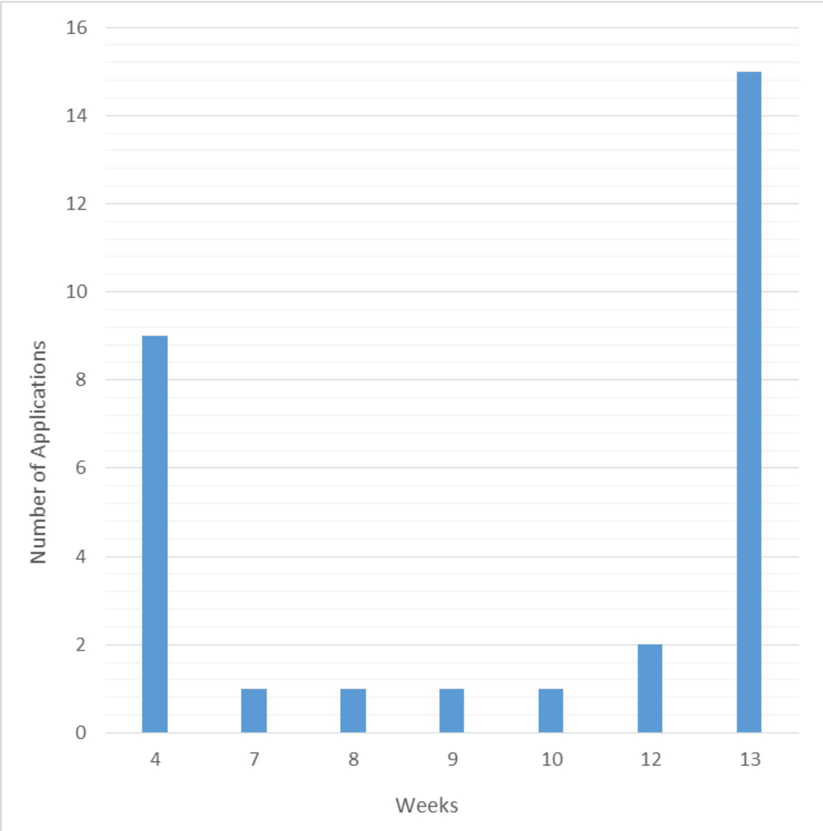

Figure 1 Period choiche until third year project

2. Introduction

At European level, a common strategy on how to overcome barrier for an effective short-term mobility of established researchers is not established; in that respect, experience during IRPWIND WP5 “Mobility of researchers” can contribute in defining objectives and giving guidelines to reach the goal.

The main points in trying to:

1. ensure an efficient implementation of the CPs and in general of the research activity in EERA;
2. facilitate the cooperation between EERA research organizations and the broad scientific community to fill gaps in the ERA in the wind energy sector;
3. connect relevant National projects/Initiatives to the IRPWind core projects and generally to the EERA JP Wind Energy Joint Sub Programmes, keeping an eye to future emerging technologies and scientific topics; and
4. conduct actions oriented to promote the concept of mobility of researchers as brain gain and foresight schemes to enable effective mobility.
5. Give a great impulse to institutional alignments between research excellence centres

The number of exchanged periods, joint publications and joint new projects are indicators related to Mobility WP that can show whether the mobility of experienced researchers can speed-up the process to overcome gaps in knowledge and expertise.

Changing mobility scheme e.g. giving flexibility in the choice of the length grant periods, combined with the above indicators, provide the conditions to statistically weight the effectiveness of each scheme. This will allow suggesting the best mobility schemes or schemas know-how transfer finalized to building trust amongst partners.

3. Main activities during year 3

CNR and DTU collaborated in the management of the mobility work flow.

Activities summary:

- The web page was continuously updated during 2016, (DTU)
- Two contributions to the IRPWind Newsletter were published. (DTU)
- A third video with the interview of two female researcher hosted at DTU was prepared and posted on the IRPWind Web page. http://www.irpwind.eu/Mobility (DTU)
- Participation to Management Board meetings in Brussels (CNR) and to the yearly conference in Amsterdam. (CNR-DTU)
- A poster regarding Mobility results for the second year was presented at the IRPWIND Conference (Amsterdam) poster session (DTU-CNR), meeting the usual interest.
- Two posters showing the results from the mobility of Hannele Holttinen (VTT) and Teresa Lo Feudo (CNR) were presented as Mobility dissemination results.
- Database on past calls and all documents, was set-up with a cloud system and regularly updated at CNR and duplicated at the IRPWind Website at DTU (CNR-DTU)
- FAQ on website have been updated (DTU-CNR)
- Participation at Mobility Task Force EERA ExCo to deliver a proposal for an operational student and researcher mobility scheme to support collaboration with its different Joint Programmes (DTU)
- A questionnaire has been developed by the mobility Task Force within the European Energy Research Alliance. The purpose is to collect relevant information on experience concerning available national and international instruments supporting researcher (academic or industrial) and student mobility in any thematic area. (DTU is leader of the questionnaire work package, working together with the coordinator of the mobility programme within the IRP Electra, European Liason on Electricity Committed Towards long-term Research Activity Integrated Research Programme). The results are under evaluation.
- An amendment to move funding, 300 K€, to WP4 Infrastructure was requested and granted by the Commission. The stationary trend of the number of application in WP5, gave rise to the possibility to move funding to WP4 to support another type of mobility i.e. the exchange of researchers during joint experiments following the calls issued by WP4 infrastructure.

Also, this year some patterns in the effectiveness of the mobility scheme has been observed. By analysing the applications, the questionnaires and reports, it emerged that 4 weeks and 12-13 weeks (equivalent to the previous existing three-month scheme) are the most successful choice. A longer period was proposed only by a PhD student, however, the proposal was rejected as at that time the call was not open for PhDs. Again, for the third year period, a grant duration of one to three months seems the most appealing.

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Table 1 Actual situation in founded grants and hypothesis for the next year with respect to the original.

Grant Period	1-4 weeks 1 month	4- 26 weeks 3-6 months
Year 1	**4**	**7**
Year 2	**2**	**9**
Year 3	**4**	**7**
Year 4	**12**	**11**
Implemented Funding Scheme	**22**	**24**
Original Funding Scheme	**30**	**36**
Daily Allowance	**161 EU**	**105 EU**
Travel Expenses	**Lump sum 600 Euro**	

For the fourth year, we implemented the suggestion to open to PhD student, from colleagues meet in different events and by email exchange. The appreciation of the mobility, also emerge when reading the acknowledgments of the opportunity offered by the programme in most final reports and from the questionnaires

Table 1 summarise the foreseen number of grants in the different schemes:

- until third year real funded grants;
- in yellow foreseen grants for the 4th year;
- considering implemented funded grant (plus hypothesized fourth year grants);
- initially planned funding scheme.

Last two rows in the table summarize financial funding schemes.

4. Summary of the Open call during third year

4.1 Open call

DEADLINE: none
RECEIVED APPLICATIONS: 11, Concluded: 1, Active: 7, In evaluation: 1, Rejected: 2 (red in Table 2 below).

Table 2 Summary of the Applications received during in the OPEN call (the reject application in red).

Submission	Applicant	Title of Research	Home	Host	Lenght (weeks)	Core Project
JUNE	SCHEPERS	INFLUENCE OF TURBULENCE INFLOW ON AIRFOIL CHARACTERISTICS	ECN	FORWIND	4	OFFSHORE
JULY	ATTYA	MULTI-DISCIPLINARY STUDY ON THE WIND POWER PLANTS AS A PROVIDER OF FREQUENCY SUPPORT IN THE FUTURE POWER SYSTEMS	UNIVERSITY OF STRATHCLYDE (UOS)	IREC	12	GRID INTEGRATION
JULY	PAUSCHER	WIND STATISTICS FROM MULTI-LIDAR MEASUREMENTS: IMPROVING TURBULENCE MEASUREMENTS AND REDUCING UNCERTAINTIES	IWES	DTU	13	GRID INTEGRATION
AUGUST	ALGARVIO	NEW MARKET PRODUCTS FOR EASILY INTEGRATION OF WIND POWER IN MULTI-AGENT ELECTRICITY MARKETS	LNEG	IWES	17	GRID INTEGRATION
SEPTEMBER	LAHUERTA	MICRO-MECHANICAL INVESTIGATION ON SHEAR AND COMPRESSION FATIGUE PROPERTIES ON THICK LAMINATES VIA 3D X-RAY COMPUTED TOMOGRAPHY USING THE SUB-LAMINATE TECHNIQUE	WMC	DTU	4	STRUCTURES AND MATERIALS
OCTOBER	GRECO	FAST AND ADVANCED ROTOR WAKE MODELLING (FARWING)	CNR	ECN	13	OFFSHORE
OCTOBER	KIRKEGAARD	AMBIGUOUS WINDS OF CHANGE – OR FIGHTING AGAINST WINDMILLS IN CHINESE WIND POWER	DTU	NTU	10	GRID INTEGRATION /ECONOMICS AND SOCIAL ASPECT
OCTOBER	VRANA	INVESTMENT COST PARAMETERS FOR TRANSMISSION PLANNING STUDIES FOR OFFSHORE WIND INTEGRATION	SINTEF	ECN	9	GRID INTEGRATION
NOVEMBER	ROCHA	MICROSCOPIC CHARACTERISATION OF MATERIAL DEGRADATION EVOLUTION DUE TO HYGROTHERMAL AGEING USING 3D X-RAY COMPUTED TOMOGRAPHY	WMC	DTU	4	STRUCTURES AND MATERIALS
DECEMBER	SZAFRANSKI	-	MILITARY UNIVERSITY OF TECHNOLOGY IN WARSAW	-	12	STRUCTURES AND MATERIALS
FEBRUARY	ROUKIS	ACOUSTIC EMISSION MEASUREMENTS DURING WIND TURBINE ROTOR BLADE SUBCOMPONENT TESTING	CRES	IWES	4	STRUCTURES AND MATERIALS

All applications are listed and described in Table 2. Two were rejected, as PhD students were not yet allowed to apply and the Home institution is not in EERA.

Table 3 Evaluation grading

GRADES	*VALUE*
0	***Out of scope***
1	***Sufficient***
2	***Good***
3	***Excellent***

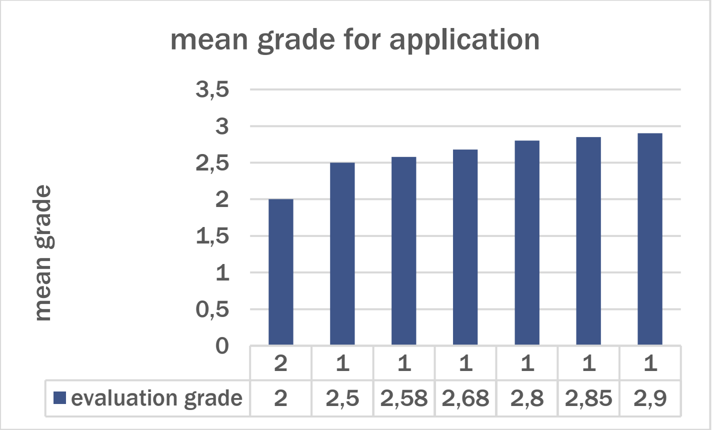

Figure 2 Mean grade for each criterion in the Open call. The missing evaluations are ongoing.

The evaluation process for last application in Table 2 is still ongoing, while mean grade evaluation for third year application are summarised in Figure 2.

4.2 Statistics

Some indicators and statistics regarding the Open call are shown as follows.

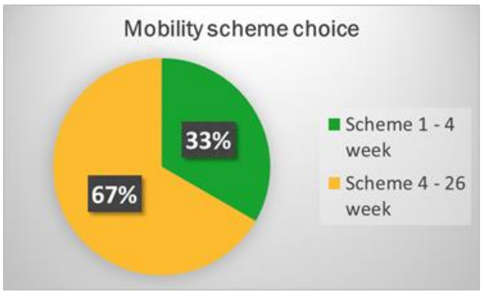

Figure 3 Preference of the length of the grant

Again, see Figure 3, period regarding 10-13 weeks is the most chosen schema (corresponding to the previous three months schema); 4 weeks remain the second choice preference. During the third period, we did not receive any manager/leader application.

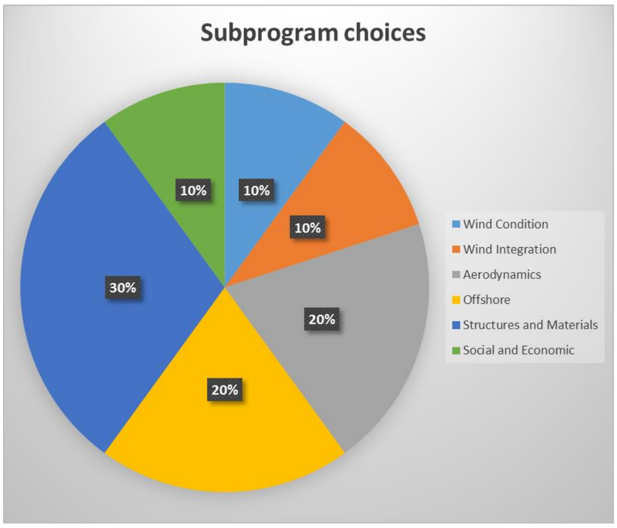

Figure 4. Figure 3 EERA JP Wind subprogram preference

During this year, applications regarding the Structure and Materials Subprogram registered an increase as well as Offshore and Aerodynamics. Also, we received the first application related to the Social and Economics Subprogram.

Mobility naturally contribute strengthening collaboration between institutions and their alignment through bilateral collaboration (home and host institution) during grant period.
In the Figure 5 involved institution are depicted considering the number of application, DTU is still on the top of hosting institution. This year new involved institutions appeared: WMC and Forwind

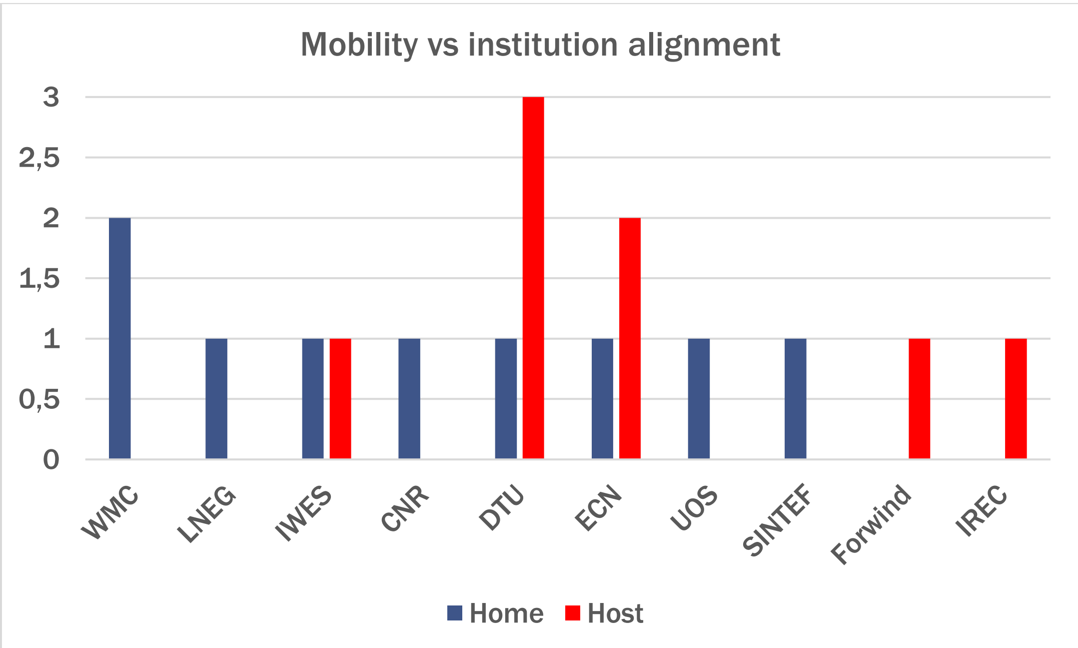

Figure 5. EERA/IRPWind partner institutions that have been active in the third year OPEN CALL both as host and as home institutions. Statistics does not include the rejected application.

5. Conclusive remarks and future perspectives

At the end of third year, the IRPWind mobility programme is stationary despite introducing no deadline for the application and a more flexible scheme with respect to the length of the grant period.

Several researchers interested on the programme submitted questions directly via e-mail with a good frequency and seems that rules and procedure now are better known that previous period.
Questionnaires feedback are positive and reveal a very good general evaluation of the programme. The mobility scheme of 2 to 4 weeks for Managers, including the IRP Coordinator and sub-programme Managers, the IRP Management board members and EERA JPWind Energy Steering Committee members have never been used.

We are confident that during the fourth year the scheme will be used to meet and discuss for strategic action plans and future collaboration after the end of the IRPWIND project. Giving part of the budget to the WP3 Call for joint experiments, the mobility programme supported a mobility not foreseen in the original scheme. Mobility scheme between 4 to 26 weeks for all scientists is largely used also if the choice is limited to 17 weeks at most.

A new IRPWind session will be organized during 2017 in connection to the annual meeting in Amsterdam to give evidence of successful collaboration within mobility programme. Claudia Calidonna, CNR, and Anna Maria Sempreviva, DTU, will be in charge of the organization. This session will address how to design the best schema for a successful mobility

6. Appendix 1 *Call for applications for mobility grants within IRPWIND*

CALL FOR APPLICATIONS FOR MOBILITY GRANTS WITHIN THE

Integrated Research Programme on Wind Energy (IRPWind)

A call for application is open in the frame of the Integrated Research Programme on Wind Energy (IRPWind) Mobility Programme and the European Energy Research Alliance, Joint Programme on Wind Energy (EERA JP Wind Energy)

The mobility scheme within the IRPWind) has the following objectives:

1) To ensure an **efficient implementation** of:
   - The Core Projects in the IRPWind;
   - The research activity of other EERA Joint Sub Programmes (EERA JSP); and
   - The EERA strategic action plan.

2) To **enhance the cooperation** between research organizations involved in the IRPWind and the broad scientific community of the EERA JP Wind Energy established to fill gaps in the European Research Area in the wind energy sector;

3) To **connect relevant National projects/Initiatives** to the IRP Wind Energy core projects and generally to the EERA JP Wind Energy Joint Sub Programmes, keeping an eye to future emerging technologies and scientific topics; and

4) To conduct actions oriented **to promote the concept of mobility** of researchers as brain gain and to foresight and implement best practice schemes for enabling effective mobility within the European Research Area.

1. ELEGIBILITY CRITERIA

The applicant must be an employee of an EERA JP Wind Energy member, hereafter called Home (Sending) organization, and have at least 5 years' experience as a researcher.

The mobility scheme is open for all EERA JP Wind Energy members; however, either the sending or the receiving (Host) organization must be an IRPWind partner. As a general rule, the sending Organization will receive the funding of the grant from the IRPWind Coordinator.

The applications should follow a template, downloadable from the IRPWind Home page and be submitted online.

2. FINANCIAL RULES

Applications are open for mobility grants of different duration: 1, 3 and 6 months according to Table 1

The grant includes travel expenses and daily allowance (see Funding Model).

Error! Reference source not found. shows the initial number of available grants for each scheme compared to the actual numbers of granted applications.

Grant Period	1 month	1-3 months	6 months
Year 1	12	6	4
Year 2	9	4	0
Year 3	9	4	4
Year 4	9	4	3

Grant Period	1 Month(4 weeks)	1-3 Months(4-26 weeks)	6 Months(4-26 weeks)
Year 1	4	7	0
Year 2	2	9	0
Year 3	4	7	-
Year 4	-	-	-

Table 4 Left: Available number of grants for each scheme at the start of the project. Right: Actual situation after year 3.

3. FUNDING MODEL FOR THE OPEN CALL

1. Eligibility criteria - now open to all EERA Participant organizations

The call is open to researchers employed at all EERA participant organizations.

The application should follow a form, downloadable from the IRPWind home page and be submitted online.

2. Mobility scheme

There will be only two mobility schemes in the actual OPEN call.

2.1 Mobility scheme of 2 to 4 weeks for IRP Wind and EERA Managers. The purpose of this scheme is to stimulate the mobility of managers in the EERA organizations to meet and discuss for laying down strategic action plans and other collaborative efforts.

2.2 Mobility scheme of 4 to 26 weeks for all scientists and experience PhD Student. The purpose of this scheme is to increase flexibility in the choice of the grant duration as requested by EERA researchers during discussions during the IRPWind general assemblies.

3. Funding Model

Grants for periods from two to four weeks: A sum of 161 Euro/day will be granted to successful applicants

Grants for periods between 4 and 26 weeks: An amount of 105 Euro/day will be granted to successful applicants

For both schemes, the financial rules remain unchanged since previous one month schema and three and six months schema.

4. EVALUATION PROCEDURE OF THE APPLICATIONS

Each application will be evaluated by a panel of two reviewers. The panel will assess the application and score it according to fixed criteria and a given grading scale. The applications will be ranked and the highest scores will be granted according to the criteria identified in Table 3. The grading score is shown in Table 4.

Table 5 Evaluation criteria.

EXCELLENCE	IMPACT	IMPLEMENTATION
Quality, innovative aspects and credibility of the research.	Enhancing research- and innovation-related human resources, skills and working conditions.	Overall coherence and effectiveness of the work plan, including appropriateness of the allocation of tasks and resources.
Clarity and quality of knowledge sharing among the participants in light of the research and innovation objectives.	To develop new and lasting research collaborations, to achieve transfer of knowledge between research institutions and to improve research and innovation potential at the European and global levels	Appropriateness of the management structures and procedures, including quality management and risk management
Quality of the interaction between the participating organizations	Effectiveness of the proposed measures for communication and results dissemination	Competences, experience and complementarity of the participating organizations and institutional commitment
Weight: 50%, 1st priority at ex equo	Weight: 30%, 2nd priority at ex equo	Weight: 20%, 3rd priority at ex equo
Grade 0-3	**Grade 0-3**	**Grade 0-3**

Table 6 Grading score for each proposal.

GRADES	VALUE
0	Out of scope
1	Sufficient
2	Good
3	Excellent

5. TIME SCHEDULE OF THE EVALUATION PORCEDURE

Application deadline: None

Results of the evaluation: Within three weeks from the application deadline

Start of the grant: Open

6. APPLICATION TEMPLATE (MAX 3 Pages)

The application template must be downloaded from http://www.irpwind.eu/mobility and submitted online.

7. Appendix 2 *Updated FAQs*

Who is going to apply, the researcher (natural persons) or the organisations?
The researcher should apply in agreement with the home and host organization. The application should also contain a letter of intent between host and home organization.

What will the grant cover?
Funding will cover:

- A lump sum for travel expenses and
- A daily allowance depending on the duration of the period

The longer the period, the smaller is the daily allowance because a long-term accommodation would cost less than a short-term one.

Who will be reimbursed? The researcher (natural persons) or the research organisations?
The IRPWIND Coordinator has allocated the funding for the mobility work package and will forward funding to the sending organization against invoice before the start of the grant.
Funding will be transferred to the sending organization for practical reasons e.g. to optimize funding avoiding monetary lost by international fund transfer fees;
In case the sending organization is not an IRPWIND participant, the coordinator will transfer funding to the host organization, against invoice, before the start of the grant.

Will the visits be only to research organizations inside the consortium or outside as well?
When specified in the calls, all organization members of the EERA JP Wind Energy and industry R&D actors can enter the funding scheme.

Can EERA JP Wind Energy members and industry R&D actors participate to the IRPWind mobility scheme as sending or host organizations?
Only in case of dedicated calls for applications, EERA JP Wind Energy members and, Industry R&D actors can participate in the mobility scheme at the same conditions as the IRP Wind Energy member organizations. This will likely (i) increase the cohesion in the EERA JP Wind Energy group including associated partners and (ii) give the possibility to integrate new innovative ideas that might come from the "outsiders".

Is the mobility scheme aimed to educational purpose?
The mobility scheme is not for educational purposes but for strengthening the research in Europe. To be eligible, a scientist must be employed by one of the EERA JP Wind Energy members or be within the last two years of a PhD project.

Can the grant period be split in shorter periods?
The grant periods must be carried out continuously and the reports should be presented within 2 month from the end of the grant.

8. Appendix 3 *Final mobility reports and their evaluation*

In this section are collected final reports and their evaluations together with applications (in evaluation) received during third year.

Outline of the application template:

Introduction

- Research topics, originality;
- Technological Readiness Level (TRL) of the proposed concept;
- Definition of Key Performance Indicators (KPIs); and
- Description of links to relevant EERA Sub Programmes (SP) and/or IRPWIND Core Projects (CP).

Description of national projects aligned to the proposed activities in both the sending and the receiving institution, including milestones, funding services, research activity (demonstration, applied research, basic research etc.) Please consider that at least one of the partners should have a national project relevant to the proposal

- Description of national project from receiving institution (please erase if not actual);
- Description of national project from sending institution (please erase if not actual); and
- Foreseen European benefit of national alignment.

Work Plan

- Deliverables, milestones etc.

Benefits to EERA objective advancement

- Contribution to the advancement of the EERA strategy goals, gaps addressed,

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

- Explain ToK or dissemination strategies and plan of future collaboration with other IRP/EERA partners

Expected results

- Methodoogies and/or databases and/or best practices functional to the activities of the IRP and EERA strategic agenda objectives.
- Assessment of the advancement of the TRL
- Assessment of the KPIs

Application must be supplemented by:

- A Curriculum Vitae
- A letter of interest from the host organization.

PROCEDURE AFTER THE COMPLETION OF THE GRANT

- A final report will be due within one month of the completion of the grant. The report must be filled and submitted online;
- A questionnaire about the evaluation of the schemes must be filled online by the recipient, the host and the sending institution referents;

- The final report will be reviewed by the panel that evaluated the proposal (The coordinator of the most relevant sub-programme and two chosen from the pool of reviewers);
- The evaluation of the panel approval will be within 2 weeks of receiving the report; and
- The sum remainder of the grant will be issued after the approval of the final report and the submission of the questionnaire.

FINAL REPORT length may depend from grant duration and argument complexity.

Outline of the final report template:

- Description of the work and major results;
- Compliance to the expected results, Key Performance Indicators KPIs and the advancement of Technological Readiness Level according to the application;
- Description of the benefit for host, home and IRP programme; and

Future perspectives. (Future research, availability of databases to other parties, expected publications, and disseminations).

Final reports evaluations and applications

Supported by:

Funded by EU

Application form for Mobility grants within IRPWIND

NOTE

- **All documents must be named as follows:**

Sub Programme letter, Number of months, Surname, Document type. Ex: A_03_Smidt_cv See Table C) below.

- **The application must be max. 6 pages, ex tables, figures and references.**

A) Applicant details

Applicant Name	Doron
Applicant Surname	Callies
Home Institution	Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES)
IRP Partner? *(yes/no)*	yes
Home Institution Postal address	Königstor 59 34119 Kassel
E-mail	doron.callies@iwes.fraunhofer.de

B) Host institution details

Institute name	Technical University of Denmark (DTU)
IRP PARTNER?	yes
Contact person	Michael Courtney
Country	Denmark
E-mail	mike@dtu.dk

Funded by EU

Final Report IRPWIND Mobility Programme

Participant: Doron Callies

Sending Institution: Fraunhofer IWES

Host institution: DTU Wind Energy

Host Contact Person: Michael Courtney

Time of Stay: 29.11.2015 – 26.02.2016

Introduction

For three months, from 29th November until 26th February I stayed at DTU in order to render possible a jointly written scientific journal article on the WindScanner.eu Kassel experiment of 2014, to prepare the *New Europan Wind Atlas* (NEWA) forested hill experiment in the autumn of 2016 (See work plan from application) and to strengthen the network between Fraunhofer IWES and DTU.

1 Description of Work and Major Results

In the following paragraphs the outcome concerning the envisaged publication is first presented. This is followed by a summary of the work and results related to NEWA.

1.1 Dissemination of the results from the Kassel Experiment

Based on the measurement data and the 'Report on standardization including best practice for data analysis and uncertainty analysis' from the WindScanner.eu project a publication was prepared. The following abstract describes the scientific content of the work related to the WindScanner Kassel experiment.

Over recent years, vertically profiling Doppler wind lidars have become popular in resource assessment applications for wind energy. However, in complex terrain their accuracy suffers from the flow heterogeneity and systematic errors in the estimation of the mean wind speed can be introduced. Also, their performance in measuring turbulence quantities is not satisfactory for site assessment for wind turbines. Both issues can potentially be overcome if multiple lidar beams are intersected in one point rather than scan conically from a single lidar. However, in this configuration the precise setup and the identification of suitable lidar locations is crucial for obtaining valuable measurement data.

In the paper prepared, results from a measurement campaign, referred to as the Kassel 2014 Experiment, employing six synchronised and centrally coordinated long-range WindScanners at a complex site in central Germany are presented. Furthermore, guidelines for identifying suitable scanning locations at complex sites and an uncertainty analysis of different WindScanner configurations are given.

During the experiment, five WindScanners were placed around a forested hill at distances of between 732 m and 3740 m. Their beams were intersected next to a reference mast. The sixth WindScanner was located next to the mast to measure the vertical component directly. Additionally, a Leosphere Windcube v2 (vertically profiling) was placed at the bottom of the mast.

The comparison of the mean horizontal wind speeds derived from multiple intersecting lidar beams and the reference mast showed excellent agreement as long as at least two systems had pointing angles which were not close to co-planarity. The Windcube v2 performed slightly worse and exhibited more scatter when compared to mast mounted sensors. The measurement of the vertical velocity derived from multiple intersecting lidars agreed reasonably well with the sonic anemometer, but at least one lidar with a sufficiently large elevation angle had to be used. Turbulence intensities of the horizontal wind speed of the combined WindScanner measurements showed promising results in comparison to the reference mast.

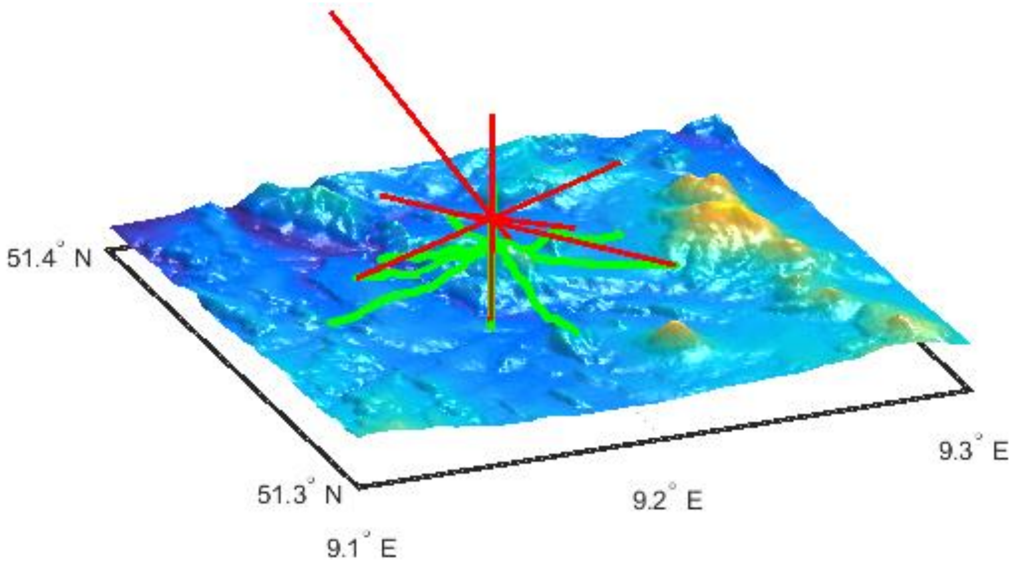

Figure 1: Visualization of the experiment, red lines represent sight measurements, green lines represent the tracks of the line of sight measurements projected on the ground

The article on the Kassel Experiment is based on a collaboration between Fraunhofer IWES, DTU, ForWind and CENER. It reflects the contribution of all these partners to the experiment and the comprehensive scientific work carried out. The title of the paper is *WindScanner Measurements in Complex Terrain: Results from the Kassel 2014 Experiment. The paper* will be submitted before 30th June for the special issue *remote sensing in wind energy* of the *Remote Sensing* Journal.

To achieve further attention, in addition to this finalized paper a contribution was made to the International Symposium for the Advancement of Atmospheric Boundary-Layer Remote Sensing (ISARS) in 2016. The abstract was submitted on 19th February 2016.

The results will also be presented at the NEWA project meeting in Portugal in May 2016 to demonstrate the performance of WindScanners to a more industrial community.

1.2 Preparation of the New European Wind Atlas Experiment in second six month of 2016

In my application I expressed my intent to complete the two SMART goals campaign design document and road map for the forested hill experiment in Kassel. Both documentations were completed.

Road Map to the Forested Hill Experiment

To ensure a smooth implementation of the new Kassel experiment, a detailed schedule including the tasks of the different partners was made. This comprehensive time schedule is the *road map to the forested hill experiment*. All dates were discussed with the different partners involved in the experiments and agreed on. They were coordinated with the availability of the measurement equipment in other NEWA experiments (e. g. in Sweden and Portugal).

Figure 2 sums up important milestones from this *road map to the forested hill experiment* schedule. On 11th July 2016 all wind profile lidars are expected to be in Kassel and will be installed next to the 140 m mast in order to perform a quality and range check of the devices. In August the systems will be installed in the field.

On 8th August the work with WindScanners will start. They will be tested and synchronized and a range test will be carried out. This will help to decide on the final location of the different scanners. In the week after, deployment will start. This is expected to take up to two weeks. An additional test phase now is then prospected to make sure that all technical problems are solved.

At the beginning of January 2017 all devices will be collected so that all devices leave Kassel on the 6th of January.

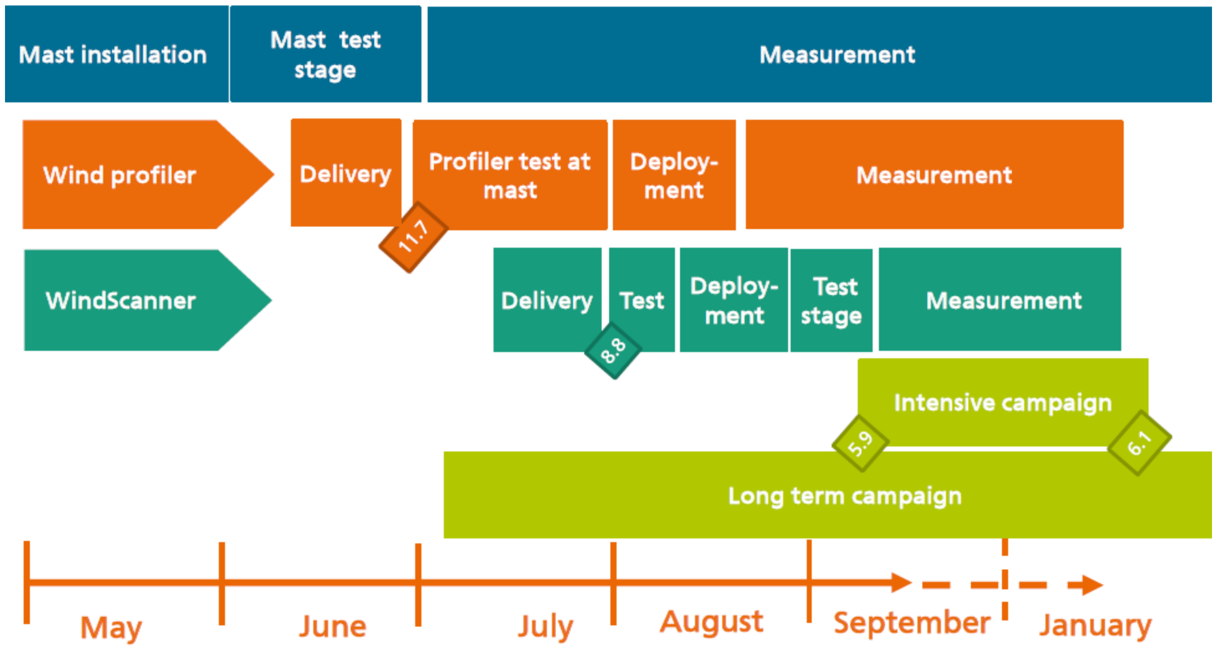

Figure 2: Schedule for the intensive stage of the Forested hill experiment

Measurement Equipment

During my stay at DTU the availability of the different devices was confirmed by the involved NEWA partners and ENERCON. I visited the latter on 29th January in Bremen to secure their contribution.

Tabelle 1: Contribution from the partners involved in the experiment

Partner	**Contribution**
Fraunhofer IWES	200 m mast, 140 m mast (new), 1 LiDAR profiler, 2 long-range WindScanners (200 S)
DTU Wind Energy	3 long-range WindScanner (200 S), up to 4 LiDAR profilers, measurement system for the 140 m mast
ForWind	3 long-range WindScanner (200 S)
ERI VIRAC and IPE	Pentalum lidar
Project	3 long-range WindScanner (200 S)
ENERCON	1 LiDAR profiler (Windcube with Power Supply) – if an official agreement with the project is reached
Total	**11 WindScanners (200 S), 2 met masts, up to 6 profilers + 1 long-range profiler**

140 m mast

The 140 m mast will be located about 3 km southwest of the 200 m mast in a field. The mast will be equipped with several ultrasonic anemometers. The layout was agreed on by DTU who provides the measurement system and Fraunhofer IWES who is responsible for the erection of the mast. Due to this arrangement a close cooperation between DTU and Fraunhofer IWES is of special importance. A number of issues had to be solved (e.g. safety requirements, lightning protection, mounting of booms and so on) to prepare the mast specification for the necessary tender.

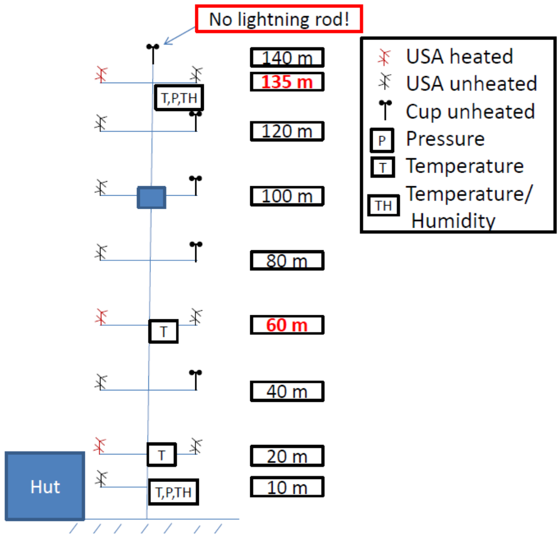

Figure 1: Layout for the 140 m mast

Campaign design

The following paragraphs describe the layout of the Kassel Forested hill experiment based on the discussions during my stay at DTU and the input from project partners at the Kassel workshop (2nd Novenber 2015). They summarize the *Campaign design document*.

The layout depicts sites that seem reasonable from a scientific point of view. The sites were visited after Christmas 2015 as part of the preparation to check their suitability. However, it is becoming apparent that not all these sites will in fact be available since power connections and permission from the land owners will be difficult to obtain at some of them. In this case the envisaged sites for the WindScanners will be changed.

The purpose of the layout is to determine the flow over the hill. The focus is on the main flow line. The newly installed 140 m mast is the starting point of the flow line which is measured in 60 and in 135 m height above ground. The flow line extends to about 2 km behind the 200 m met mast which is located at the ridge of the hill. To measure the flow line, the WindScanners will scan range height indicator (RHI) and complex step stare trajectories. Additional sampling points will be provided by wind profile lidars.

Using the plan position indicator (PPI) mode additional Windscanners shall measure the flow in the area around the hill of the 200 m mast. However, this measurement will only be possible if Fraunhofer IWES participates in the experiment with its new long range WindScanners which are not part of the NEWA project budget.

The sites of the wind profile lidars (WINDCUBE WLS 7 (DBS), ZephIR 300 (VAD), SpiDAR) with normal range (e. g. 200 m) were selected in a way that they either provide additional wind profiles (WP 1,3 and WPP) for the main flow line or profiles of incoming wind from other wind directions (WP 2,4 and5). The WINDCUBE WLS 70 with the extended profile range is sited next to the 140 m mast to measure the inflow up to tall heights (Figure 2).

To observe the wind profile along the main stream line one range height indicator (RHI) will carry out a scan from the start and one from the end of this line (Figure 2). Since the WindScanners measure only in the direction of the mast only a small elevation angle change is required in order to reach tall heights at the 200 m masts. This allows fast measurement.

In order to determine the flow over the hill and behind the hill two flow lines, each in two heights, are measured using the step stare mode (Figure 3). The first flow line is measured between the 140 m met mast and the 200 m met mast. The second flow line is measured from the 200 m met mast to a distance of about 2 km behind the hill and is thus a prolongation of the first flow line. For each flow line 3 scanners are used, which results in some redundancy and ensures the quality of the measurements. Although three WindScanners will be installed it is unlikely that the vertical component can be determined correctly because the elevation angle of the measurement will remain low.

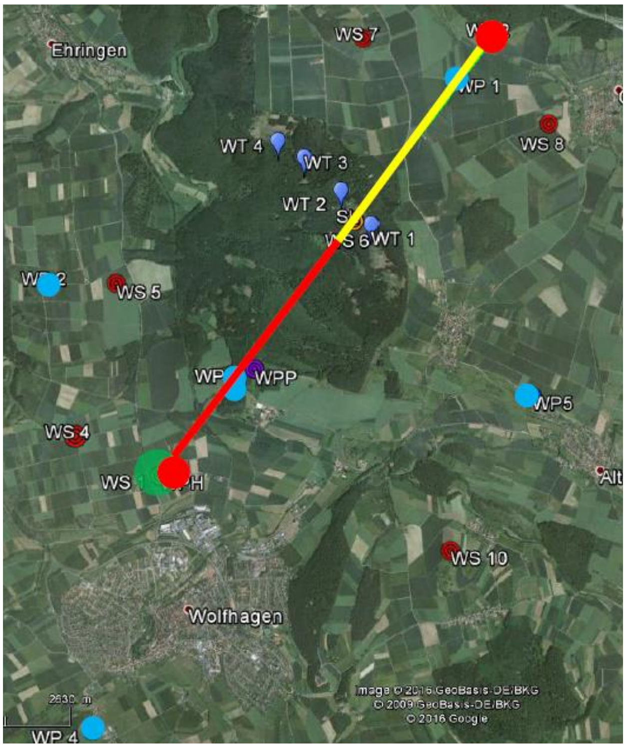

Figure 2: Location of the different lidars – Streamline profile (RHI)

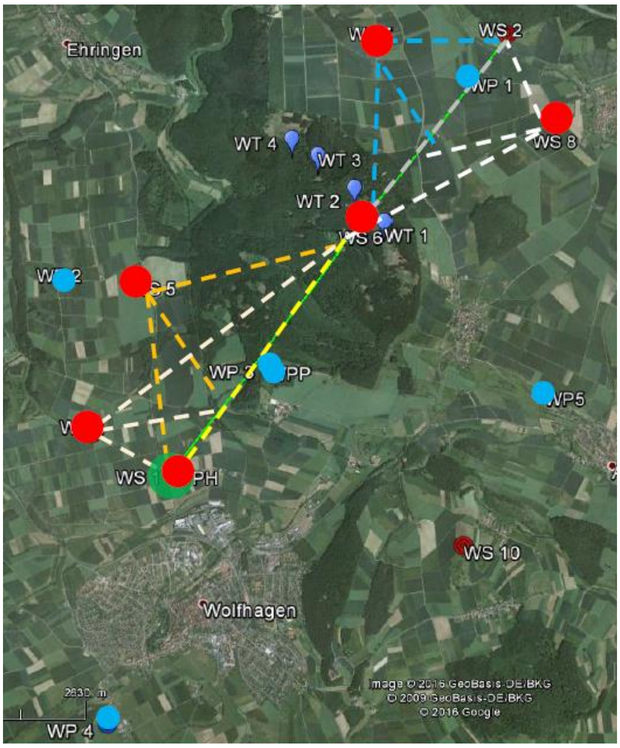

Figure 3: Location of the different lidars – Streamline flow measurement in 60 m and 135 m

The PPI overlay will provide insights into the spatial flow of the wind over the (mesoscale) region of the hill. Therefore it is intended to measure plan position indicator (PPI) from the front, the back and the side of the hill.

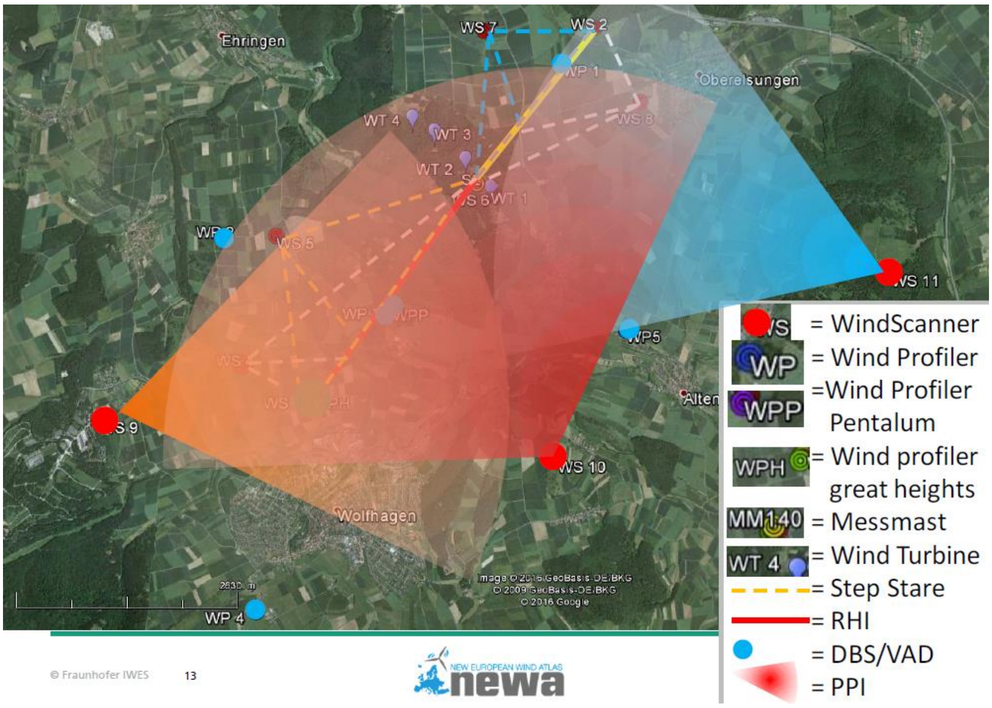

Figure 4: Location of the different lidars – Regional Overlay PPI

In my application I promised to submit a paper to a scientific journal and to spread the WindScanner know how in the scientific community. Both of these goals have already been achieved or will be achieved within the next three months.

In my application I promised to complete the two SMART goals campaign design documentations and the road map for the forested hill experiment in Kassel. These goals also were achieved.

2 Compliance with the expected results

Topic	Application	Result
Research topics, originality	The experiment carried out is up to now the most extensive experiment worldwide using long range scanning lidars. It was the first time that six synchronised wind scanners were tested to act as virtual met mast in complex terrain. The analysis of measurements from different distances and scan angles in relation to the met mast will allow todetermine the optimised campaign layout for future experiments. The innovative concept used for the measurements has offered new insights to wind field which will be generated in the NEWA experiment in the summer of 2016.	The results show the dependence of the accuracy on the different combinations of wind scanners. This is due to their azimuth angle. The angle between two scanners should be close to 90° to maximise the accuracy of the horizontal wind speed. To measure the vertical wind speed which is mostly very small, a lidar has to measure vertically. These results are taken into account in design of the experiment for the NEWA Forested Hill in 2016

Technological Readiness Level (TRL) of the proposed concept	The long range wind scanner technology is now available on the market. However, synchronisation of the scanners including a common control is a new development from DTU that has yet to prove its capabilities during the campaign. The TRL level is high but the proof of the technology can only be provided by means of a measurement campaign. The research proposed at DTU will help to prove the performance of the technology in comparison to current technologies and disseminate the WindScanner know how. Additionally the new experiment will prove the capability of WindScanners for 3-D wind field modelling.	The performance of the synchronisation and control of the WindScanner was proven. The results showed that horizontal wind speeds derived from multiple intersecting WindScanner beams showed excellent concordance with those measured by the ultrasonic anemometer mounted at the 200 m mast. The WindScanners measured more accurately than the WindCube WLS7. Hence the technology readiness level for WindScanners in complex terrain was proven.
Definition of the Key Performance Indicators (KPIs)	The KPI is the dissemination of the results of the WindScanner.eu project A paper describing the set up and the results of the wind scanner experiment in Kassel in 2014 will have been submitted to a scientific peer reviewed journal. In case of acceptance of the paper the knowledge transfer to the scientific community will support the breakthrough towards a wider use of the WindScanner technology. For NEWA, a forested hill campaign design plan including sites and scanning patterns shall be compiled A road map for a smooth implementation of the NEWA experiment shall be elaborated	The scientific paper *WindScanner Measurements in Complex Terrain: Results from the Kassel 2014 Experiment* on the Kassel Experiment was written in collaboration between Fraunhofer IWES, DTU, ForWind and CENER. I is already far advanced and will be submitted before 30th June 2016 to the *Remote Sensing* journal. Additionally an abstract on that topic has been submitted for the ISARS conference 2016 and the results will be presented at the NEWA project meeting. For the NEWA project the *road map to the forested hill experiment* and the *campaign design document* have been compiled and agreed on with the partners involved.

Description of links to relevant EERA Sub Programmes (SP) and/or IRPWIND Core Projects (CP)	Since the research planned is related to the windscanner.eu project it is heavily linked to EERA **Sub-programme 1: Wind Conditions** as the wind scanner technology allows pre-competitive research into the fundamental understanding of atmospheric motions. Since the 'forest experiment' in 2016 will also take place at the site of the 200 m mast the results of the experiments will help to optimize planning and realization of the measurement campaign in this project with many EERA partners. As the aim of the WindScanner.eu project is to prepare a joint European infrastructure within the ESFRI framework, there is a strong link to the aims of **Sub-programme 6: Research Infrastructure**.	The work carried out was linked to **Sub-programme 1: Wind Conditions** and **Sub-programme 6: Research Infrastructure**. It provides a link between past (WindScanner.eu), ongoing (NEWA) and even future cooperation (WINDIA proposal for integrating activities for starting communities) and thus sustainably strengthens the EERA network.

3 Benefits to the researcher, host and home organization and IRP programme

I personally have benefited from the stay in a variety of different ways. I saw the differences in the priorities between Fraunhofer IWES and DTU Wind Energy. The research of Fraunhofer IWES relies greatly on projects on behalf of industrial clients while DTU always promotes the publication of its excellent results and their dissemination in the scientific community. Essentially the fields of research are the same, whereby DTU possibly does more basis research.

Fraunhofer IWES, DTU and I personally will benefit from the network I was able to establish with a number of DTU researchers for future collaboration.

DTU will have an important role in the Kassel experiment through its contribution of WindScanners and LiDAR profilers. All the relevant milestones and the detailed planning of the NEWA were agreed upon with DTU during my stay, which will allow an efficient preparation of the experiment. The agreement on the mast layout and the consideration of DTU safety requirements ensure that the DTU staff installing the measurement system at the Fraunhofer 140 m mast can work according to their standards.

Both researchers from DTU and other EERA research institutes will contribute to the research paper under the direction of Fraunhofer IWES. This paper will attract attention of scientists all over the world and demonstrate the excellence achieved in the field of remote sensing.

I was also able to contribute to a common project proposal together with other EERA partners during my stay. This will be the next step to deepen Pan European collaboration and preparing a WindScanner European Infrastructure.

4 Future perspectives

During my stay several opportunities for further collaboration came up which will be used to enhance research activities and an efficient cooperation in the future.

For the NEWA project the cooperation with Fraunhofer Iwes will enable the use of the high quality forest and elevation data provided by the federal state of Hesse to which only the University of Kassel has access. Therefore a common master project of Fraunhofer IWES, University of Kassel and DTU is planned. It is planned that a master student from Kassel goes to DTU and does calculations on forest height and density according to the methods developed by DTU.

Currently DTU together with other EERA partners is preparing a Horizon 2020 proposal as part of the "Integrating Activities for Starting Communities" program to enhance the collaboration between the European WindScanner partners and other leading research infrastructures. I was able to contribute to this with my ideas and represent Fraunhofer IWES in this project.

The NEWA projects will generate a huge amount of high quality data. These data could be used as a base by PhD students for developing innovative products in the context of their theses. The MARIE SKŁODOWSKA-CURIE INNOVATIVE TRAINING NETWORK might offer a funding opportunity.

Last but not least I was able to establish personal contacts to staff of DTU which I expect will be very valuable for future cooperation and efficient implementation of common projects. Of course I also invited staff of DTU to visit Fraunhofer IWES for a scientific stay especially within the IRP Programme.

All these achievements were made possible through the European IRPwind Mobility Programme, the hospitality, welcoming atmosphere and cooperation of DTU, the willingness of my home institution Fraunhofer IWES to extend the cooperation with DTU. I am most grateful for the many personal encounters with staff from DTU and the suggestions I have received from them. I appreciate the possibilities offered to me by my host of 3 months and hope to be able to reciprocate, perhaps in hosting DTU staff in at Fraunhofer IWES in Kassel.

Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**I** **3 MONTHS** **Doron Callies/DTU**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	☐ yes
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO The report describes the activities that have been performed. The results of the activities are not included in the report. These are included in the papers that have been written. The report would benefit from reducing the amount of text on procedure (what has been done) and more on results. Not the abstract should have been copied, but an interesting result should have been included.	☐ No
Was the used methodology effective ? Please comments if NO	☐ yes
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	☐ yes
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	☐ yes
How do you evaluate the report?	4
Is any missing information in the report? Please comments if yes	☐ No
Rate the overall experience as described in the final report.	4

Other Suggestions?

[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

The report is highlighting the benefits of collaboration:

- Sharing results
- Experiencing cultural differences between institutes and different R&D perspective
- Expanding network
- Creating synergy in technology development

In that respect the exchange was a great success.

The writer can improve the writing by taking the reader through the text: what do you want to say? Including years to all the dates would help, a clear summary what has been intended and been performed would also help.

The report should be less ‘defensive’ – ‘I have done what I promised’
To be more impactfull – ‘this is the great improvement that has been achieved’

Showing a graph or picture showing the impact and result which is understandable by the public would certainly help.

In any case, I know what great achievement has been performed. I compliment the exchange researcher with the achievements and the effort to collaborate outside the boundaries of the own institute.
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Funded by EU

Final Report for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	**José Luis**
Applicant Surname	**Domínguez-García**
Home Institution	**Catalonia Institute for Energy Research (IREC)**
IRP Partner? *(yes/no)*	**yes**
Home Institution Postal address	**Jardins de les dones de negre 1 2nd floor, 08930, Sant Adrià de Besòs, Spain**
E-mail	**jldominguez@irec.cat**

B) Host institution details

Institute name	**University of Strathclyde (UoS)**
IRP PARTNER?	**yes**
Contact person	**Olimpo Anaya-Lara**
Country	**United Kingdom**
E-mail	**olimpo.anaya-lara@strath.ac.uk**

C) Relevant Programme and scheme

CORE PROJECT? YES/NO *(Please erase the non-relevant)*	**(B) Wind Integration**	**RELEVANT EERA SUB-PROGRAMME Max 2** (Please erase the non-relevant)	**(A) Offshore Wind Energy** **(B) Wind Integration**
Length of the grant scheme *(Please erase the non-relevant length)*	**(03) 3 months**	**Start date:**	**5th March, 2016**

D) Project description and outcomes

ANCILLARY SERVICES PROVISION FROM WIND POWER PLANTS

The integration of wind power to power systems leads to a change on power systems dynamics and response. To overcome this, TSOs are asking wind power plants to contribute to ensure power systems stability and security with novel grid code requirements. How wind power may provide such requirements is a challenge. This mobility allowed a fruitful and deeper collaboration of a researcher from IREC visiting the leading group of WP81 in IRPWind, University of Strathclyde. This mobility facilitated the identification of synergies between IREC and UoS long-term objectives aligned with IRPWind and EERA JP Wind main goals.

The main contribution has been on designing different control schemes for providing ancillary services from wind power plants (both onshore and offshore) within AC grids considering Multi-terminal HVDC networks as well as the installation of energy storage systems. One part of the work carried out contributes to Task 8.1.2 Control Strategies for Integrating and Operating Future International Clusters of Wind Farms and is being incorporated within Deliverable D81.3 where University of Strathclyde and IREC are key contributors.

D).1. Work during mobility period at University of Strathclyde

As expected José Luis Domínguez-García had the opportunity to increase his knowledge and experience not only on control strategies for wind power but also on power electronics design and energy storage. José Luis Domínguez-García was an active participant on the Renewable Energy System Integration group from the Electronic and Electrical Engineering department of the university, which allowed to be involved in other research fields as hybrid power electronics, grid integration of brushless reluctance generators, microgrids and energy storage.

Moreover, fruitful discussions on the ongoing work carried out by each IREC and University of Strathclyde within competitive projects as EU H2020 LIFES50+, SuperGen Wind Energy Hub, among others lead to better understanding of the existing and future collaboration opportunities.

He contributed to RES integration group of the University of Strathclyde to widen his know-how on ancillary services provision including frequency support and power oscillation damping, as well as the integration and control of Multi-terminal HVDC networks for wind power transmission.

Fruit of such research exchange programme and collaboration, two journal papers have been submitted (and are under review) to IET Renewable Power Generation and Renewable and Sustainable Energy Reviews, and further collaborative and joint research is ongoing.

José Luis also gave two presentations within special seminars organized by the RES Integration and Power system dynamics Group. Moreover, during the mobility period he taught an Invited Lecture on power system stability and wind power integration issues and control to master students of the University of Strathclyde.

Meetings with other renewable energy actors were organised. Discussion with ORE Catapult, Siemens Wind, SgurrControl, Scottish Power and Scottish and Southern Energy regarding future challenges in energy systems, with focus on ancillary services provision and requirements for ensuring proper dissemination the mobility task. Additionally, there was the opportunity to attend various conferences/meetings as AllEnergy 2016 and SuperGen Wind Energy HUB General Meeting.

IREC and UoS were not successful in the spring 2016 LCE7 proposal REASONS neither for the Research Infrastructure call from IRPWind. However, future collaborative projects and calls actively searched for. Currently, different joint proposals for applying to the new LCE7 2017 call, 2nd call for Joint Research Infrastructures, ITN Marie Curie Actions, among others are being investigated and under preparation. Also, new applications for mobility exchange of researchers among the institutions are planned.

D).2. Dissemination and Transfer of Knowledge to other IRP and EERA Wind participants

Dissemination, communication and Transfer of Knowledge of the research carried out and the results obtained to general audience (including IRP and EERA Wind participants) was made through the participation on seminars organized by RES Integration and Power system dynamics groups in Glasgow, open to anyone interested in University of Strathclyde as well as through joint publications (two journal papers submitted), personal interviews/meetings (e.g. ORE Catapult) and special topical lectures.

Special emphasis to the dissemination and Transfer of Knowledge to IRPWind and EERA Wind participants is given by including some research done and results obtained as part of the IRPwind deliverable D81.3. Also, the publications (journal papers) will be part (listed) as IRPWind and EERA Wind articles. Finally, it is expected to disseminate the results to the interested EERA wind partners at IRPWind Conference in Amsterdam.

It is worth noting that further results coming from the joint research from both institutions will be disseminated also to IRPWind and EERA JP Wind Subprogramme Grid Integration.

D).3. Results

The outcomes accomplished at the end of the mobility period can be divided into two types i.e. technical and general results.

Technical results:

From the technical perspective, the main outcomes from the research carried out during the mobility stage period are focused on two topics:

- The **technical review** of the existing control techniques for allowing **wind power to provide frequency support** to power systems. The review also considers additional technologies that can play a role on extra power supply as energy storage and power dispatch as HVDC systems. Technical challenges, research opportunities and recommendations are given in this work.
- The **evaluation and coordination** of different proposed **control methods for frequency stability** support developed for various **power-electronic based technologies such as MT-HVDC, onshore and offshore wind power as well as energy storage**. This research focused on the potential coordination and interaction among such technologies for providing primary frequency support, taking into consideration some technical limitations and restrictions as dead-bands and communication delays. It has been shown that system security and stability may be escalated as long as the quantity of frequency support (i.e. power reserves or sharing capacity) is increased. It has been presented that the frequency support provision can be managed carefully through the coordinated MT-HVDC controller; however, the proper selection of the frequency dead-bands providing priority of action is a crucial factor.

General results:

During the mobility period, we have organised two open seminars in the University of Strathclyde, we have pursued new ideas and calls for joint project proposal between IREC, University of Strathclyde and ORE Catapult (including European funded projects, mobility exchanges and IRPWind Joint Research Infrastructures experiments) and we have written two joint journal publications. Moreover, some results have been included in the Deliverable D81.3 of IRPWind Project WP8

The visits and discussions with wind energy actors with base in United Kingdom were very fruitful for disseminating the results obtained, the work carried out and show the proper alignment among Industry and IRP and EERA JP Wind SP Grid Integration main challenges for research and development. How the offshore wind power will be transferred, the impact of HVDC technology to the power systems, the ancillary services distribution within the wind farm, were under discussion.

In the following table, the evaluation of the contribution of this mobility stage to KPI's of IRPWind is given:

Key Performance Indicator (KPI)	Metric and measure
Number of (existing and new) projects that cooperate actively with IRPWIND and that exchange knowledge (and data) with IRPWIND	1 new EU project: INCITE-ITN 1 project from IRPWind Research Infrastructures Some proposals under review/under preparation that will exchange information, including national funded projects, EU funded and IRPwind RI projects.
Number of joint publications by IRP participants supported by national funding accepted/published in peer reviewed journals	2 journal papers submitted (under review): - IET Renewable Power Generation - Renewable and Sustainable Energy Review
Number of researchers involved in mobility and exchange programmes	1
Number of reports from researchers involved in mobility and exchange programmes	1
Number of days of mobility and exchange	93 days (from 5th of March to 5th of June).
Number of joint publications related to the participation in the exchange programmes	2 journal papers submitted: - IET Renewable Power Generation - Renewable and Sustainable Energy Review Other, from the ongoing work, are expected.
Number of dissemination events related to the participation in the exchange programmes	2 seminars (workshops) at University of Strathclyde: - RES integration Group - Power System Dynamics Group 1 Invited Lecture at University of Strathclyde: Assistance/Participation in conferences/meetings: - AllEnergy 2016 - SuperGen Wind Energy Hub Visits and discussion with industry: - Siemens Wind - SgurrControl - Scottish Power - Scottish and Southern Energy

Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**III** **3 months** **Dominguez-Garcia/University of Strathclyde**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	x yes ☐ No
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	x yes ☐ No
Was the used methodology effective ? Please comments if NO	x yes ☐ No
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	x yes ☐ No
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	x yes ☐ No
How do you evaluate the report? Good (4)	1 2 3 4 5
Is any missing information in the report? Please comments if yes	☐ yes x No
Rate the overall experience as described in the final report. Good (4)	1 2 3 4 5

Other Suggestions?
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[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Application form for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	**Néstor**
Applicant Surname	**Ramos García**
Home Institution	**DTU Wind Energy**
IRP Partner? *(yes/no)*	**Yes**
Home Institution Postal address	**Nils Koppels Alle, Building 403, 2800 Lyngby, Denmark**
E-mail	**nerga@dtu.dk**

B) Host institution details

Institute name	**CENER**
IRP PARTNER?	**Yes**
Contact person	**Alvaro González Salcedo**
Country	**Spain**
E-mail	**agonzalez@cener.com**

C) Relevant Programme and scheme

CORE PROJECT? ***YES/NO***	**(A) Offshore Wind Energy**	**RELEVANT EERA SUB-PROGRAMME**	**(A) Offshore Wind Energy** **(E) Aerodynamics**
Length of the grant scheme	**(01) 1 month**	**Start date:**	**25th January**

RESEARCH COLLABORATION ON THE DEVELOPMENT AND VALIDATION OF TWO-DIMENSIONAL PANEL METHODS FOR STALL SIMULATIONS

N. Ramos-García, A. González and M. Aparicio

February 22, 2016

Contents

Chapter 1
Description of the work and major results

1.1 Introduction

The collaboration project between CENER and DTU Wind Energy is mainly based on the development and validation of state of the art aerodynamic solvers conceived independently by both partners. CENER has since 2010 worked in the development of AdaptFoil2D [1] [2] [3]. In parallel, DTU Wind Energy has upgraded its steady double wake model, DWM [4] [6], into an unsteady version coupled to an integral boundary layer solver, the USDWM [5] [7] [8].
Both codes, AdaptFoil2D and USDWM, are based in the idea that the flow past a solid body can be modeled by a distribution of flow singularities around the body's contour. However, in the process of implementation CENER and DTU followed different fundamental approaches:

- AdaptFoil2D uses a Dirichlet boundary condition of zero internal potential, USDWM implements a Neumann condition of zero normal velocity at the airfoil surface.
- AdaptFoil2D uses two-dimensional point doublets while USDWM uses higher order linear vorticity distribution. This difference is key in the treatment of the separated region.
- AdaptFoil2D uses a point vortex to initially model the vorticity shed by the body. USDWM uses a panel with constant vorticity distribution. Both solvers use vortex blobs further downstream.

The way these singularity distributions and boundary conditions are treated and solved forms the core of the panel methods, being the main characteristic that differentiates the codes from each other, and making very interesting a detailed comparison and validation of the solvers. Furthermore, different implementation strategies have been taken in terms of Kutta condition, vortex modeling and wake-body interaction.

1.2 Initial Comparison

An initial comparison between USDWM and AdaptFoil2D has been carried out for two different geometries.

1.2.1 NACA 0015

In this case AdaptFoil2D inputs have been used as a baseline and the inputs for USDWM have been modified accordingly. The inputs for both solvers are shown in Table 2.1 and 2.2.

Simulations have been performed at five different angles of attack and a detailed comparison has been carried out. The two more representative cases, 25 and 45 degrees, are presented in Figures 2.1 and 2.2. In general USDWM tends to over-predict the suction peak while AdaptFoil2D presents a larger vorticity accumulation in the separated area creating a higher absolute pressure and increasing the drag. In terms of the lift fluctuations spectra, generally a good agreement is obtain between both codes.

1.2.2 Cylinder

Simulations of flows past a circular cylinder at subcritical, supercritical, and transcritical flow regimes are carried out. All the calculations are compared against the experimental data of Schewe [10], from which the separation location is obtained. In this case USDWM inputs have been used as a baseline and the ones from AdaptFoil2D have been modified accordingly. The inputs for both solvers are shown in Table 2.3 and 2.4.

In the supercritical flow regime, 2.3, both solvers have a very similar behavior. It is important to note the transient of USDWM simulations which seems to last the first 60 seconds. In terms of lift, Figure 2.3(a) an excellent agreement is obtained between both solvers, as well as in the Strouhal frequency, Figure 2.3(c), both solvers predict an non-dimensional frequency of approximately 0.4. The main discrepancy in the average pressure distribution is seen just downstream of separation, where the Kutta condition applied in AdaptFoil2D forces a zero velocity forcing a stagnation point, see Figure 2.3(d).

In Figure 2.4 is shown the initial validation of the average Cd and St quantities against Schewe's experiments [10]. It is observed from 2.4(a) how the USDWM has a good prediction of the Strouhal frequency for lower and higher Reynolds numbers, underpredicting it for the supercritical regime. In terms of Cd, Figure 2.4(b), the inverse scene is captured, overpredicting at lower and higher Reynolds and giving a good Cd estimate for the supercritical case. In this initial comparison AdaptFoil2D over-predicts the average Cd in the subcritical regime while the Strouhal frequency is under-predicted for both subcritical and supercritical cases.

1.3 Recognition of limitations and proposed solutions

1.3.1 Suction peak over-prediction at large AoA in USDWM

An initial proposed solution has been the modification of the Kutta condition to make the leading and trailing vorticity of panel S equal to zero. This has been implemented following the steady Double Wake Model (DWM) approach [6]. This modification has a small effect in the suction peak, however judging from the average Cp curves the vorticity is seen to be slightly redistributed in the separated region.

It has been found that the use of a lower nascent angle for the USDWM simulations has a critical effect in the pressure peak as well as in the level of the separation plateau. Lowering the nascent angle from 45 degrees (initially force to be equal to AdaptFoil2D input) to 15 degrees lowers considerable the suction peak and increases the absolute pressure in the separated area, see 2.5. The latter is clearly related to the release of vorticity closer to the airfoil surface.

1.3.2 Vortex-body interaction

The proposed solution is a correction of the vortex trajectory and the generation of a limiting layer around the body contour that prevents the vortices from approaching the body surface. The following corrections have been implemented in USDWM:
Correction of vortices that penetrate the body:

- The vortices are reflected outwards perpendicular to the body surface a distance equal to the normal penetration distance.
- The vortices are moved outwards perpendicular to the body surface a distance equal to the limiting layer.

Correction of vortices that penetrate the limiting layer:

- The vortices are moved outwards and place in the limiting layer
- The vortices with negative normal velocity, in local panel coordinates (closest panel), have their normal velocity reset to zero. The tangential velocity remains unmodified.

The best results have been obtained by pushing the vortex blobs to the boundary edge in either case, body surface or limiting layer penetration.

1.3.3 Pressure over-prediction in the separated region

The pressure over-prediction in the separated region is identified as directly related to the accumulation of vorticity in the area [9]. It is believed that this issue is inherent to the two-dimensional nature of the simulations since it is also inherent to other two-dimensional methods like 2D DES [11]. The proposed solutions are the implementation of a Random Walk, a Core Growth model and a Vortex coalescence criteria.

Core Growth model

A core growth mode has been implemented in USDWM. The model increases the size of the viscous core radius in function of time as follows,

$$r_c(t) = \sqrt{4\alpha_v \delta_v \mu(t + t_o} \tag{1.1}$$

The turbulent eddy viscosity, δ_v, has been identified as the key parameter to model diffusion. In Table is shown the changes in the aerodynamic quantities with δ_v for transcritical flow conditions. Higher values of δ_v tend to reduce the drag coefficient, approaching the experimental data.

Random Walk

The time variation of the vorticity in a fluid can be modeled in two steps, a convective and a diffusive one. The convective part is governed by the Biot-Savart law, while the diffusive part is known to be equal to the probability density function of a Gaussian random variable. Therefore, the solution to the diffusive part of the vorticity equation can be modeled by a two-dimensional displacement of the vortex blobs using two independent Gaussian random numbers, each having a zero mean and a standard deviation as follows,

$$\sigma = \sqrt{\frac{2dt}{Re}} \tag{1.2}$$

The splitting technique has been implemented in USDWM. A validation against cylinder flow cases has shown a minor effect in the average aerodynamic quantities. The instantaneous values however, are strongly affected, specially for subcritical flows. The random walk model avoids the generation of regions with concentrated vorticity in the surface vicinity.

Vortex coalescence

The vortex coalescence is defined as the merging of two vortices with opposite strength that are close to each other. It has been tested that the use of vortex coalescence with a critical radius equal to the viscous core does not affect the average aerodynamic quantities.

1.3.4 Calculation of the potential term in Bernoulli equation, $d\phi/dt$

AdaptFoil2D assumes that the time variation of the potential is equal to the time variation of the doublet distribution. USDWM calculates the potential by integrating the velocities from infinity up to the target collocation point. A correction needs to be added in the separated region to account for the pressure jump over the separation shear layer. This correction can be calculated in different ways. The first option is to use the vorticity at the separation panel to compute the pressure jump, a second approach is to use the separation panel velocity. The two approached have been tested and compared against AdaptFoil2D simulations, see Figure 2.6.
In this case AdaptFoil2D simulations have been performed with a nascent angle of 20 degrees, this seems to be critical to capture the correct level of the pressure plateau. A much better agreement is obtained in this case, although the proximity of the nascent vortex generates higher amplitude oscillations and noise in the aerodynamic coefficients.

1.4 Final Comparison

A final comparison has been performed between USDWM, AdaptFoil2D and Schewe's experimental data to evaluate the new implementations performed during the collaboration project. In general, a better prediction of the drag characteristics is obtained for subcritical and transcritical flows in both solvers, Figure 2.7(b). AdpatFoil2D has improved the Strouhal frequency prediction for both subcritical and supercritical flows, USDWM has a good Strouhal prediction for subcritical and transcritical flows, under-predicting it in the supercritical regime, Figure 2.7(a).

Chapter 2
Conclusion and future work

2.1 Compliance to the expected results.

The KPI for the collaboration project is a publication that is in process, the present report for the IRP-WIND programme and an extended report with a detailed description of the development and improvements applied in the codes. The TRL has advanced to a level 8, the proposed solutions to the detected limitations of the panel methods have been implemented and the codes have been verified against experimental data.

2.2 Benefits for the different partners involved.

Benefits for the host organization:

- Validation of AdaptFoil2D for cylinder flow cases, including a modification in the Kutta condition.
- Implementation of USDWM boundary layer solver in Adaptfoil2D using a direct viscous-inviscid interaction.

Benefits for the researcher and home organization:

- Implementation of various vortex-body interaction procedures.
- Implementation and initial validation of a Random-walk diffusion model.
- Implementation and initial validation of a viscous core growth model.
- Improvement of the code structure and makefile.

Benefits for the IRP programme:

- Share of knowledge between two IRP-Wind participants.
- Further Development of tools that are being used in IRP-Wind projects.

2.3 Future perspectives.

- Implementation of time dependent terms in AdaptFoil2Ds new b.l. solver.
- Implementation of a random walk model in AdaptFoil2D.
- Implementation of a multi-element double wake model.
- Implementation of a quasi-3D solver to lower the accumulation of vorticity.
- Conference paper to present the work done during the collaboration.

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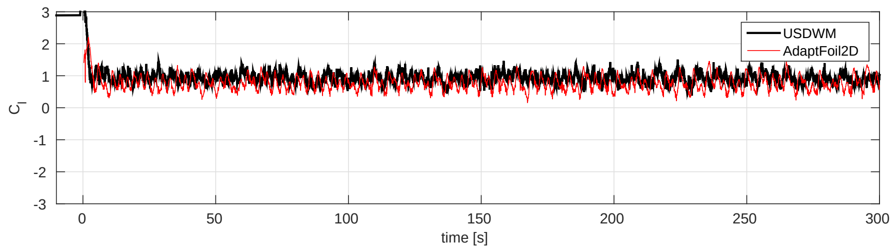
List of Figures



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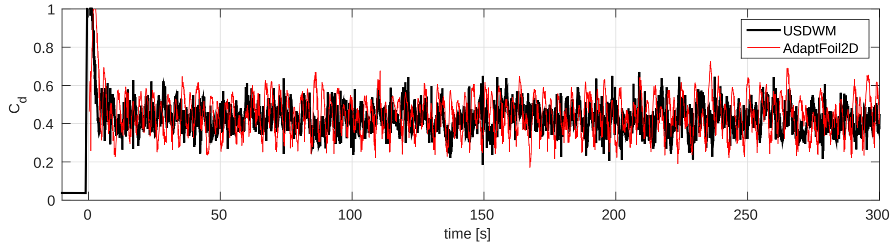

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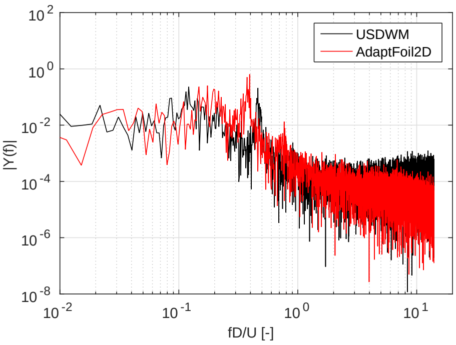

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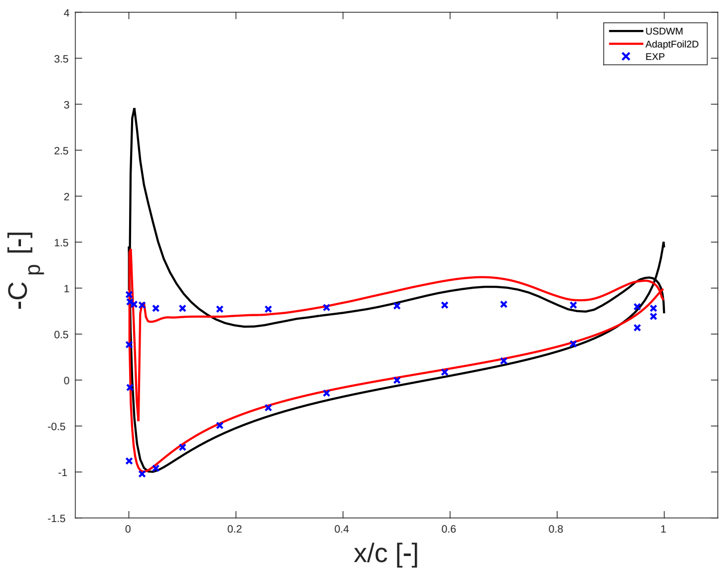


(d)

Figure 2.1: NACA 0015, angle of attack 25 deg (a) Cl, (b) Cd, (c) Spectrum and (d) Cp .

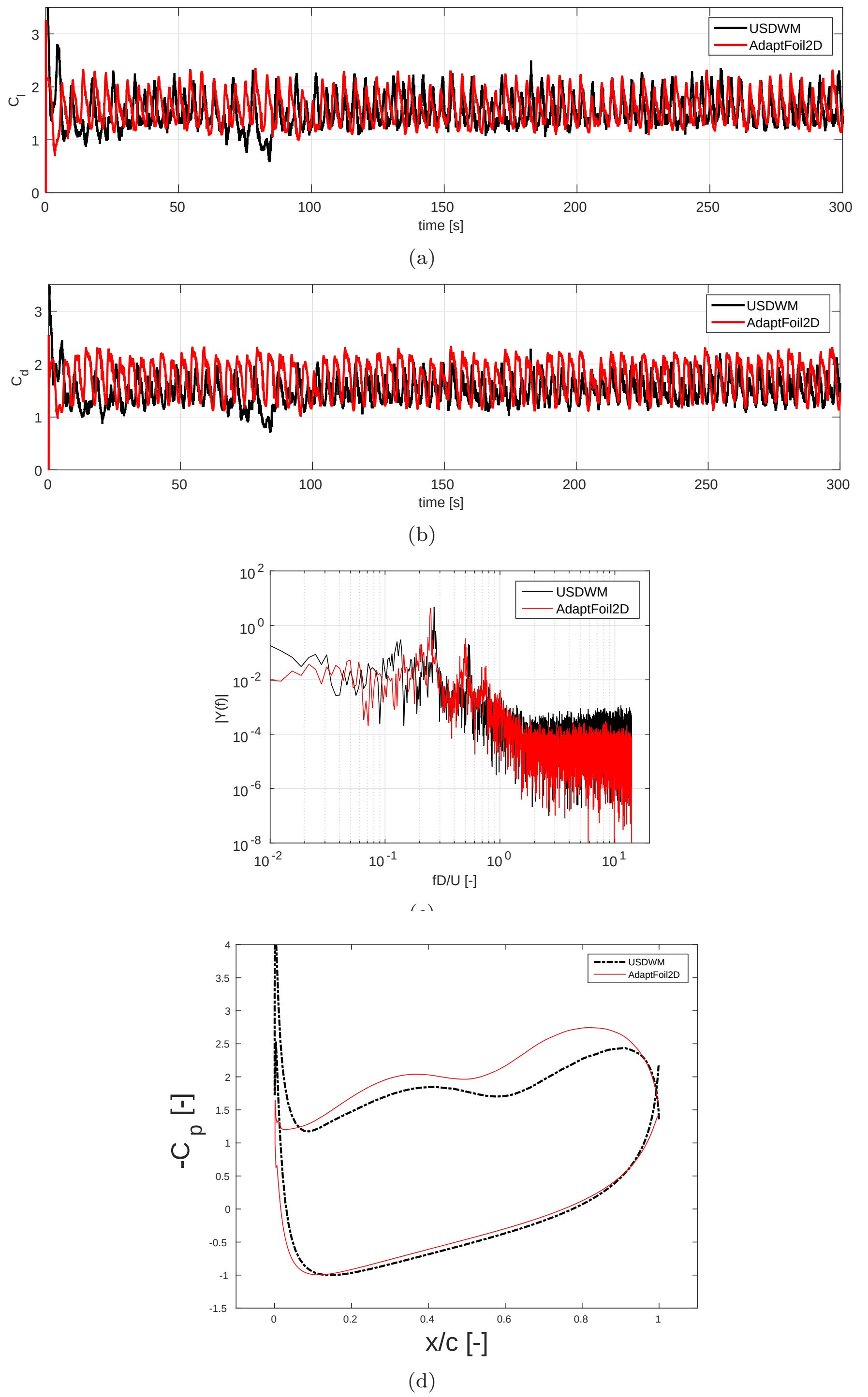
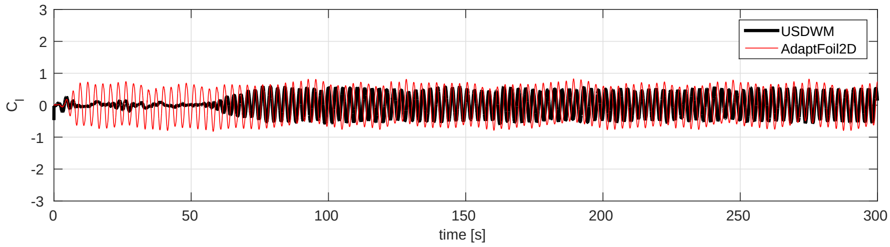


Figure 2.2: NACA 0015, angle of attack 45 deg (a) Cl, (b) Cd, (c) Spectrum and (d) Cp .



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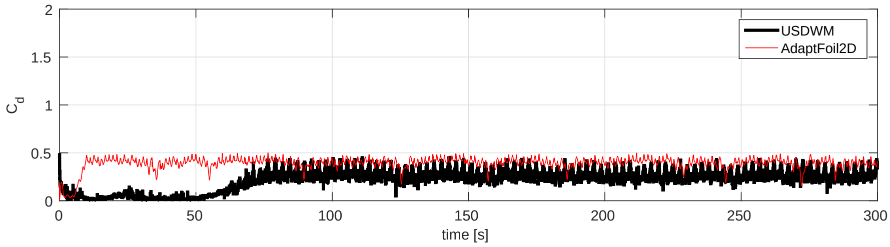

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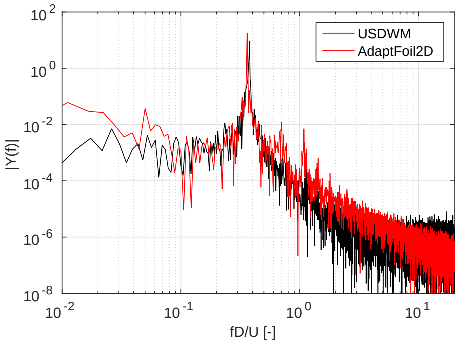

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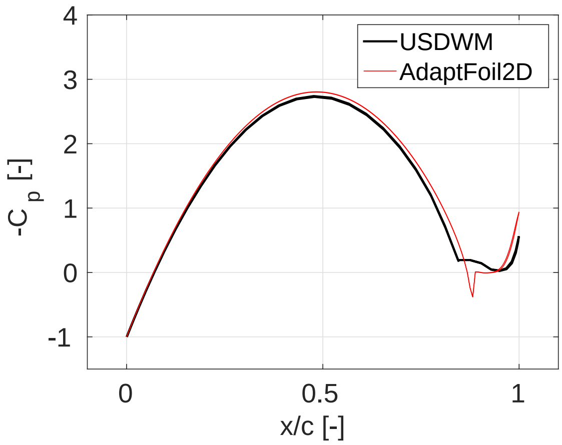

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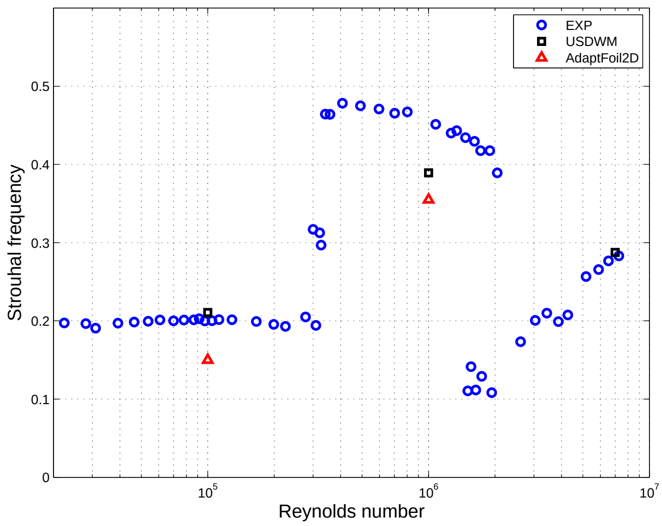
Figure 2.3: Supercritical flow past a circular cylinder (a) Cl, (b) Cd, (c) Cl spectrum and (d) Cp .



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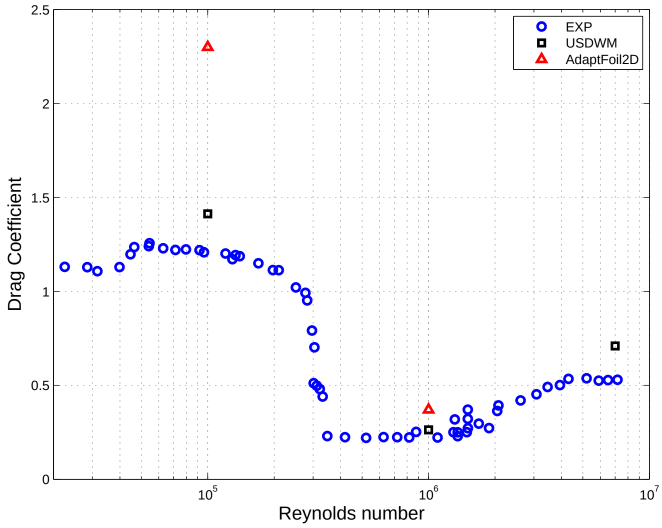

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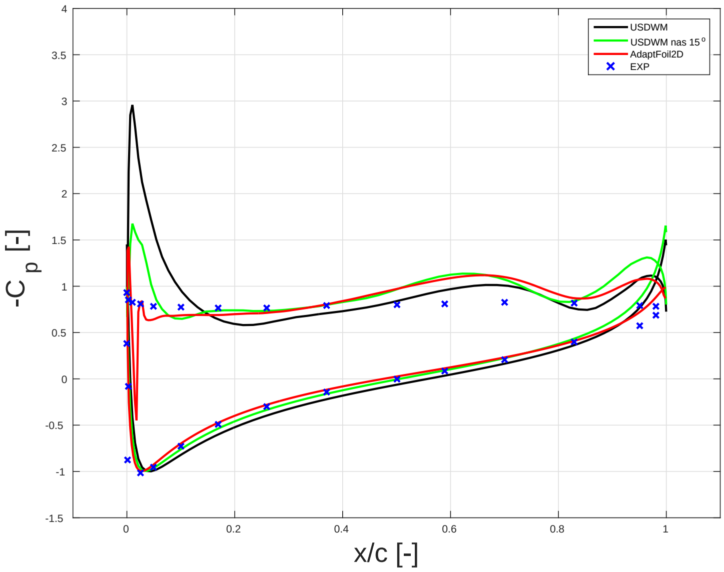
Figure 2.4: Circular cylinder flow, initial comparison against Schewe [10] experimental data (a) St (b) Cd .



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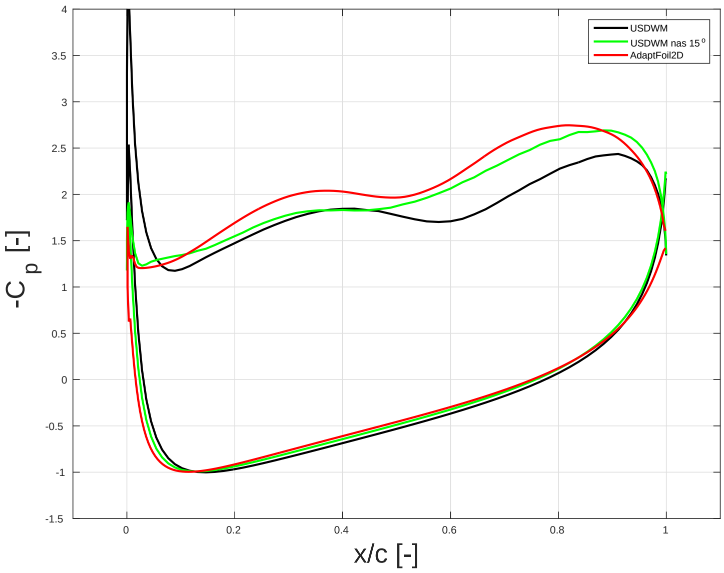

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Figure 2.5: NACA 0015 simulation with nascent angle modification, surface pressure coefficient at angle of attack (a) 25 and (b) 45 degrees.

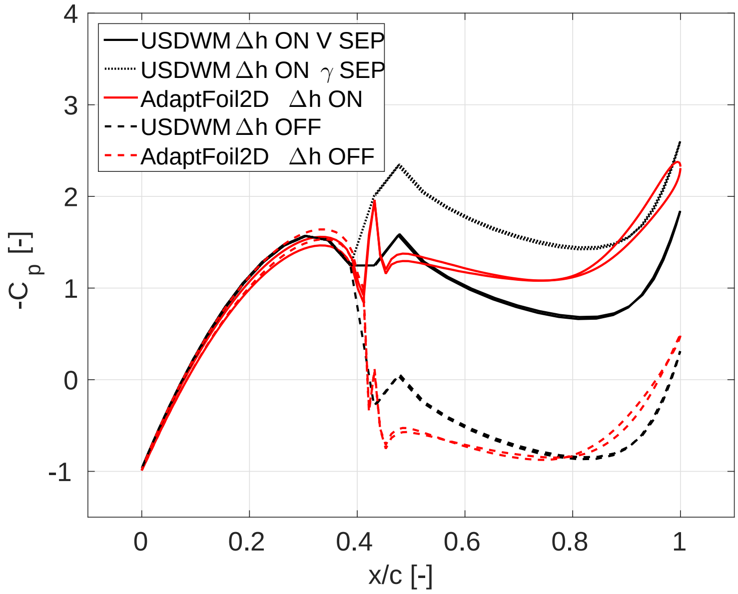
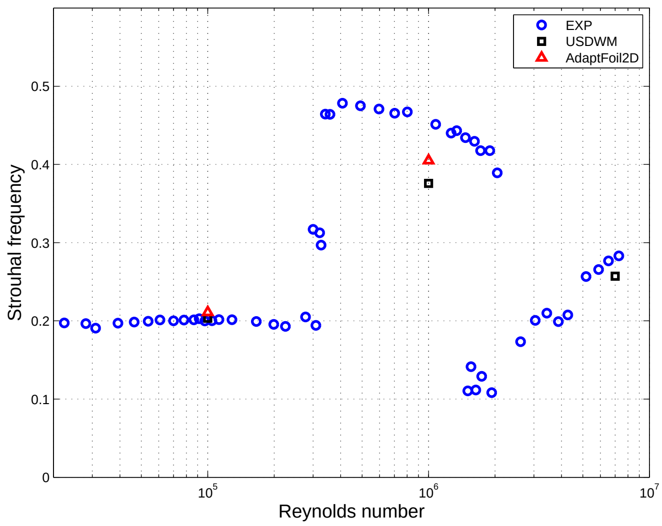


Figure 2.6: Circular cylinder, subcritical flow, surface pressure coefficient with various pressure head calculations .



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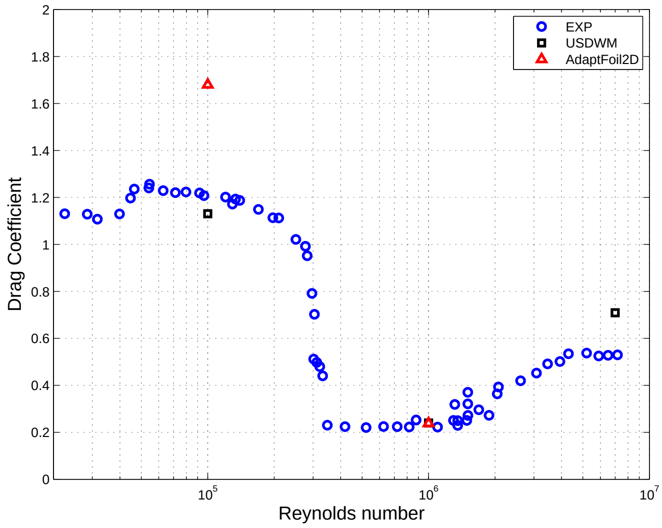

(b)

Figure 2.7: Circular cylinder flow, final comparison against Schewe [10] experimental data (a) St (b) Cd .

List of Tables

solver	c $[m]$	U_{inf} $[m/s]$	Npan	N blobs	dt $[s]$
USDWM	1.0	1.0	140	1000	3.58e-2
Adaptfoil2D	1.0	1.0	300	600	3.58e-2

Table 2.1: Solvers inputs for initial NACA 0015 comparison

solver	r_c $[m]$	h_{bl} $[m]$	$\theta_{nas}[deg]$
USDWM	6.7e-3	1.64e-2	45
Adaptfoil2D	6.7e-3	1.64e-2	45

Table 2.2: Solvers inputs for initial NACA 0015 comparison

solver	D $[m]$	U_{inf} $[m/s]$	Npan	N blobs	dt $[s]$
USDWM	1.0	1.0	140	1000	2.0e-2
Adaptfoil2D	1.0	1.0	300	1000	2.0e-2

Table 2.3: Solvers inputs for initial cylinder comparison

solver	Rc $[m]$	h_{bl} $[m]$	$\theta_{nas}[deg]$
USDWM	4.0e-2	4.0e-2	45
Adaptfoil2D	4.0e-2	4.0e-2	45

Table 2.4: Solvers inputs for initial cylinder comparison

Flow Regime	δ_v	C_l'	$\bar{C_l}$	$\bar{C_d}$	St
Transcritical	0.0	0.7502	0.0190	0.8500	0.2999
	200.0	0.7516	0.0230	0.8467	0.2999
	1000.0	0.7721	0.0179	0.8438	0.2999
	5000.0	0.7936	0.0174	0.7936	0.2999
	10000.0	0.7752	0.0140	0.7329	0.2999

Table 2.5: Aerodynamic force characteristics for different apparent viscosity values, δ_v

Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**III** **1 month** **N. Ramos-Garcia/CENER**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	☐ yes
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	☐ yes
Was the used methodology effective ? Please comments if NO	☐ yes
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	☐ yes
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	☐ yes
How do you evaluate the report? (with some interesting pictures/figures that gives the general public a quick insight in the value of the project, the evaluation would be 5)	4
Is any missing information in the report? Please comments if yes	☐ No
Rate the overall experience as described in the final report.	5

Other Suggestions?
some interesting pictures/figures that gives the general public a quick insight in the value of the project.
In any case: my compliments on the good collaboration between institutes!

[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Application form for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	**Malo**
Applicant Surname	**Rosemeier**
Home Institution	**Fraunhofer IWES Northwest**
IRP Partner? *(yes/no)*	**yes**
Home Institution Postal address	**Am Seedeich 45** **27572 Bremerhaven, GERMANY**
E-mail	**malo.rosemeier@iwes.fraunhofer.de**

B) Host institution details

Institute name	**DTU Wind Energy**
IRP PARTNER?	**yes**
Contact person	**Kim Branner**
Country	**Denmark**
E-mail	**kibr@dtu.dk**

C) Relevant Programme and scheme

CORE PROJECT? YES/NO *(Please erase the non-relevant)*	**(C) Structures and Materials**	**RELEVANT EERA SUB-PROGRAMME** **Max 2** (Please erase the non-relevant)	**(C) Structures and Materials**
Length of the grant scheme *(Please erase the non-relevant length)*	**(03) 3 months**	**Start date:**	**March 1, 2016**

Fraunhofer IWES
Am Seedeich 45
27572 Bremerhaven
Germany

Report

VALDEMOD

Validation and Improvement of Component Test Design Models

Malo Rosemeier

June 17, 2016

Contents

1 Introduction

The goal of this project was to develop and validate design models for an integrated process towards defining a trailing edge (TE) sub-component test out of a full-scale rotor blade structure. Therefore, the test loading conditions were defined and the test configuration was designed using analytical and numerical models.

Future design standards such as the IEC61400-5 Rotor blades and the new guideline DNVGL-ST-0376 Rotor blades for wind turbines [1] will encourage designers to use validated models and appropriate analysis methods. Component tests represent a relatively economic way for validation. Thus, the outcome of this project will support the industry with proposals for applicable methods and modeling strategies for component tests. This project provides the following deliverables:

- Proposals for current design model improvements to predict a more compliant test behavior based on the available measurement data from experiments.
- Proposal for a test setup using the improved design model for future component tests.

2 Description of the work and major results

Within IRPWind WP7.1 WMC, DTU and IWES are working together to define and design TE sub-component test setups. Two different setups are followed: IWES uses an available testing machine enabling static and dynamic testing, whereas DTU (similar to WMC) designed a new test frame where the load is introduced via two hinged beams (Fig. 1).

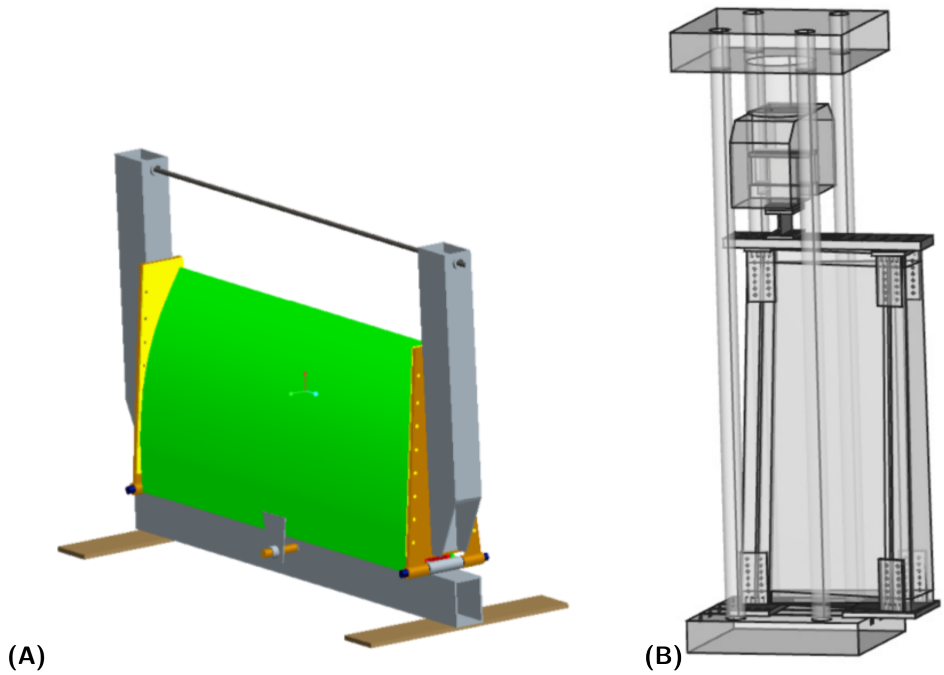

Figure 1: Sub-component test setups proposed by: (A) DTU [2] and (B) Fraunhofer IWES [3].

The goal of the trailing edge test in general and thus in both setups is to mimic the strain state of the lead-lag-wise full-scale certification test. Due to the kinematics of the test rigs, the boundary conditions are different in both setups (Fig. 2). The IWES test rig has unsymmetric boundary conditions and a movable axial plus bending moment load introduction, whereas the DTU test rig has a symmetric boundary condition and a fixed pure bending moment load introduction.

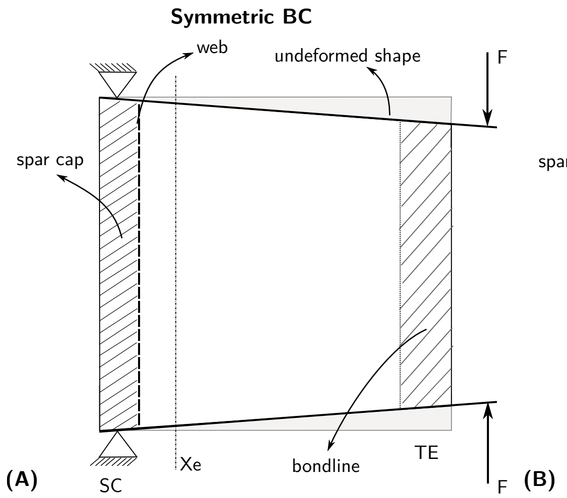

Figure 2: Load introduction, boundary conditions and deformation principle of sub-component test setups: (A) symmetric load introduction and boundary conditions (DTU) and (B) unsymmetric boundary conditions (IWES). The load introduction dx and dy in (B) can be varied.

To analyze and improve the test rig design, a numerical full-scale rotor blade model was developed based on the SSP34 blade laminate plan and geometry [2]. The model has been verified with two existing finite element (FE) models of other software packages [4, 5], and validated with full-scale experiments conducted at DTU (Fig. 3a/b).

For the TE sub-component test setup, the TE was cut-out of the full-scale FE model. Simulations were conducted for the four extreme load introduction positions (Fig. 4) The longitudinal strain on the sub-component and full-scale blade's surface was used as indicator to compare the performance of sub-component tests with the full-scale test (Fig. 5a-d). Fig. 5d shows the strain deviation of the numerical simlations of the sub-component compared to the full-scale test. In the area of focus at the trailing edge (at 0.0 and 1.0 arc-length) the deviations are about 2.0 % to 2.7 % for both loading conditions, xmin_ymin and xmin_ymax respectively. Along the pressure-side panels (at 0.05 to 0.33 arc-length) the maximum deviation is about 6.0 % to 13.0 %, respectively. Along the suction-side panels (0.71 to 0.95 arc-length) the maximum deviation is about 9.0 %to 23.0 %, respectively.

Further focus was on the load introduction device (LID) of the test rig transferring the load from the testing machine into the specimen (Fig. 6). The LID introduces the load by means of shear plates at the four corners at both the top and bottom of the specimen connection. The integrity of these regions needs to be determined to verify the local and global effects on test, due to the local load introductions. At this point in the analysis the goal is to determine the local stress distributions and concentrations in the bonded region.

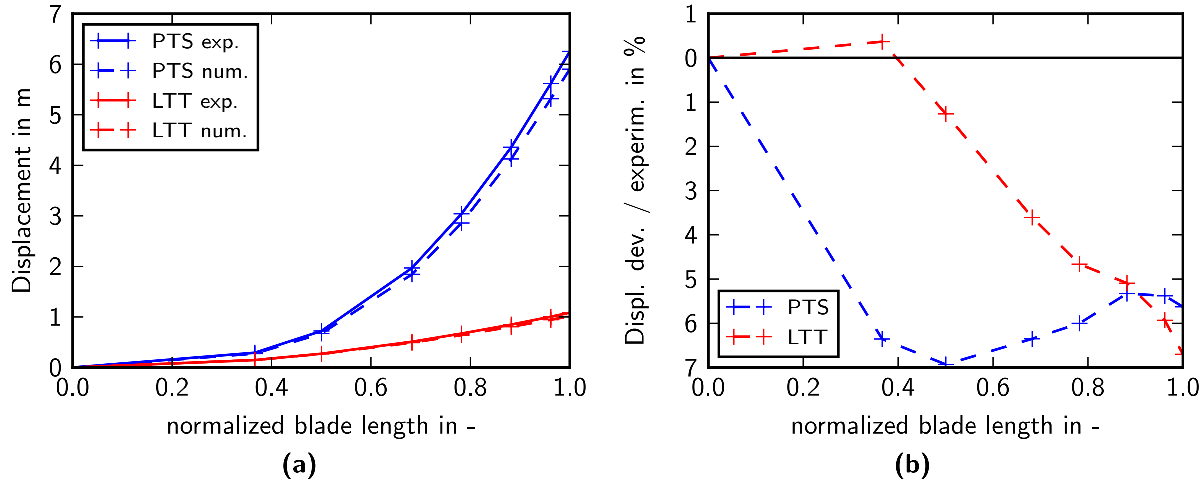

Figure 3: Displacements in flap- and lead-lag-wise direction for the flap-wise (PTS) and lead-lag-wise (LTT) full-scale certification tests [6]: (a) absolute displacements of the experiments (exp.) and the numerical model (num.), and (b) relative deviation of the numerical model w.r.t the experiment.

Therefore, a detailed finite element model was developed to evaluate the integrity of the adhesive area between load introduction and specimen surface.

The major results of the project are summarized in the following:

- A numerical finite element model was developed and validated directly with full-scale experiments and indirectly with other validated finite element models. Further, the numerical model was verified with an analytical model.
- A TE test setup and load introduction device was designed using the numerical model.

3 Compliance to the expected results, Key Performance indicators KPIs and the advancement of Technological Readiness Level accorrding to the application

As written in the application the results of this project were expected to be the jointly developed methodologies and component test design model improvements based on experimental results. Comparing the expected results with the major results (section 2) show that these results were fulfilled.

The key performance is indicated by the quality of the design models' prediction of the experimental behaviour, i. e. capturing the structural response from experiments in the numerical model. Mathematically it is defined as deviation between the model's response and the experimental measurements (strains, deflections, damage, etc.). In the application it was expected that sub-component test results were available to validate the numerical model. During the project it was emphasized that the design of the sub-component test is more complex than expected and requires the developed model is the basis for a proper sub-compnent test design. This indicates that the model could not be validated with

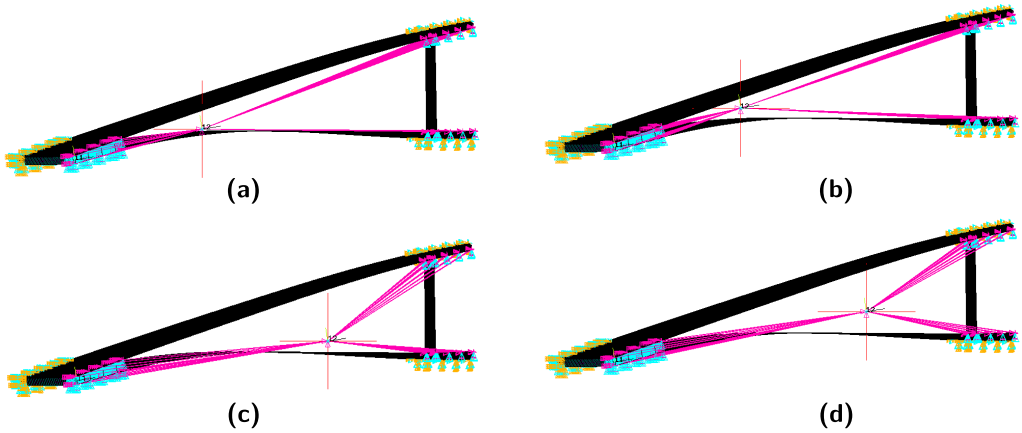

Figure 4: Finite element model of the TE sub-component test setup seen from the top and its variation of the load introduction point at the master node of the multi-point constraint: (a) xmin_ymin, (b) xmax_ymin, (c) xmin_ymax, and (d) xmax_ymax.

sub-component test results within the visiting period, but is planned in the next future. However, the KPIs could be evaluated by validating the numerical model with the test results of conducted full-scale blade experiments. Further, the developed numerical model is validated indirectly by verifiying the model with other already validated models.

The Technological Readiness Level (TRL) according to [7] at the beginning of the project VALDEMOD was 2-3: Simple models were available to design a sub-component test and the specimen were available to be prepared for experiments. Preliminary test results were available. With the development of the numerical models it is possible to predict the structural response as expected in the experiments. Further, it is possible to model the boundary conditions properly. However, the experimental setups are still in its design phase. That is, the specimen are prepared and processed, but the final test setup, i. e. the load introduction needs to be determined based on the numerical simulations. Thus, the TRL at the end of the VALDEMOD project is still at 2-3, since the technology concept is formulated but we do not have yet the experimental proof of concept. This is also the reason why the current TRL is not as the expected TRL of 3-4 as of the application.

4 Description of the benefit for the researcher, the host and home organization and IRP programme

Frequent meetings were held during the stay at DTU. Within these meetings it was possible to interact closely with the researchers of the hosting institution. Different approaches and ideas were exchanged and discussed.

The host and home institute benefit from the joint development of methodologies since the experiences and insights into the different approaches of the IWES and DTU test setups were exchanged and discussed openly.

The model developed in the VALDEMOD project was shared between the IRPWind WP7.1 partners. The consortium benefits, since the partners are working on the same type of specimen within the IPRWind project.

5 Future perspectives

The future plan is to further collaborate within this project. That is exchange of experiences with the sub-component experiments and the test setups itself will be exchanged. A further goal is to write a joined publication about the sub-component test methods.

Acknowledgements

This project was funded by the IRPWind mobility program within the European Commission's Seventh Framework Programme (grant agreement No. 609795).

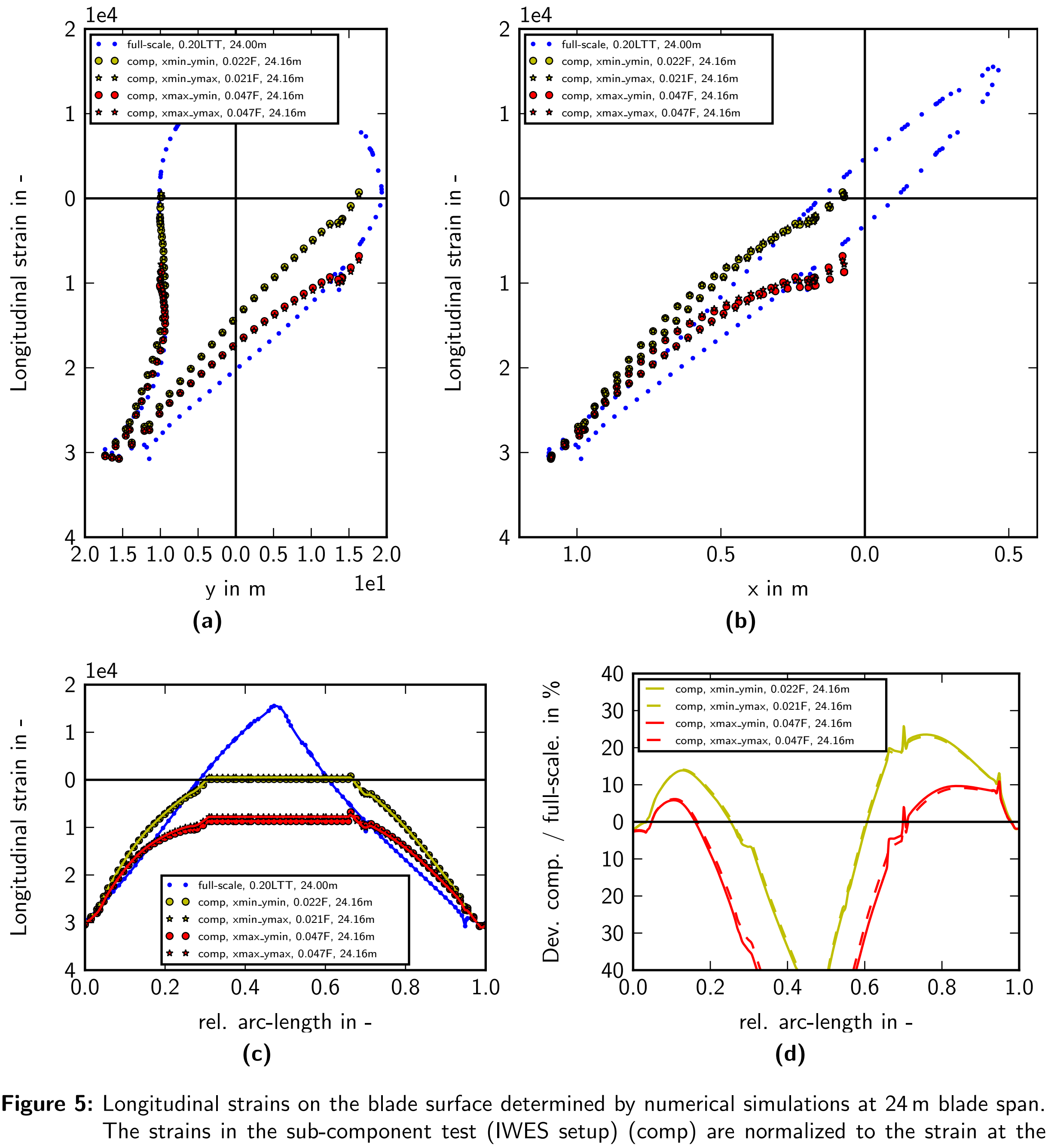

Figure 5: Longitudinal strains on the blade surface determined by numerical simulations at 24 m blade span. The strains in the sub-component test (IWES setup) (comp) are normalized to the strain at the trailing edge at 20 % load level of the full-scale lead-lag-wise certification test (0.20LTT). The strains are plotted over the blade thickness y (a), chord length x (b) and over the relative arc length of the blade surface. The deviation of the component strain w.r.t the full-scale LTT test is shown in (d). Four different load introductions positions are shown.

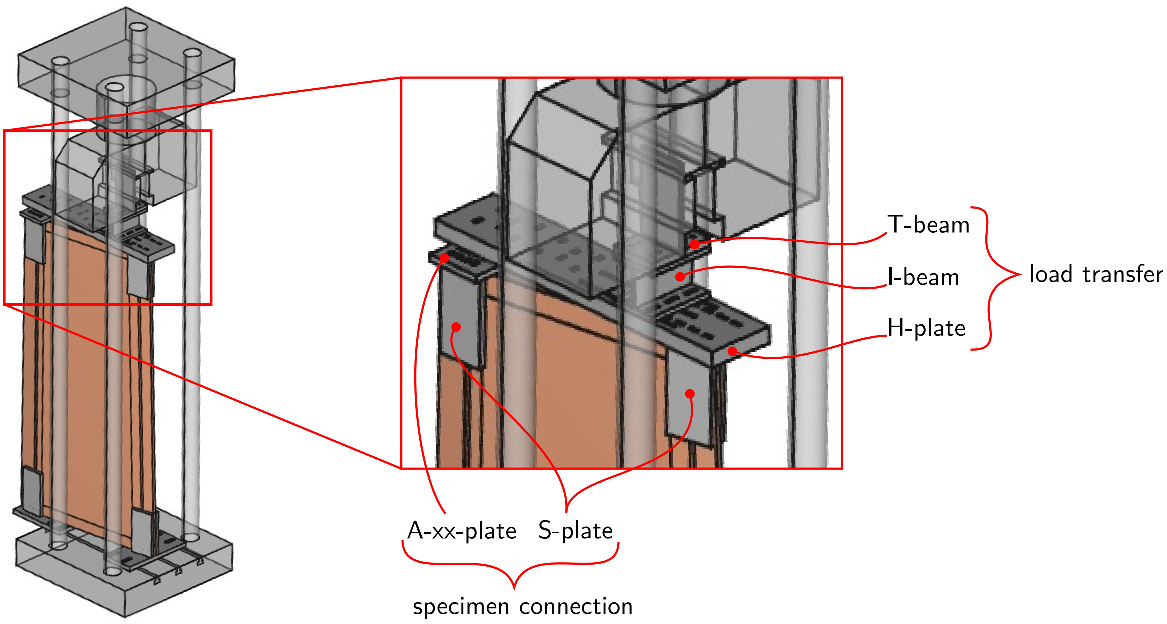

Figure 6: Load introduction device (LID) of IWES test setup.

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Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**III** **1 MONTH** **ROSEMEIER / DTU**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	X yes ☐ No
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	X yes ☐ No
Was the used methodology effective ? Please comments if NO	X yes ☐ No
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	X yes ☐ No
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	X yes ☐ No
How do you evaluate the report?	1 2 3 **4** 5
Is any missing information in the report? Please comments if yes	☐ yes X No
Rate the overall experience as described in the final report.	1 2 3 **4** 5

Other Suggestions?
……
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[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Application form for Mobility grants within IRPWIND

- **All documents must be named as follows:**

Sub Programme letter, Number of months, Surname, Document type. Ex: A_03_Smidt_cv
See Table C) below.

A) Applicant details

Applicant Name	Philipp
Applicant Surname	Härtel
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B) Host institution details

Institute name	SINTEF Energi AS
IRP Partner?	Yes
Contact person	Hans Christian Bolstad
Country	Norway
E-mail	hans.christian.bolstad@sintef.no

C) Relevant Programme and scheme

CORE PROJECT? YES/NO	**(B) Wind Integration**	**Relevant EERA SUB PROGRAMME** **Max 2**	**(B) Wind Integration**
Length of the grant scheme	**(02) 4-26 weeks**	**Number of weeks** **Start date:**	**13 weeks (April-June 2016)** **1 April 2016**

Fraunhofer IWES

FRAUNHOFER-INSTITUT FÜR WINDENERGIE UND ENERGIESYSTEMTECHNIK IWES

IRP MOBILITY PROGRAMME

Final Report

IRP MOBILITY PROGRAMME FINAL REPORT

Impact of alternative flexibility options on offshore grids in the North Sea

Philipp Härtel

Fraunhofer Institute for Wind Energy and Energy Systems Technology, IWES
in Kassel, Germany.

Reference: 4th Call of the IRP Mobility Programme, deadline January 31, 2016
Host institution: SINTEF Energi AS in Trondheim, Norway.

Table of Contents

0 Abstract

As part of the IRP Mobility Program, researcher Philipp Härtel of Fraunhofer IWES (Kassel, Germany) has been working at SINTEF Energi AS (Trondheim, Norway) as a visiting researcher from April 1 until June 30, 2016. Together with teams from both the Department of Energy Systems at SINTEF and the Department of Electric Power Engineering at NTNU, which also included members of the Norwegian NSON (North Sea Offshore Network), he worked on several topics regarding the issue of alternative flexibility options and their impact on offshore grids in the North Sea.[1]

Based on previous and ongoing NSON research activities on both the SINTEF/ NTNU and Fraunhofer IWES side, the need for a thorough comparison and evaluation of cost parameters for VSC HVDC transmission technology was identified. As the main result, a journal article "Review of Investment Model Cost Parameters for VSC HVDC Transmission Infrastructure" has been written which is to be submitted to the Journal of Electric Power Systems Research. For the development of aggregated hydro power representations, a new aggregation approach developed in the German NSON project was presented and discussed in detail, which is now being used in an offshore grid expansion model and other unit commitment models at Fraunhofer IWES. Comparing two market-based offshore grid expansion planning models, crucial characteristics and differences were identified. As a consequence, different input data clustering approaches were investigated and the results are to be published at the EERA DeepWind'2017 conference in January. Finally, a commonly agreed upon cost-benefit evaluation methodology for power market operations was discussed and will now be used for further research activities in the German NSON-DE project.

These results and the overall knowledge gained through the opportunity of this IRP Mobility project helped to significantly advance the NSON-DE research activities. Furthermore, the new contacts which could be established during the three months in Trondheim have already helped to realize future research collaboration.

1 http://blog.sintefenergy.com/wind-power/impact-of-alternative-flexibility-options-on-offshore-grids-in-the-north-sea/

1 Introduction

1.1 Motivation and research topics

The ongoing generation shift from dispatchable hydro-thermal generation towards fluctuating renewable feed-in in the respective generation portfolios is an important driver of energy system evolution as it demands increased flexibility of the energy system and yields a new allocation of power flows at the same time. In an energy system dominated by renewable energy generation, the efficient utilization of spatial and temporal fluctuations induces increased energy transfer between market areas. Offshore transmission infrastructure in the North Sea Region, especially in the form of an integrated offshore grid, can provide additional flexibility to the system and avoid heavy curtailment of weather-dependent renewable energy generation.

Therefore, discussions about offshore grids serving the twofold purpose of integrating offshore generation into onshore energy systems and at the same time enabling cross-border electricity trade are intensifying. As offshore infrastructure is comparatively costly and has to compete with other flexibility options, accounting for the flexibility potential that already exists in the system or which is likely to be tapped in the future is critical. These alternative flexibility options among others include existing storage plants across Europe, demand-side management/ demand response options and more flexible fossil power plants (CHP flexibility by means of power-to-heat).

As a consequence of the above, the main focus and also the originality of this IRP Mobility project lies on methods and modelling approaches for assessing the impact of alternative flexibility options on offshore grid designs in the North Sea. This involves finding and implementing suitable transmission expansion planning (TEP) models for offshore grid investments. As one part of this modelling process, building aggregated but adequate models of hydro power systems across Europe plays an important role as well as aligning cost data for offshore grid components for the investment decisions. Based on the need of evaluating the cost-benefit allocation on a single market area level, a commonly agreed upon cost-benefit evaluation methodology is necessary.

Since 2012 the founding institutes SINTEF, Fraunhofer IWES, University of Strathclyde and newer members DTU, ECN, NTNU and UCD have been developing the North Sea Offshore Network (NSON) Initiative with national activities. It is closely linked to the EERA Joint Programme Wind and its Sub Programme (SP) Wind Integration. Integrating knowledge from nationally funded projects and gathering results on a collaborative level is at the core of the NSON Initiative.

Regarding the IRP Mobility project proposed here, SINTEF Energi AS brings in experience from several national projects in which offshore grid design concepts and scenarios have been defined and evaluated. Given Norway's energy system dominated by hydro power, SINTEF has substantial knowledge in building and operating hydro power models. This was combined with the in-depth expertise of Fraunhofer IWES on energy economy, system analysis, and grid planning. The possibility of discussing different approaches and comparing data assumptions in person held great merits, both from a methodological and a result's point of view. Complex tasks such as the assessment of cost-benefit implications of offshore grids could be collaboratively investigated and evaluated. Moreover, an improved quality of published research could be established on the daily basis of collaboration.

1.2 Objectives

The planned objectives of this IRP Mobility project show a close connection to the overall NSON Initiative's research agenda and are listed below as a reminder:

- Applicability and usefulness of a consistent data set covering cost parameters for offshore grid transmission technology options,
- Availability and functionality of aggregated models for hydro power representation in unit commitment/ transmission expansion planning models,
- Completed comparison of two market-based offshore grid expansion planning models,
- Commonly agreed upon cost-benefit allocation evaluation methodology,
- Successful submission of a journal paper containing central results of this IRP Mobility project.

2 Activities during Mobility period

2.1 Main activities and results

2.1.1 Investment cost parameters for VSC HVDC offshore grid technology

Investment models for transmission expansion planning studies always need cost estimates for infrastructure options. Although valid cost models are used in offshore grid studies, the uncertainty of the cost parameter input data for VSC HVDC components poses a significant problem for the validity of the results. High-quality input data covering the cost of VSC HVDC components is difficult to obtain. However, due to a large number of recent and ongoing projects, significantly more data is becoming available.

Based on published cost data of real VSC HVDC projects and cost parameter sets of existing studies, all the available information was condensed into a more accurate cost estimation data set. This can serve as a more solid basis for future transmission investment studies in the offshore grid context, thereby increasing the validity of the findings.[1]

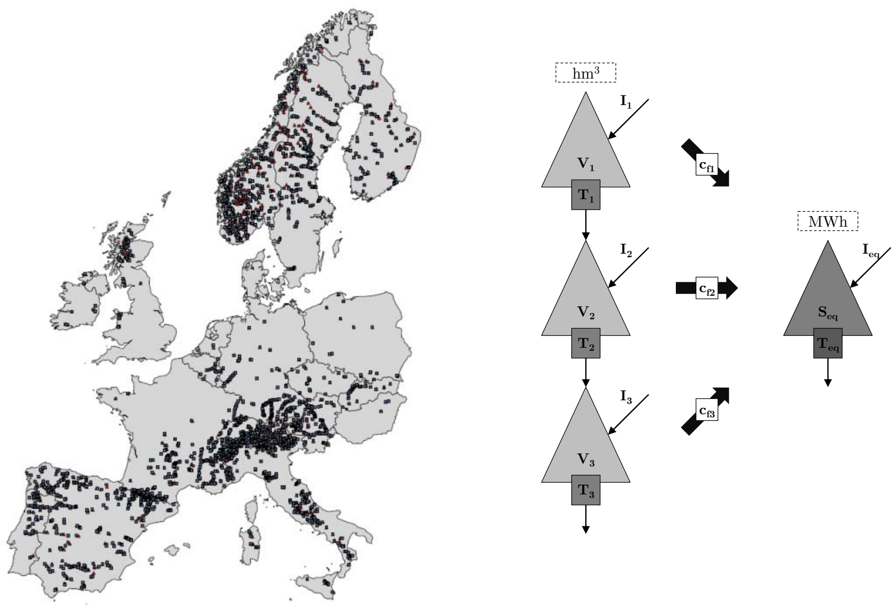
As a main result of the IRP Mobility project, a journal article with the title "Review of Investment Model Cost Parameters for VSC HVDC Transmission Infrastructure" has been prepared in collaboration with Til Kristian Vrana (SINTEF Energi AS) and two colleagues at Fraunhofer IWES. It is to be submitted to the Journal of Electric Power Systems Research soon. Please find the draft version attached in the Appendix of this report (Chapter 4). The abstract of the nearly finished article is given below:

Cost parameters for VSC HVDC transmission infrastructure have been collected from various sources. Additionally, an average parameter approach was determined as the arithmetic mean of these parameter sets and included in the study. In a first step, the cost parameter sets are compared with each other. The identified large differences between the parameters sets can only partly be explained by differences in the focus and modelling approach of their sources; they also reflect a high level of uncertainty regarding the cost of VSC HVDC transmission infrastructure. Consequently, this implies limitations regarding the validity of the parameters sets as well as of the results from grid expansion studies carried out on the basis of these parameter sets. In a second step, the cost parameter sets and their average have been evaluated against reference project cost data which has been gathered from an extensive collection of techno-economic information about realised and planned VSC HVDC back-to-back, interconnector, and offshore wind connection projects. This evaluation has again shown large variations between the parameter sets. The average indicates that the cost for back-to-back systems and offshore wind connections are frequently underestimated while the cost for interconnectors tend to be overestimations. Considering the interest in and momentum of offshore grid development, as well as the number of offshore grid investment and evaluation studies being conducted, both the availability of reliable cost reference data and the validity of investment model cost parameters need continuing attention.

[1] http://blog.sintefenergy.com/gridsmartgrids/offshore-grid-transmission-knowledge-has-been-identified/

2.1.2 Aggregated hydro power models

This task involved building an aggregated version of a detailed deterministic unit commitment model of hydro power plants in Europe. Based on a detailed database developed at Fraunhofer IWES including plant and reservoir characteristics, the complex hydraulic connections within hydro valleys, as well as inflow information, a computationally more efficient model is necessary to represent hydro power flexibility and seasonal characteristics in future energy system analysis studies.



(a) (b)

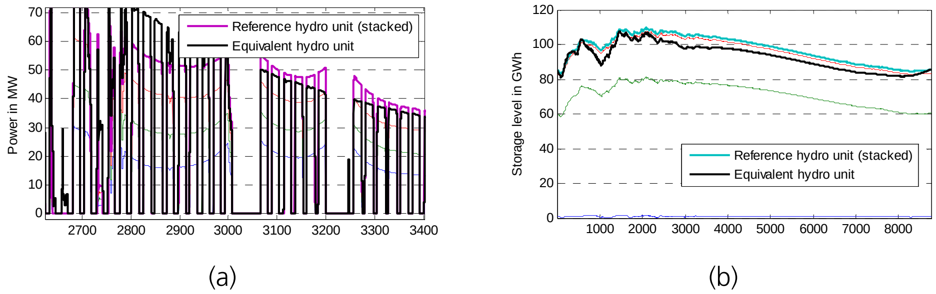
Fig. 01 Geographical distribution of hydro power units in Europe (a) and the equivalent reservoir model aggregation approach (b)

Fig. 01 shows the geographical distribution of the hydro plant and reservoir database developed at Fraunhofer IWES (a), as well as the equivalent reservoir model[1] aggregation approach which was applied to develop the aggregated hydro power models (b). By means of conversion factors c_f, the main idea is to convert the detailed water balance of the detailed reservoir in hector cubic meters (hm³) into an equivalent energy unit-based balance, making it possible to accumulate inflow and storage volumes of single reservoir stages. The aggregation is fairly straightforward in the case shown above, but in real-world hydro valleys, the hydraulic connections can be far more complex. This makes the computation of aggregate inflows and storage volumes far more challenging as a lot of special cases had to be considered.

The equivalent reservoir model was implemented and tested and is now being used in the German NSON-DE project as well as in other Fraunhofer IWES projects. The following Fig. 02 exhibits a comparison of the detailed reference hydro power model and the equivalent reservoir model for an exemplary hydro valley in Spain.

[1] Equivalent reservoir method based on Turgeon, Charbonneau (1998): An aggregation-disaggregation approach to long-term reservoir management, in Water Resour. Res. (34), p. 3585–3594.

Fig. 02 Optimized unit schedule (a) and storage trajectory (b) of detailed hydro unit (reference) and equivalent reservoir model in comparison



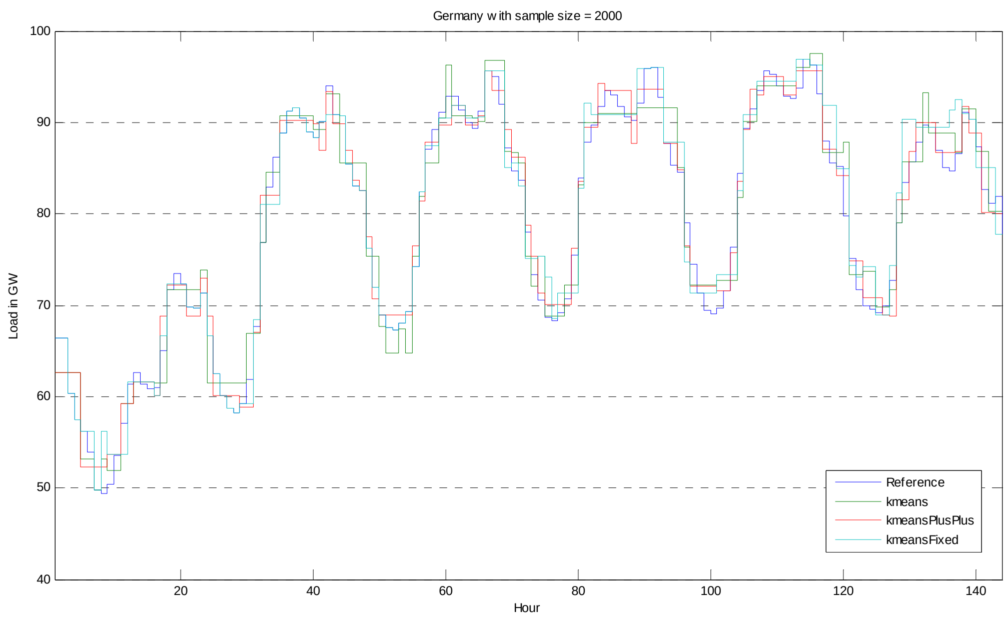
All in all, the developed aggregated hydro power model has been found to be a suitable and computationally efficient solution for the application in transmission grid expansion planning and unit commitment models.

2.1.3 Comparison of market-based offshore grid expansion planning models

As a further task, a model comparison of two market-based offshore grid expansion planning models, SINTEF's NetOp model and the TEP model developed at Fraunhofer IWES within the NSON-DE project, was conducted. A major difference which could be identified between the two deterministic TEP models is the reduction of the optimization horizon: a sample of hourly time-steps vs. a full consecutive year in hourly resolution.

Most power systems around the world experience an increasing share of variable and non-dispatchable generation in their energy mix. At the same time, more complex and adequate models for both short-term and long-term planning become necessary. In order to keep long-term transmission expansion planning (TEP) models tractable for a large geographical area and a high level of detail, a common approach is to use load duration curves or other generic scenario reduction approaches such as sampling and clustering methods on the model's input data, see Fig. 03. It remains a challenge that metrics describing the quality of a raw data sample might significantly deviate from the effect it eventually has on the TEP model's result quality which needs to be addressed.

Fig. 03 Clustering approaches of input data for transmission expansion planning (TEP) problems in the case of a German electricity load



Activities during Mobility period

Therefore, the work conducted as part of this task of the IRP Mobility project was to assess the impact of uni- and multivariate sampling and clustering techniques reducing the number of hourly time steps being considered by a TEP model on its performance and the quality of its results.

The results of this task are to be published under the title “Assessing the impact of uni- and multi-variate sampling techniques on offshore grid expansion planning” at the *14th Deep Sea Offshore Wind R&D Conference* (*EERA DeepWind'2017*), 18-20 January 2017, Trondheim, Norway.

2.1.4 Cost-benefit evaluation methodology

A minor task of the IRP Mobility project was to discuss and align the cost-benefit evaluation methodology for the upcoming analyses in the German NSON-DE project. Being able to quantify and evaluate the cost-benefit allocation related to an offshore grid investment decision is vital when analysing the impacts of new infrastructure on the overall energy system and on an individual market area level. The next paragraph will summarize the basics of the cost-benefit calculation methodology.

The main idea is to calculate the producer and consumer surplus occurring as a result of market operations in the power system. For obtaining the producer surplus, the total quantity sold q in the market is multiplied by the clearing price and subtracted by the generation costs. In a graphical context, this corresponds to the integral below the market price p and above the supply curve (merit order). A similar procedure can be used for determining the consumer surplus. Its potential gain, in contrast to the supply side with the marginal cost, is the difference between the consumer’s willingness to pay for electricity and the market price, i.e. the area under the demand curve and above the clearing price. This requires a predefined price for energy not served, which can vary in the different market areas.

As schematically depicted in Fig. 04, the cost-benefit allocation in two market areas is affected by additional transmission capacity between them. Market area 1 with an original clearing price p_1 being lower than p_2 in market area 2 will use additional transmission capacity (e.g. new offshore grid connections) to export to market area 2. Thereby, the clearing price increases to p_1' and consumer surplus decreases while producer surplus grows. Contrary, in market area 2 the clearing price reduces to p_2' and, at the same time, consumer surplus increases while producer surplus decreases.

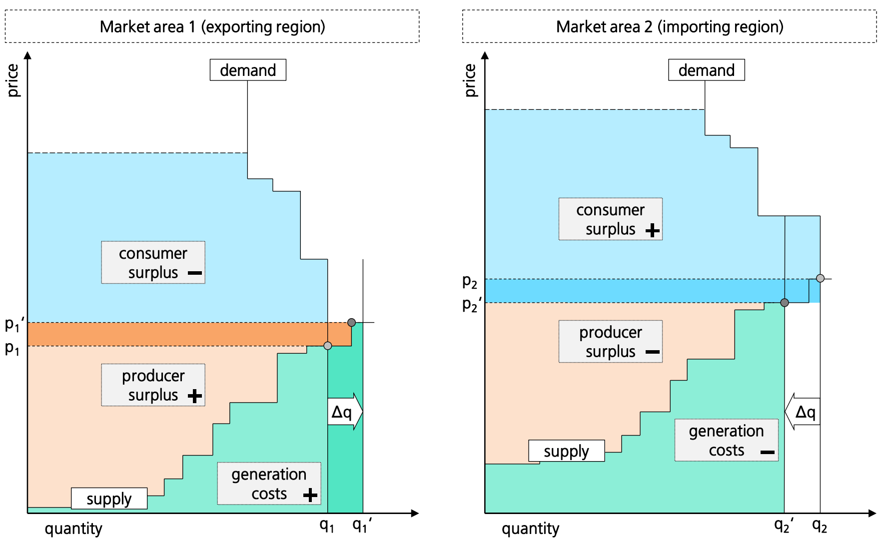


Fig. 04 Schematic cost-benefit allocation in two market areas affected by additional transmission capacity (e.g. offshore grid investments)

2.2 Other activities

Over the course of the IRP Mobility project, Philipp Härtel gave several presentations in regular workshops and meetings at SINTEF Energi AS and NTNU. Among other more specific topics, he presented his Energy Economy and Systems Analysis group at Fraunhofer IWES including the SCOPE model family which is being used to answer various research questions in Germany.

As a result of the interaction with the Department of Industrial Economics and Technology Management at the NTNU during the IRP Mobility project, Philipp Härtel was invited to present at the SET-Nav Modelling Workshop – Top-Down Bottom-Up Hybrid Modeling, taking place on 24-25 November 2016 in Trondheim. [4]

In order to bring the hosting and home institution closer together and identify potential areas of collaboration, a meeting between SINTEF Energi AS, NTNU and Fraunhofer IWES was arranged and took place in mid-June 2016. Prof. Dr. Clemens Hoffmann, head of the Fraunhofer IWES in Kassel, travelled to Trondheim and presented the full range of research activities of his institute, while SINTEF Energi AS and NTNU representatives presented their main research areas. A first specific item of collaboration is the research project proposal "Pricing Balancing Services in the Future Nordic Power Market" (PRIBAS) by SINTEF Energi AS to the Norwegian Research Council. Fraunhofer IWES has declared to participate as an international collaborator in this project.

[4] http://www.ntnu.no/web/censes/kalender/-/event/c9b801bc-e099-307f-bf54-ada51ed0d669

3 Acknowledgement

First and foremost, I would like to thank Hans Christian Bolstad for providing and co-organizing the opportunity to work with the Department Energy Systems at SINTEF Energi AS and, secondly, Magnus Korpås for welcoming me into his working group at the Department of Electric Power Engineering at NTNU. The cooperation was very pleasant and they both have been very attentive in supporting me. Particularly, I would like to thank Til Kristian Vrana and my two office colleagues Martin Kristiansen and Martin Hjelmeland, it has been a pleasure working with them and the rest of their teams at SINTEF Energi AS and NTNU. At NTNU's Department of Industrial Economics and Technology Management, I would also like to thank Ruud Egging for enabling me to present and discuss my research with his colleagues in a more cross-disciplinary setting.

In general, I would like to thank the IRP Mobility Programme for facilitating this cooperation and the Federal Ministry for Economic Affairs and Energy (BMWi) for funding the German "North Sea Offshore Network" (NSON-DE) project, financed as part of the funding initiative "Zukunftsfähige Stromnetze"[5].

[5] http://forschung-stromnetze.info/en/

4 Appendix

Review of Investment Model Cost Parameters for VSC HVDC Transmission Infrastructure

Philipp Härtel[a], Til Kristian Vrana[b], Tobias Hennig[a], Michael von Bonin[a]

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[b] *SINTEF Energi, Trondheim, Norway*

Abstract

Cost parameters for VSC HVDC transmission infrastructure have been collected from various sources. Additionally, an average parameter approach was determined as the arithmetic mean of these parameter sets and included in the study. In a first step, the cost parameter sets are compared with each other. The identified large differences between the parameters sets can only partly be explained by differences in the focus and modelling approach of their sources; they also reflect a high level of uncertainty regarding the cost of VSC HVDC transmission infrastructure. Consequently, this implies limitations regarding the validity of the parameters sets as well as of the results from grid expansion studies carried out on the basis of these parameter sets. In a second step, the cost parameter sets and their average have been evaluated against reference project cost data which has been gathered from an extensive collection of techno-economic information about realised and planned VSC HVDC back-to-back, interconnector and offshore wind connection projects. This evaluation has again shown large variations between the parameter sets. The average indicates that the cost for back-to-back systems and offshore wind connections are frequently underestimated while the cost for interconnectors tend to be overestimations. Considering the interest in and momentum of offshore grid development, as well as the number of offshore grid investment and evaluation studies being conducted, both the availability of reliable cost reference data and the validity of investment model cost parameters need continuing attention.

Keywords: Offshore grids, Transmission Expansion Planning, Cost model, HVDC, VSC

1. Introduction

Many transmission expansion studies have investigated and optimised the topology of a future North Sea Offshore Network [1]. A solid cost parameter basis, serving as input for the optimisation algorithms, is crucial to producing reliable results regarding the investment planning. As with offshore wind investment cost [2], these types of cost parameters have been widely used by academia and policymakers for assessments and decision support. However, the cost parameters of offshore transmission infrastructure show significant variations from study to study and indicate a strong uncertainty. Clearly, and also in light of scientific standards, this calls for a cautious and transparent attempt to compare previously used cost parameter sets and evaluate them against real project cost data in order to avoid flawed recommendations stemming from grid investment studies.

The cost parameters for AC and current source converter (CSC) HVDC transmission infrastructure can be based on a long track record. However, voltage source converter (VSC) HVDC technology is rather new and has seen a significant technological progression in the last years with new projects being developed and deployed. Given this context, finding adequate parameter sets yielding valid cost estimates for this type of transmission technology is a challenging task. Thus, in this article, the focus is on VSC HVDC transmission infrastructure.

In the remaining part of this article, Section 2 describes a linear cost model which is often used for determining optimal investments in transmission infrastructure. Section 3 provides a brief literature overview of the collected cost parameter sets needed for the subsequent comparison exercises. Based on these parameter sets, Subsection 3.2 introduces an average parameter set approach relevant to the overall analysis. In Section 4 the various cost parameter sets are compared with each other as a first step. Preparing the second step, Section 5 presents, segmented into back-to-back, interconnector and offshore wind connection systems, realised and contracted VSC HVDC projects including publicly available cost figures as reference data. Section 6 then evaluates the cost model parameters against these collected techno-economic reference data. Section 7 discusses the obtained comparison and evaluation results and Section 8 concludes the study.

2. Description of the cost model

Transmission grid expansion problems are usually formulated by a set of nodes representing connection points, generators, and load centres, as well as a set of branches representing potential transmission lines between these nodes. On the basis of a cost model function which assigns investment cost parameters to potential nodes and branches, an optimisation algorithm identifies the connections to invest in and computes the transmission capacities of expanded or new lines.

A linear cost model depending on the branch length l and power capacity p as input parameters is used in this article. The only assumption regarding the branch length l is that it can be computed in a pre-processing phase because the potential node locations are known beforehand. This model provides an approximation of the investment cost associated with offshore grid HVDC infrastructure and yields reasonable accuracy regarding long-term large-scale transmission expansion studies. For a detailed justification, the authors refer to e.g. [3].

The nomenclature used for the cost model is:

C_I	total investment cost for an HVDC grid
b	number of branches
n	number of nodes
s	number of nodes which are deployed at sea
l_i	total line length of branch i
p_i	installed power rating of branch i
p_j	total power rating of all installed converters at node j (for a back-to-back HVDC system, this is twice the rating of the system)

The cost parameters used for the cost model are:

B_0	fixed cost for building a new branch
B_l	length-dependent cost for a new branch
B_{lp}	length- and power-dependent branch cost
N_0	fixed costs for building a new node
N_p	power-dependent cost for a new node
S_0	fixed additional cost for deploying a node at sea
S_p	power-dependent additional offshore cost

Based on [3], [4], the linear cost model for HVDC grid investments is then defined as follows:

$$C_\mathrm{I} = \sum_{i=1}^{b} B_i(l_i, p_i) + \sum_{j=1}^{n} N_j(p_j) + \sum_{j=1}^{s} S_j(p_j) \quad (1)$$

$B_i(l_i, p_i)$ represent the cost for branch i, given by Equation (2):

$$B_i(l_i, p_i) = B_{lp} \cdot l_i \cdot p_i + B_l \cdot l_i + B_0 \quad (2)$$

$N_j(p_j)$ represent the cost for node j, given by Equation (3):

$$N_j(p_j) = N_p \cdot p_j + N_0 \quad (3)$$

$S_j(p_j)$ represent the additional cost for node j, if it is deployed at sea, given by Equation (4):

$$S_j(p_j) = S_p \cdot p_j + S_0 \quad (4)$$

3. Cost parameter sets

As previously mentioned, cost parameter sets for HVDC infrastructure components have been widely used and published in literature. The sources range from technology cost reports, over journal and conference contributions to offshore grid investment project reports. Primary data for branches and nodes is available in different formats. Branch cost data is given for the transmissible electrical power or the cross section of the cable or line core. In most of the references provided, cost data for the converter stations is divided into converter and platform costs.

However, most of the publications do not provide parameter sets which exactly match the investment cost model in Equation (1). In some cases:

- only a share of the model's parameter options regarding one of the three components are given, (e.g. only B_{lp} and not B_l or B_0). This implicitly sets the not specified parameters regarding that component to zero, as no cost have been associated with the phenomena represented by them.

- only a share of the model's components are specified, while others are explicitly excluded from the scope (e.g. only $B(l,p)$ and $N(p)$ and not $S(p)$). This does, of course, not set the excluded components cost to zero. In such cases, the parameter set has not been included when studying the excluded component.

- none of the aforementioned cost model parameters are obtainable at all, but rather discrete cost options for single VSC HVDC converter stations or cable system components in various formats. The required linear model coefficients have in these cases been derived by means of linear regression of given cost-power or cost-length relations. Cost parameters that were not created by linear regression are mentioned in the footnote of the corresponding studies.

Table A.1 and Table A.2 show the compilation of used primary data and derived model parameters for branch, node and platform costs from the different sources. The remainder of this section is dedicated to briefly review the respective sources.

3.1. Collected cost parameter sets

RealiseGrid [5] compares different interconnection technology options at national and cross-border level in order to assess techno-economic benefits of transmission expansion. Both HVDC and HVAC cables for submarine and underground application are considered by the project. The data is based on technical and scientific literature, internal knowledge and on questionnaires of TSOs who took part in the project.

Windspeed [6] gives an assessment of transmission costs for the North Sea by taking a closer look at location-specific effects. For support structure, installation and O&M different technological and logistical options are considered and a cost methodology is developed for each. To determine the costs, a bottom-up approach is used accounting for weight and material costs of each component. In addition, future developments and learning curves are taken into consideration.

ENTSO-E's technology cost report [7] involves all TSOs from North Sea's Regional group as well as suppliers and manufacturers. The study gives a broad overview of different offshore technology costs and particularly addresses new technology components for offshore transmission such as subsea cables, HVDC converters, and offshore platforms.

Ergun et al. [8] from the University of Leuven develop a software tool in order to determine the economically best and technically feasible way to transmit offshore wind power to shore. The study uses a cost model for cables, transformers and converter stations which is based on data from previously published literature.

ETYS13 (the Electricity Ten Year Statement) [9] is a technology report which is annually published by Great Britain's TSO National Grid. With the intention of presenting future investment plans, this source describes a broad range of technical approaches for offshore and onshore transmission technologies while at the same time providing cost data for most relevant components. The data has been gathered from suppliers of the technology options in question.

NSTG (North Sea Transnational Grid) investigated benefits of an offshore grid connecting all North Sea countries [10]. Comparing the results of a bottom-up and a top-down approach, the project derives cost parameters for the assessment of benefits associated with offshore grids. It has to be mentioned that platform costs are omitted in the context of the report as platforms are assumed to be unnecessary for the suggested offshore ring network topology.

NSOG [11] was conducted for the European Commission and assesses a range of potential benefits for a meshed offshore grid design in the North Sea, Irish Sea and the English Channel on the background of various scenarios. For the calculation of techno-economic benefits, investment and O&M costs of radial and meshed grid designs are analysed with input from previous studies and a consultancy firm.

Imperial College [12] focuses on the North Sea region to calculate the maximum benefit of an interconnected grid design using a minimum regret approach. The underlying cost model makes use of only two parameters to cover all the costs induced by transmission expansion investments.

NorthSeaGrid [13] was a project co-funded by the EU involving many stakeholders to analyse costs, benefits and barriers for the connection of offshore wind farms and onshore electricity grids. Drawing upon a wide range of sources and stakeholders involved, a broad selection of input data is considered in the cost estimation of offshore grid infrastructure.

OffshoreDC [14] focuses on the benefits of an offshore grid which further integrates electricity markets in the Baltic Sea region. The linear transmission expansion planning approach includes power flow calculations and a simplified cost model to determine the optimal grid design. Input data is based on publicly available literature.

Madariaga et al. [15] from the Offshore Renewable Energy (ORE) Catapult give an overview of existing cost literature from former studies and include inputs from industry consultation to provide cost data for all components being crucial for an HVDC transmission system. The resulting costs are compared to realised projects, namely BorWin2 and SylWin1.

ETYS15 [16] is the most recent version of the

ETYS this review refers to. Following *ETYS13* as the earliest version containing a detailed cost compilation for HVDC technology, *ETYS15* comprises technology cost data based on updated project information.

Torbaghan [17] from the Delft University of Technology includes a cost model for the offshore grid related investigations conducted in his doctoral thesis. Assessing offshore grid investments on a more theoretical level, the cost model uses only one parameter to cover all costs incurred by offshore transmission investments.

3.2. Average parameter set

Every cost parameters set regarded here (shown in Tables A.1 and A.2) was created with a specific purpose and thus concentrates on individually relevant aspects. This applies to the underlying assumptions as well as the potential simplifications made while deriving the respective cost coefficients. It is important to stress that focusing on some aspects (e.g. interconnectors) while neglecting others (e.g. back-to-back systems) when determining a cost parameter set can have great consequences for its cost estimation results regarding HVDC systems outside the focus.

Given the different foci as well as the advantages and disadvantages of the different parameter sets, a robust cost estimation might exist somewhere in the middle. In contrast to looking at a single parameter set, it is interesting to assess the 'cost parameter sets' as a whole. Therefore, an additional synthetic average cost parameter set has been calculated as the arithmetic mean of all the collected cost parameter sets, which is presented as the average cost parameter in Table 1.

Table 1: Average approach as arithmetic mean of cost parameter sets in Table A.1 and Table A.2

Parameter	Value	Unit
B_{lp}	1.09	M€/GW·km
B_l	0.56	M€/km
B_0	0.70	M€
N_p	80.88	M€/GW
N_0	28.38	M€
S_p	90.34	M€/GW
S_0	48.54	M€

4. Comparison of cost parameter sets

In this section, all the collected parameter sets (summarised in Table A.1 and Table A.2) and the average parameter set (specified in Table 1) are compared.

4.1. Branch cost parameters

Figure 1 presents the cost parameters B_{lp}, B_l and B_0, that represent the branch cost part of the investment model, specified in Equation (2).

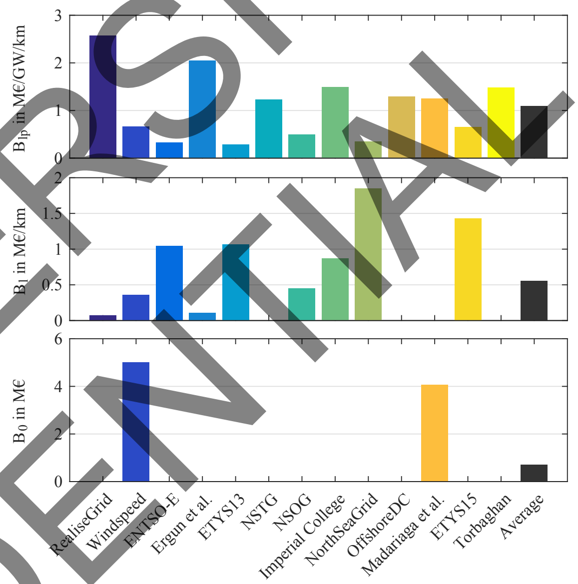

Figure 1: Comparison of branch cost parameters B_{lp}, B_l and B_0

It can be observed that all parameter sets use the parameter B_{lp}, most use B_l, and only two of them use B_0. This tendency to neglect B_0 can lead to an underestimation of costs when considering very short cable routes. As a rather straightforward finding, those sets with a high B_{lp} generally show a lower B_l and vice versa. *Windspeed* is the only parameter set using all three parameters.

4.2. Node cost parameters

Figure 2 presents the cost parameters N_p and N_0 constituting the node cost part of the investment model, specified in Equation (3).

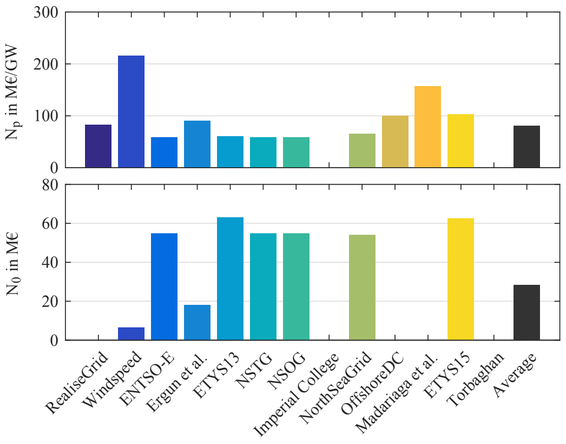

Figure 2: Comparison of node cost parameters N_p and N_0

Three of the sets solely draw upon the N_p parameter while neglecting N_0, which can potentially yield cost underestimations for low power converter stations. *Torbaghan* and *Imperial College* are the only sources not providing separate node costs, leading to both N_p and N_0 being zero. Coupled with these two sources' B_0 parameter being zero, their resulting cost function is only proportional to the transmission length with no offset. Therefore, these two parameter sets always estimate the cost of a back-to-back HVDC station with zero transmission length to be zero, which clearly highlights the drawbacks of such a simplified approach.

4.3. Platform cost parameters

Figure 3 presents the cost parameters S_p and S_0, that represent the platform cost part of the investment model, specified in Equation (4).

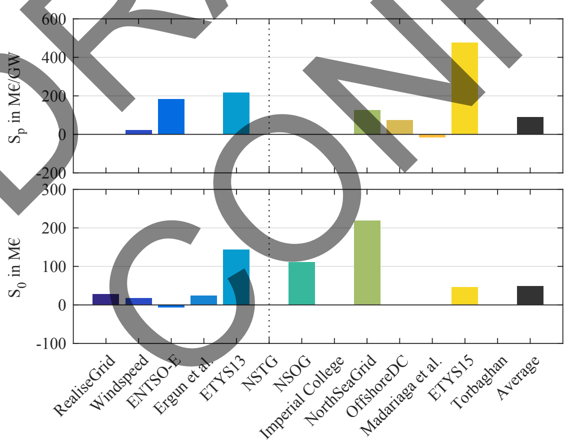

Figure 3: Comparison of platform cost parameters S_p and S_0

The platform cost parameters are only given by some of the reviewed parameter sets, and they are subject to high variations. Other parameter sets do not consider extra cost for offshore stations, implicitly setting the platform cost to zero. *Madariaga et al.* considers a higher cost for the onshore converter than for the offshore converter, implying negative platform cost. The linear fit of the considered technology options provided by *ENTSO-E* and, more specifically, its extrapolation to a power rating of 0 GW lead to a slightly negative S_0.

5. HVDC projects

The sources of information available in the public domain are scarce and sometimes divergent [15]. It is, therefore, difficult to extract sound reference data to validate the parameter sets against. Hence, from publicly available data (i.e. mainly contract values published in suppliers' press releases), the authors obtained cost figures which for some of the projects could also be allocated to the cable system, converter station or in one case to the platform.

The costs for the branches are usually published as a single figure, even though the branch consists of several sections of underground cables (UGC), overhead lines (OHL) and submarine cables (SMC). A cost split, specifying the cost of each type of transmission line, is usually not available. In order to determine the reference cost information, assumptions about the cost split are necessary, although it may significantly vary from country to country and project to project. This is aggravated by the fact that effects such as public opposition against overhead lines or ammunition found along cable routes are difficult to economically quantify. With that in mind, only a rough approximation was feasible in the context of this article and the assumptions below could not be verified due to a lack of required information. Equation (5) specifies the branch cost ratios which are also needed for the evaluation of cost parameters in Section 6:

$$B_{\mathrm{UGC}} = \frac{3}{2} \cdot B_{\mathrm{SMC}} \qquad B_{\mathrm{OHL}} = \frac{1}{2} \cdot B_{\mathrm{SMC}} \qquad (5)$$

The remaining part of this section provides an overview of back-to-back, interconnector and offshore wind connection projects which are referred to in the following evaluation analysis. Only realised or at least finally decided projects with published cost figures have been taken into account.

5.1. *Back-to-back*

Table 2 provides an overview of back-to-back projects including their relevant techno-economic parameters.

Table 2: Techno-economic figures of realised and contracted VSC HVDC back-to-back projects

Project name	Rated power MW	Cost Converter M€[*]	Source
Mackinac	350	68.0	[35]
Kriegers Flak	500	125.7	[36]

[*] Currency other than € was converted with the monthly average exchange rate [34] corresponding to the press releases' date of publication.

Mackinac was built as a back-to-back VSC HVDC station in upper Michigan in order to control the power flow between the upper and lower Peninsulas of Michigan and provide dynamic voltage support. The two directly connected converters were designed, supplied and installed by ABB [35].

Kriegers Flak back-to-back HVDC station in Bentwisch will connect the asynchronous AC power grids of TSOs Energinet.dk and 50Hertz Transmission, thereby linking Danish and German power grids. The back-to-back station will be entirely provided by ABB [36].

5.2. *Interconnectors*

Table 3 displays a summary of the techno-economic parameters of VSC HVDC interconnector projects relevant for the cost parameter evaluation.

Estlink 1 connects the power grids of Finland and Estonia across the Gulf of Finland. *East-West-Interconnector* (EWIC) links the Irish and UK transmission grids between North Dublin and Wales. *NordBalt* is a link between the power grids of LITGRID turtas AB in Lithuania and Svenska Kraftnät in Sweden. *Åland* link is located at the entrance of the Gulf of Bothnia in the Baltic Sea, connecting the power grid of Kraftnät Åland AB on this Finnish archipelago to the Finnish mainland, which had been previously connected only by an AC cable to the Swedish mainland. At these four HVDC links, the entire system including converters and cables was designed, supplied, installed and commissioned by ABB.

Skagerrak 4 upgraded the existing HVDC links Skagerrak 1-3 between the power grids of Energinet.dk in Denmark and Statnett in Norway. The two converter stations were supplied by ABB [24]. The submarine cable and the underground cable at the Norwegian end were designed, manufactured and installed by Nexans [25], while the underground cable on the Danish side was supplied by Prysmian Group [26]. As a distinct project feature, Skagerrak 4 is operated in a bipole mode with the existing Skagerrak 3, which is why only one transmission cable has been laid (half-bipole).

NordLink is the first direct transmission link between the power grids of Norway (Statnett) and Germany (TenneT). The converter stations will be supplied solely by ABB, while the corresponding cable system will be manufactured and commissioned by ABB and Nexans. ABB is responsible for the underground cable on

Table 3: Techno-economic figures of realised and contracted VSC HVDC interconnector projects

Project name	Rated power MW	Line length: SMC[+] km	Line length: UGC[+] km	Line length: OHL[+] km	Cost: Line M€[*]	Cost: Converter M€[*]	Cost: Total M€[*]	Source(s)
Estlink 1	350	74	31	-	84.8		84.8	[18]
EWIC	500	186	76	-	291.1	130.6	421.7	[19], [20]
NordBalt	700	400	13	40	268.7	169.9	438.6	[21], [22]
Åland	100	158	-	-	99.1		99.1	[23]
Skagerrak 4	700	138	92	12	127.0	131.9	258.9	[24], [25], [26]
NordLink	1,400	516	54	53	936.5[a]	395.9[a]	1,332.3	[27], [28]
North Sea Link	1,400	720	7	-	890.0	408.9	1,298.9	[29], [30], [31]
COBRA cable	700	299	26	-	250.0	170.0	420.0	[32], [33]

[+] SubMarine Cable (SMC), UnderGround Cable (UGC), OverHead Line (OHL)

[*] Currency other than € was converted with the monthly average exchange rate [34] corresponding to the press releases' date of publication.

[a] When calculating the converter and cable costs of the NordLink project, equal distance-specific submarine cable cost for both the Nexans and ABB contract were assumed.

German soil and the German subsea route [27], and Nexans will manufacture and install the HVDC cable system in Norwegian and Danish waters [28].

North Sea Link will establish a connection between the electricity systems of the UK and Norway. ABB will provide the two VSC HVDC converter stations, one in Blyth, UK and one in Kvilldal, Norway [29]. The responsibility for supplying and installing the submarine cable systems and a short path of underground cable on the UK side of the link rests with Prysmian Group [30]. Nexans will provide the Fjord submarine section as well as the tunnel/lake and underground cable at the Norwegian end of the link [31].

The *COpenhagen BRussels Amsterdam* or *COBRA* cable is an HVDC link between the electricity grids of Energinet.dk in Denmark and its Dutch counterpart Tennet TSO. Both converter stations will be supplied by Siemens AG [32] and the cable system by Prysmian Group [33].

5.3. *Offshore wind connections*

Table 4 displays a summary of the techno-economic parameters of offshore wind connection projects relevant for the cost parameter evaluation.

All currently existing VSC HVDC systems connecting offshore wind power plants to the onshore grid are located in the German exclusive economic zone of the North Sea, and all of them are also in the responsibility of TenneT. Several of the offshore wind connection projects have experienced significant delays and cost overruns. Additional costs caused by the offshore converter stations are reported for both ABB and Siemens [56]. However, no final costs including the overruns have been published for these delayed projects. Given the limited availability of information, the cost figures presented here rely on publicly accessible awarded contractual volumes in press releases, and the cost overruns are captured and included as good as possible based on reported additional cost for Siemens and ABB [56] [45].

BorWin1 was built by ABB and it was the first HVDC connection for offshore wind, and it is the only one based on two-level-converter technology. The project's commissioning phase took about seven months longer than expected [45]. Even after this extended commissioning phase problems were existing for several years, leading to significant down-times [57] [58] [59].

DolWin1 and *DolWin2* were also built by ABB. This included the entire HVDC system consisting of the two converter stations, the cable system, and the offshore platform.

BorWin2, *HelWin1*, *SylWin1* and *HelWin2* were built by a consortium of Siemens AG and Prysmian Group. Siemens was responsible for the converter stations and the offshore platforms while Prysmian was in charge of the cable system.

DolWin3 was awarded to a consortium of Alstom (now acquired by General Electric Co.) and Prysmian

Table 4: Techno-economic figures of realised and contracted VSC HVDC offshore wind connection projects

Project name	Rated power MW	Line length: SMC[+] km	Line length: UGC[+] km	Line length: OHL[+] km	Cost: Line M€[*]	Cost: Converter M€[*]	Cost: Platform M€[*]	Cost: Total M€[*]	Source(s)
BorWin1	400	125	75	-		422.8[a] (line, converter and platform combined)		422.8	[37]
BorWin2	800	125	75	-	300.0	445.3[a] (converter and platform combined)		745.3	[38], [39]
HelWin1	576	85	45	-	150.0	595.3[a] (converter and platform combined)		745.3	[39], [40]
DolWin1	800	75	90	-		682.4[a] (line, converter and platform combined)		682.4	[41], [42]
SylWin1	864	160	45	-	250.0	495.3[a] (converter and platform combined)		745.3	[43], [44], [45]
DolWin2	916	45	92	-		614.8[a] (line and converter combined)	217.8	832.6	[46], [47]
HelWin2	690	85	45	-	200.0	645.3[ab] (converter and platform combined)		845.3	[48], [49]
DolWin3	900	83	79	-	350.0	800.0 (converter and platform combined)		1,150.0	[50], [51], [52]
BorWin3	900	132	29	-	250.0	1000.0 (converter and platform combined)		1,250.0	[53], [54], [55]

[+] SubMarine Cable (SMC), UnderGround Cable (UGC), OverHead Line (OHL)
[*] Currency other than € was converted with the monthly average exchange rate [34] corresponding to the press releases' date of publication.
[a] In this context, platform cost include cost increases for ABB's and Siemens' offshore converter stations reported in [56] which were equally distributed among the affected projects.
[b] While Siemens mentions the combined contract value being higher than 500 M€ [48], Prysmian Group indicates an amount exceeding 600 M€ [49]; the latter is used here.

Group, and its commissioning is expected in mid-2017.

BorWin3 differs from its preceding projects to the extent that it has been awarded in two separate tenders, one to Siemens (together with Petrofac) and another to Prysmian Group. Initial power transmission on the link is to commence in early 2019.

6. Evaluation of cost parameter sets

In this section, the investment model cost parameters in Table A.1 and Table A.2 are related to real-world VSC HVDC project data gathered in Table 2, Table 3 and Table 4. To this end, the reference cost data is increased by a markup of 10 % [10] to account for the difference between contractual and total project investment cost caused by internal, engineering and concession project costs [45]. Equation (6) specifies the markup used in the following evaluations:

$$C_{\mathrm{I}} = 1.1 \cdot C_{\mathrm{Contracted}} \tag{6}$$

Note that operation and maintenance costs as well as financing costs are not considered in this article. The following figures show the relative investment cost deviations between the cost model estimates and the according reference data for back-to-back, interconnector, and offshore wind connection projects. In this context, a deviation value of 1 per unit (pu) implies that the total cost of a real project was overestimated by 100 %, whereas a value of -1 pu stands for an underestimation of 100 %, i.e. the investment cost equal zero. Relying on relative deviations ensures an adequate assessment of both small and big projects.

6.1. Back-to-back

In Figure 4, it is important to remember that only N_p and N_0 play a role in this back-to-back project assessment as branch investment costs are not applicable here. Because it is inherent to a back-to-back station that both converters are located at the same site and immediately connected to each other, the fixed node cost parameter N_0 is counted once, and B_0 is not relevant.

As a result, the different cost parameter sets reveal deviations in both directions with a slight tendency towards underestimating the reference costs of the two back-to-back projects. Accordingly, the average cost parameter set exhibits a mean deviation per project of -0.3 pu. However, the relative investment cost deviations for the Kriegers Flak project are a little higher. Since *Imperial College* and *Torbaghan* do not specify separate node cost parameters and their parameter sets are fully dependent on the length parameter, they estimate zero investment costs and consequently show deviations of -1 for both reference projects.

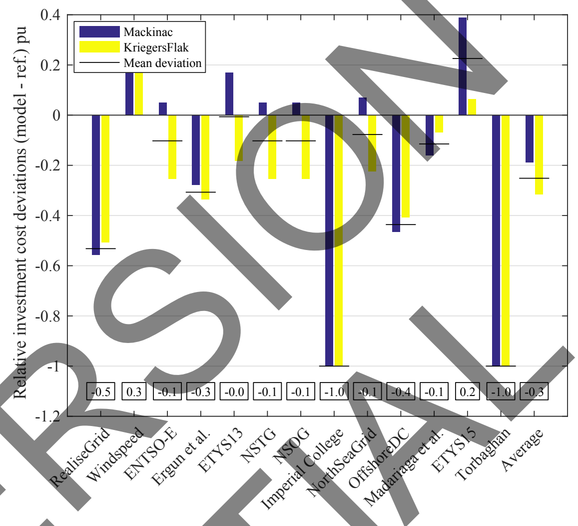

Figure 4: Evaluation of model estimates vs. reference cost for back-to-back projects (mean deviations per project shown in boxes)

6.2. Interconnectors

Figure 5 illustrates the resulting deviations for all available cost parameter sets taking N_p, N_0, B_{lp}, B_l and B_0 into account. In this case, N_0 is included twice, and B_0 once for the VSC HVDC link.

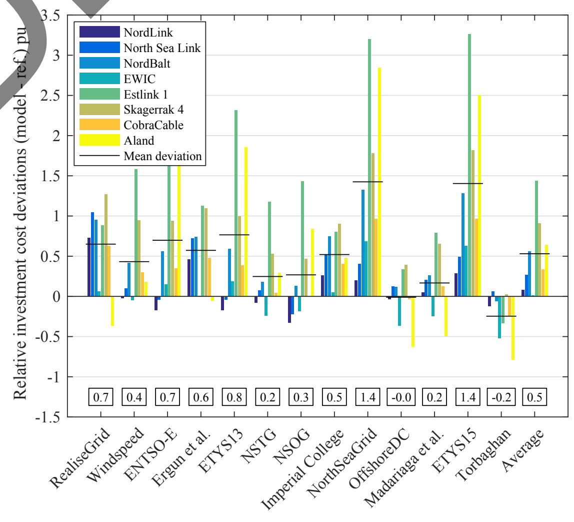

Figure 5: Evaluation of model estimates vs. reference cost for interconnector projects (mean deviations per project shown in boxes)

The illustration shows that the majority of cost parameter sets overestimate the reference investment costs for interconnector projects, most notably Estlink 1 and Skagerrak 4. That said, Åland project costs are both over- and underestimated which might be due to the fact that it is a comparatively small project, in terms of both length and power rating, which most of the parameter sets do not seem to be well adjusted to. Interestingly, for the interconnector projects in focus, the parameter set of *Torbaghan* which is only employing the B_{lp} parameter shows relatively small deviations. In comparison, the cost estimates of the *OffshoreDC* parameter set exhibit low absolute deviations for all projects and a very small mean deviation. While the average parameter set overestimates many of the interconnector projects as well, it presents a moderate performance with its mean deviation per project being 0.5 pu.

6.3. Offshore wind connectors

In Figure 6, all parameters of the investment cost model in Equation (1) come into effect, i.e. S_p and S_0 are considered once for estimating the offshore converter station cost. As with the interconnector projects, N_0 is taken into account twice for both nodes. The *NSTG* study [10] does not supply platform costs and explicitly excludes offshore converters and platforms from its analysis, which is why this source is left out of the evaluation conducted here.

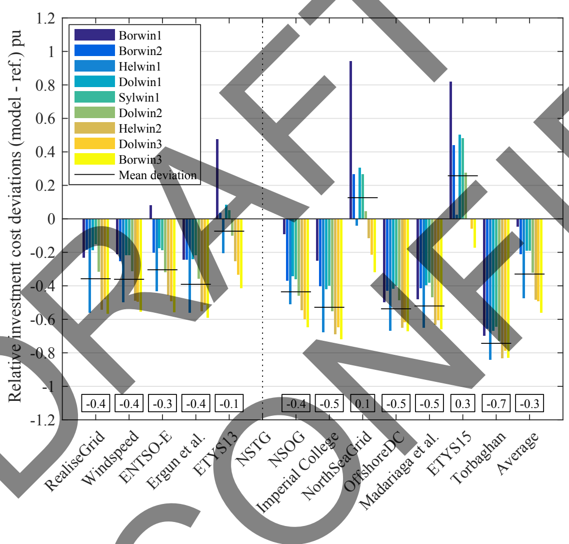

Figure 6: Evaluation of model estimates vs. reference cost for offshore wind connection projects (mean deviations per project shown in boxes)

The most important fact that can be observed here is that most of the cost model parameter sets significantly underestimate the reference cost values of offshore wind connection projects. To be more specific, only *ETYS15* and *NorthSeaGrid* distinctly overestimate the majority of projects, and, in comparison, they both reveal smaller deviations for the more recent BorWin3 and DolWin3 projects. In fact, *ETYS15* yields particularly good approximations of these more recent and expensive offshore wind connection projects, thereby leading to higher positive cost estimate deviations for the earlier projects. In this context, the cost estimations of the average parameter set are among the better results for offshore wind connection projects with a mean deviation per project of -0.3 pu.

7. Discussion

It has to be stressed that this analysis does not include the effects of learning curves and inflation corrections when comparing and evaluating previously published investment model cost parameters for VSC HVDC infrastructure. One limitation of our analysis is that it assumes a simplified cost ratio between submarine cables and underground cables as well as overhead lines. Assuming different ratios could have minor effects on the parameter evaluation for projects with large underground cable or overhead line sections. Using a blanket markup on the contractual cost figures when evaluating cost estimates against reference project cost is a further limitation of the study that has to be kept in mind. As previously mentioned, however, a markup is necessary as the contractual cost underestimate the total investment cost.

In summary, the demonstrated analysis substantiates the claim for reliable cost parameters for VSC HVDC investment models. On the basis of the linear investment cost model for HVDC transmission infrastructure in Section 2, the presented analysis shows that parameter sets obtained from literature employ or provide different types of cost coefficients. As shown by the comparisons above, these cost parameters spread over a wide range, which can to some extent be explained by their chronological emergence, and thus different reference projects they were adjusted to.

Going through the process of collecting information about realised and planned VSC HVDC projects, it became clear that the obtainable cost information in the public domain does not provide a sound and transparent reference to evaluate the parameter sets against, as the data often is proprietary and undisclosed. More specifically, the offshore wind connection projects experienced significant cost overruns incurred by the offshore converter stations and their platforms. Having said that, the contract values provided in our overview are the only publicly available data to rely on and, to the best of the author's knowledge, this review tried to account for these additional costs. Given the fact that more and more experience is being gained with the offshore wind connection projects, contractual values might better reflect real costs of offshore converter stations (e.g. the higher contract values of DolWin3 and BorWin3). Still, the techno-economic overview of back-to-back, interconnector, and offshore wind connection projects should prove to be also useful for further investigations and reviews.

The evaluation of cost parameter sets reveals that their validity is of heterogeneous nature and the resulting variations of cost estimates are in fact very distinct. Some of the parameter sets fit one type of project, e.g. interconnectors, or even single projects very well but fail to produce reasonable cost estimates for the others. To put it another way, the parameter sets in this review most likely oriented themselves towards specific reference projects and the available cost data at the time of their creation. For instance, this can be seen in the case of *ETYS15* which produces smaller deviations for the more recent offshore wind connection projects BorWin3 and DolWin3. At the same time, *ETYS15* but also other parameter sets exhibit disproportionate cost estimates for single projects, e.g. overrating reference cost of Estlink 1 by more than 350 %. Consequently, a significant variance of deviations becomes visible which, on the one hand, shows the high uncertainty associated with the different parameter sets in focus, but on the other hand, the evaluation helps to put them into perspective and interpret their results.

Another important insight is that the average cost parameter approach performs moderately well for back-to-back, interconnector, and offshore wind connection projects. Therefore, employing this parameter set can lower the uncertainty to some degree and deliver more robust overall cost estimates for all three types of VSC HVDC projects.

As N_0 and B_0 have been used as overall fixed node and branch parameters, respectively, it would be interesting to further distinguish these by splitting N_0 into one-time fixed cost per station and multiple fixed cost per converter (e.g. bipole HVDC links); and B_0 into one-time fixed cost per line and multiple fixed cost per cable system, correspondingly. It must be noted, however, that this can only be done with a sufficient level of reference cost data.

All things considered, the review confirms that transparent and robust cost information on real-world VSC HVDC projects is still not available. Despite the limitations in data availability, however, the obtained reference cost allow for an approximate evaluation of the collected investment model cost parameter sets. As shown above, there is a significant level of uncertainty associated with investment model cost parameters for VSC HVDC transmission infrastructure.

8. Conclusion

Investment model cost parameter sets for VSC HVDC transmission infrastructure are compared and evaluated in this article. Based on a linear investment cost model depending on the branch length and the power rating of cable systems and converter stations, a comprehensive review and collection of cost parameter sets from literature has been presented and compared with each other. In addition, an average parameter approach was determined as the arithmetic mean of these parameter sets and included in the comparison.

Carrying this analysis one step further, comprehensive cost reference data from realised and planned VSC HVDC back-to-back, interconnector, and offshore wind connection projects has been gathered. Evaluating the parameters sets against these reference cost data helped to create an understanding of whether a previously used parameter set tends to over- or underestimate the investment cost of a certain type of HVDC project. The average parameter set reduces the uncertainty associated with VSC HVDC investment costs for all three of the considered project types and can, therefore, be a more robust approximation for future investment studies. Clearly, both the availability of reliable cost reference data and the validity of investment model cost parameters need continuing attention.

Finally, it would be interesting to determine a new cost parameter set based on the reference cost data which was obtained. For instance, by carefully applying a component-based fitting, i.e. converter stations, cable system and offshore converter platform, a potentially more accurate representation of VSC HVDC transmission infrastructure cost in investment models can be achieved.

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Appendix A. Cost parameter sets

Table A.1: Branch cost model parameters from previously published cost parameter data

Name	Option/ variant	Cost	Unit	B_{lp} M€/GW·km	B_l M€/km	B_0 M€	Source
RealiseGrid	700 MW	1.90	M€/km				[5]
2011	1000 MW	2.60	M€/km				
	1200 MW	3.20	M€/km	2.58	0.07	0.00	
WindSpeed	600 MW	0.40	M€/km				[6]
2011	Installation	0.36	M€/km				
	Mobilisation	5.00	M€	0.67	0.36	5.00	
ENTSO-E [a]	850 MW	0.43	M€/km				[7]
2011	967 MW	0.43	M€/km				
	1069 MW	0.46	M€/km				
	1133 MW	0.53	M€/km				
	Installation	0.91	M€/km	0.33	1.05	0.00	
Ergun et al.[b]	450 MW	0.98	M€/km				[8]
2012	500 MW	1.07	M€/km				
	550 MW	1.17	M€/km				
	900 MW	1.85	M€/km	2.05	0.11	0.00	
ETYS [a]	855 MW	0.32	M€/km				[9]
2013	967 MW	0.33	M€/km				
	1069 MW	0.34	M€/km				
	1133 MW	0.38	M€/km				
	Installation	0.59	M€/km	0.29	1.06	0.00	
NSTG[c]	1200 MW	1.47	M€/km				[10]
2013				1.23	0.00	0.00	
NSOG [a]	403 MW	0.60	M€/km				[11]
2014	1373 MW	1.32	M€/km				
	1510 MW	1.12	M€/km				
	2146 MW	1.47	M€/km				
	Installation	0.40	M€/km	0.50	0,45	0.00	
Imperial College[c]	Fixed cable costs, annuity[c]	0.07	M€/km·a				[12]
2014	Variable cable costs, annuity[c]	120.00	M€/GW·km·a	1.50	0.87	0.00	
ETYS	600 MW	0.34	M€/km				[16]
2015	800 MW	0.39	M€/km				
	1000 MW	0.45	M€/km				
	1200 MW	0.55	M€/km				
	Installation	0.63	M€/km	0.66	1.43	0.00	
NorthSeaGrid	1400 MW	0.57	M€/km				[13]
2015	1000 MW	0.43	M€/km				
	700 MW	0.32	M€/km				
	Installation	1.78	M€/km	0.35	1.85	0.00	
OffshoreDC[d]	Low	1.10	M€/GW·km				[14]
2015	Medium	1.30	M€/GW·km				
	High	1.50	M€/GW·km	1.30	0.00	0.00	
Madariaga et al.[e]	100 MW, 900 MW	150.21	M€				[15]
2015	110 MW, 900 MW	162.74	M€				
	120 MW, 900 MW	175.25	M€				
	130 MW, 900 MW	187.78	M€				
	140 MW, 900 MW	200.29	M€				
	150 MW, 900 MW	212.82	M€	1.25	0.00	4.06	
Torbaghan[c]	Interconnector	1.48	M€/GW·km				[17]
2016				1.48	0.00	0.00	

[a] Transmittable power is derived from the cross-section of the cable according to [16].
[b] The proposed non-linear model is used to create cost data for the respective transmissible power. A voltage level of 320 kV is assumed.
[c] The provided cost parameters already fit the cost model coefficients.
[d] Personal contact to the author revealed that the fixed cable cost are annuitised as well. A discount rate of 5 % p.a. is specified in the source and a service life of 20 a is assumed to convert annuities to investment costs.
[e] The cost for the land cable section is deducted from total cable cost.

Table A.2: Node and platform cost model parameters from previously published cost parameter data

Name	Option/variant	Cost	Unit	N_p M€/GW	N_0 M€	S_p M€/GW	S_0 M€	Source
RealiseGrid[a]	Converter costs	83.00	M€/GW					[5]
2011	Platform costs	28.00	M€	83.00	0.00	0.00	28.00	
Windspeed[a]	600 MW, off	143.40	M€					[6]
2011	Installation, off	23.80	M€					
	600 MW, on	129.60	M€					
	Installation, on	6.50	M€	216.00	6.50	23.00	17.30	
ENTSO-E	VSC 500 MW	83.50	M€					[7]
2011	VSC 850 MW	101.50	M€					
	VSC 1250 MW	135.50	M€					
	VSC 2000 MW	170.00	M€					
	Platform 400 MW	66.60	M€					
	Platform 800 MW	140.00	M€	58.90	54.90	183.50	-6.80	
Ergun et al.[b]	Converter station	72.00	M€					[8]
2012	Converter station	85.50	M€					
	Converter station	99.00	M€	90.00	18.00	0.00	24.00	
ETYS	500 MW VSC	61.26	M€					[9]
2013	850 MW VSC	80.21	M€					
	1250 MW VSC	98.34	M€					
	2000 MW VSC	124.54	M€					
	1000 MW platform	237.40	M€					
	1250 MW platform	268.43	M€					
	2000 MW platform	384.11	M€	60.80	63.17	216.60	143.66	
NSTG[c]	Pair of 1200 MW VSC, fixed cost	110.00	M€					[10]
2013	Pair of 1200 MW VSC, variable cost	117.80	M€/GW	58.90	54.90	0.00	0.00	
NSOG	Platform	111.30	M€					[11]
2014	VSC 500 MW	83.50	M€					
	VSC 850 MW	101.50	M€					
	VSC 1250 MW	135.50	M€					
	VSC 2000 MW	170.00	M€	58.90	54.90	0.00	111.30	
Imperial College	-	-	-					[12]
2014				0.00	0.00	0.00	0.00	
ETYS	800 MW VSC offshore	64.43	M€					[16]
2015	1000 MW VSC offshore	85.06	M€					
	1200 MW VSC offshore	116.91	M€					
	1800 MW VSC offshore	130.30	M€					
	2200 MW VSC offshore	161.07	M€					
	800 MW VSC onshore	77.82	M€					
	1000 MW VSC onshore	88.32	M€					
	1200 MW VSC onshore	96.64	M€					
	1800 MW VSC onshore	121.25	M€					
	2200 MW VSC onshore	157.81	M€					
	1000 MW platform	296.80	M€					
	1250 MW platform	330.28	M€					
	1500 MW platform	402.67	M€					
	1750 MW platform	459.68	M€					
	2000 MW platform	521.21	M€					
	2250 MW platform	583.64	M€					
	2500 MW platform	650.61	M€	103.00	62.60	475.90	46.07	
NorthSeaGrid	1400 MW platform	340.00	M€					[13]
2015	1000 MW platform	290.00	M€					
	1400 MW VSC	145.00	M€					
	1000 MW VSC	119.00	M€	65.00	54.00	125.00	218.95	
OffshoreDC[a]	Onshore station (Medium)	100.00	M€/GW					[14]
2015	Offshore station 50 % (Medium)	150.00	M€/GW					
	Offshore station 100 % (Medium)	200.00	M€/GW	100.00	0.00	75.00	0.00	
Madariaga et al.	900 MW Onshore HVDC Converter	141.38	M€					[15]
2015	900 MW Offshore HVDC Converter	127.88	M€	157.00	0.00	-14.93	0.00	
Torbaghan	-	-	-					[17]
2016				0.00	0.00	0.00	0.00	

[a] The provided cost parameters already fit the cost model coefficients.
[b] The proposed non-linear model is used to create cost data for the respective transmissible power, a voltage level of 320 kV is assumed.
[c] Platform costs are not considered in this study.

Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	IV 4-26 weeks **Haertel/ IWES**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	☐ yes
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	☐ yes
Was the used methodology effective ? Please comments if NO	☐ yes
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	☐ yes
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	☐ yes
How do you evaluate the report?	5
Is any missing information in the report? Please comments if yes	☐ No
Rate the overall experience as described in the final report.	5

Other Suggestions?
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[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Report for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	Hannele
Applicant Surname	Holttinen
Home Institution	VTT
IRP Partner? (yes/no)	yes
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B) Host institution details

Institute name	LNEG
IRP PARTNER?	yes
Contact person	Ana Estanqueiro
Country	Portugal
E-mail	ana.estanqueiro@lneg.pt

C) Relevant Programme and scheme

CORE PROJECT? *YES/NO* *(Please erase the non-relevant)*	(B) Wind Integration	RELEVANT EERA SUB-PROGRAMME Max 2 (Please erase the non-relevant)	(B) Wind Integration
Length of the grant scheme *(Please erase the non-relevant length)*	Scheme: (02) 4-26 weeks	Number of weeks: Start date:	7 28th March, 2016

D. Project description and outcomes

Use of forecasting tools for wind power in electricity markets

Integrating wind power to European power systems and electricity markets involves changes in market design as well as improved forecast tools and use of those tools, for wind power operators participating in the different markets. This mobility continued a 3 month long mobility (Dec2015-Feb2016) with 7 weeks in April-May. The topic was updated to focus more on use of forecasting tools, from general electricity market issues with wind power.

This mobility aimed at a fruitful collaboration of a senior researcher from VTT visiting a group actively involved in IRPwind WP8 opening new possibilities through cross-feeding ideas and the identification of synergies between VTT and LNEG long-term objectives aligned with IRPWind main goals. The main contribution will be for Task 8.3.1 Market design for high wind power penetration and Task 8.3.2 Mitigation of the impact of wind power variability (Deliverables D8.12 Market design with multi-agent systems; D8.13 New market products; D8.14 Role of forecasting in the power system).

1. Work during mobility period at LNEG

This period, the opportunity was used to discuss more the strategic bidding and multi agent market models. Plans were made on how to use the available wind forecast data, to capture meaningful snapshots for the model showing the impacts on markets. A conference article was submitted in May.

On top of that the joint article to European Energy Markets EEM 2016 conference, was revised with some new analyses applying the Nordic market rules to Portugal data. The results showed that the balancing settlement of Portugal cannot be fully reproduced by the models constructed based on the MIBEL market organization published and available data. The results obtained are not entirely cost reflective and penalize variable renewable power sources and wind energy. The results obtained were sent to the regulator ERSE (where an interview was organised during the previous mobility that is also investigating this situation.

Meetings with other Portuguese actors were organised to TSO REN research organisation Nester (Mr. Nuno de Souza e Silva, General Manager and Executive Board Member, and Mr. Rui Pestana, deputy director of system management), the utility EDP renewables wind control room, and of GECAD - Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development Director Prof Zita Vale. These were both as general interviews/interaction regarding future changes in energy systems and more concretely to discuss and disseminate the mobility task. In addition there was a possibility to join one interesting workshop at EDP, Lisbon, results workshop of Sustainable EU project.

On top of these activities, LNEG and VTT future collaborative projects were actively searched for and several suitable topics were found – but no funding scheme yet.

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

Dissemination and communication were made to the regulator ERSE, and through visit to FEUP, Porto. The joint publication (a review conference paper) was presented in IRPWIND WP8 workshop 16th March, Kassel, as well as the EEM2016 conference in Porto in June. It will be part of IRP.Wind and EERA Wind articles, as well as the submitted article.

The general findings of changes in future business models and market mechanisms for energy sector reported to the Finnish national projects EL TRAN and FLEXe will be disseminated also to IRPWIND and EERA JP WIND subprogramme Grid integration. A presentation of the total 3 mobility periods will be given at the Irp.Wind workshop on business models for ancillary service provision in Helsinki (or Trondheim) summer 2016 as agreed with Kurt Rohrig (the workshop was postponed to fall, 2016). The 3 times 3 month visit programme originally planned for, giving an opportunity to link new knowledge to several countries will now result in the three countries Spain, Portugal and Finland – Ireland visit was not eligible (UCD withdrawn from EERA Wind to lead EERA ESI). The 7 weeks was not long enough to fulfil the proposed extension from wind to solar section, however that was not at the core of the planned activity.

3. Results

At the end of the mobility period, we have organised an internal seminar (GECAD) and presented the mobility period common work in Irpwind workshop 16th March, Kassel. We have submitted a joint publication to IATEM conference, Porto, September 2016: Hugo Algarvio, Antonio Couto, Fernando Lopes, Ana Estanqueiro, Hannele Holttinen. Forecast Uncertainty and Market Closing Time impacts on Multi-Agent Energy Markets with High Levels of Renewable Generation.

The interviews of Portugues actors (system operator REN; large power producer EDP and research institute GECAD) have been made with following main observations (on top of the previously reported):

- Experience with wind and PV integration: 2015 first time wind exceeding load during some hours. Impacts on balancing: more downregulation seen.
- High wind situations in Portugal, near zero prices in market, but domestic consumers do not feel the benefit as tariffs are fixed within no/load, peak and intermediate periods. However, for large consumers operating on the electricity markets there is a clear benefit. Demand side response is being addressed in Portugal in specific smart grids case studies, but so far the main experience on the markets impact is coming from US.
- Cross-Border balancing services: moving for more collaboration, but keeping the balancing responsibility in Portugal is important for the PT TSO REN S.A..
- Balance settlement rules: in Portugal very complicated rules for calculating the payments for individual producers, an algorithm is used by the TSO but its application is not reproducible.
- Research of TSO focus on energy system in transformation: changes in consumers and increasing renewables, collaboration with Distribution system operators, and European grid planning and internal markets.

General findings of changes in future business models and market mechanisms for energy sector will be reported to both the Finnish national projects EL TRAN and FLEXe and to EERA JP WIND subprogramme Grid integration. A publication for EL TRAN will be written in summer and a presentation to EERA JP WIND subprogramme is planned for autumn 2016.

The KPI's of IRPWIND have the following additions:

- Number of (existing and new) projects that cooperate actively with IRPWIND and that exchange knowledge (and data) with IRPWIND +1 (Finland national project ELTRAN).
- Number of joint publications by IRP participants supported by national funding accepted/published in peer reviewed journals +0 (submitted paper was to a conference, there is still a possibility to submit to journal after)
- Number of researchers involved in mobility and exchange programmes +1
- Number of reports from researchers involved in mobility and exchange programmes +0
- Number of days of mobility and exchange +49
- Number of joint publications related to the participation in the exchange programmes +1
- Number of dissemination events related to the participation in the exchange programmes +2 (2 internal presentations: at GECAD, Porto and REN, Lisbon).

Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**IV** **4-26 WEEKS** **HOLTTINEN/LNEG Portugal**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	x yes □ No
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	x yes □ No
Was the used methodology effective ? Please comments if NO	x yes □ No
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	x yes □ No
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	x yes □ No
How do you evaluate the report? Good (4)	1 2 3 4 5
Is any missing information in the report? Please comments if yes	□ yes x No
Rate the overall experience as described in the final report. Good (4)	1 2 3 4 5

Other Suggestions?
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………
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[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Final Report for Mobility grant within IRPWIND

A) Applicant details

Applicant Name	**Ariane**
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Home Institution	**BERA (Cenaero)**
EERA/IRP Partner?	**Yes (EERA member but not IRP)**
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B) Host institution details

Institute name	**DTU**
EERA/IRP PARTNER?	**Yes (both EERA and IRP)**
Contact person	**Torben Larsen**
Country	**Denmark**
E-mail	**tjul@dtu.dk**

C) Relevant Programme and scheme

CORE PROJECT? ***NO***		**RELEVANT EERA SUB-PROGRAMME**	**(E) Aerodynamics**
Length of the grant scheme	**Scheme:** **(02) 4-26 weeks**	**Number of weeks:** **Start date:**	**13 weeks** **2/5/2016**

D. Description of the project: HiFi_LES_4_Wind
Description of the work and major results.

The collaboration aims at applying an innovative CFD methodology which already proved its worth on turbomachinery applications to geometries critical for the Wind Industry. The CFD methodology developed in the sending institution, BERA-Cenaero, is compared to state-of-the-art wind turbine tools developed and used in a wind energy research leader, the receiving institution, DTU Wind.

More precisely, the collaboration permitted to evaluate the potential of the Discontinuous Galerkin (DG) methodology, in-house code developed in BERA-Cenaero, for Large-Eddy Simulation (LES) of wind turbine airfoils. The DG method has shown high accuracy, excellent scalability and capacity to handle unstructured meshes but is not used in the wind energy sector. The present study aims at evaluating this methodology on an application which is relevant for that sector and focused on blade section aerodynamics characterization. To be pertinent for large wind turbines, the simulations has to be at low Mach numbers (M ≤ 0.3) where compressible approaches are often limited and at large Reynolds numbers (Re ≥ 106) where wall-resolved LES is still unaffordable. At these high Re, a wall-modeled LES (WMLES) approach is thus required. In order to first validate the LES methodology, before the WMLES approach, the sent researcher performed airfoil flow simulations at low and high Reynolds numbers and compared the results to state-of-the-art models used in industry, namely the panel method (XFOIL with boundary layer modeling) and Reynolds Averaged Navier-Stokes (RANS) performed by N. Sørensen at DTU Wind. At low Reynolds number (Re = 6 × 10^4), involving laminar boundary layer separation and transition in the detached shear layer, the Eppler 387 airfoil is studied at two angles of attack. The LES results agrees slightly better with the experimental chordwise pressure distribution than both XFOIL and RANS results.

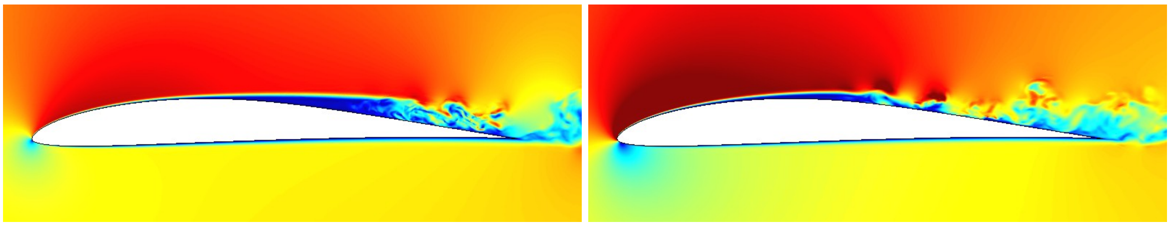

Figure 1: E387 instantaneous velocity field in the periodic plane at α = 4° (left) and α = 8° (right).

At high Reynolds number (Re = 1.64 × 10^6), the NACA4412 airfoil is studied close to stall condition. In this case, although the wall model approach used for the WMLES is very basic and not supposed to handle separation nor adverse pressure gradients, all three methods provide equivalent accuracy on averaged quantities. The collaboration BERA-Cenaro/DTU Wind granted by the IRPWIND Mobility permitted hence to perform a strong step forward in the use of LES for high Reynolds number wind turbine airfoils.

Compliance to the expected results, Key Performance indicators KPIs and the advancement of Technological Readiness Level according to the application.

To assess the compliance compared to the expected results, KPI and advancement in TRL, the application text is provided in blue and the achievements are provided/discussed in black.

- *Expected results*

1. Deployment and assessment of the use of DG methodology for Wind applications.

As described in the previous section, the collaboration permitted to compare DG methodology to state-of-the-art models and showed that the DG methodology has added-values at low Reynolds numbers (i.e. flow conditions interesting for scaled prototype turbines).

2. Discussion on WMLES validity, computational gain and interest compared to state-of-the-art models.

At large Reynolds numbers (i.e. for large wind turbines), a LES is unaffordable and a wall model approach (WMLES) needs to be used. The wall-model can have various accuracy and in this project, as a first test, the simplest and least accurate model has been used. Even with this model, the DG WMLES approach provided equivalent results as the state-of-the-art tools (XFOIL and RANS). This is a very promising results. Indeed, although the panel and RANS approaches, being computationally much cheaper, will remain the main design tools, WMLES (or equivalently DES) and LES are needed to provide complementary results and more physical insights.

In view of the high computational difference between the methods (few seconds (XFOIL), ≈ 10 minutes on 10 CPU ((U)RANS), ≈ 2 days on 500 CPU (WMLES)), the WMLES approach used in DG has no added-value yet compared to the state-of-the-art tools. But, although the wall stress model is so far very basic, i.e. not supposed to handle separation nor adverse pressure gradient, the present WMLES already provides quite acceptable results.

It is expected that more advanced wall model will be required to improve the results. The Two-Layer Model has provided good results on multiple test cases including a backward facing step, a trailing-edge and an airfoil near stall. Adding this approach to the presented WMLES would likely permit to improve strongly the results. This feature is currently being implemented and tested. The collaboration started during the 3 months stay will continue to observe the gain in accuracy with this improved wall-model.

3. Results of low Reynolds airfoil and add-ons LES and WMLES of high Reynolds airfoils provided in database and discussed in a report available for the entire EERA Wind community.

The results of the low and high Reynolds airfoil simulations will be available through an open-access peer-reviewed paper (conference Torque 2016). As the computations on the airfoils were more challenging than expected, there was no time left to study add-ons. This would be transferred to a following collaboration between BERA and DTU.

4. List of complementarity activities between BERA and DTU Wind. Strategy for better collaboration, alignment and future steps.

Ariane Frère (sent researcher and vice-president of BERA Wind) took advantage of her 3 months stay in DTU Wind to discuss about BERA Wind with EERA Wind management and secretariat (Peter Hauge Madsen, Søren Siggard Knudsen, Mattias Andersson, Anna Maria Sempreviva, Christian Orup Damgaard, Anna Maria Sempreviva…). By discussing also with researchers in DTU Wind, Ariane found interesting topics where BERA and DTU could collaborate. In particular, two future collaborations were clearly identified between DTU and BERA:

- VG aerodynamic characterization at low Reynolds: use of DG method as described previously and comparison to DTU experimental study.
- Crack propagation with MORFEO (in-house BERA tool) on wind turbine main frames.

- *Advancement of the TRL*

By being validated on Wind Energy environment, ArgoDGM LES will during this project evolve from TRL4 to 5 (technology validated in relevant environment in the case of key enabling technologies). The WMLES will evolve from TRL2 to TRL5.

The TRL advancement planned for the LES (4 to 5) has been achieved, validating the LES approach in the Wind case. The TRL advancement for the WMLES could not achieve the ambitious evolution planned (2 to 5). This because the industrial test case gave rise to new questions (e.g. change of the wall-model to take the pressure gradient into account) and hence to new technologies to be validated in lab (TRL4).

- *Assessment of the KPIs*

Improvement of the CFD models:

- prove feasibility of running WMLES at high Reynolds --> at least one converged simulation of an airfoil at Re=1,000,000.

KPI achieved, results presented in the submitted and accepted Torque2016 paper.

- reduction of the error → 10% improvement of airfoil lift and drag accuracy compared to state of the art codes (Xfoil, EllipSys RANS).

The use of DG methodology permitted to reduce the error on the drag by more than 10% but had no impact on the lift as presented on the following figure. The addition of an improved wall-model should permit to obtain better results. Based on the work performed, this KPI is however not very relevant as the main objective with LES or WMLES is to bring complementary information which are not available with the current codes (unsteady data, pressure fluctuations…).

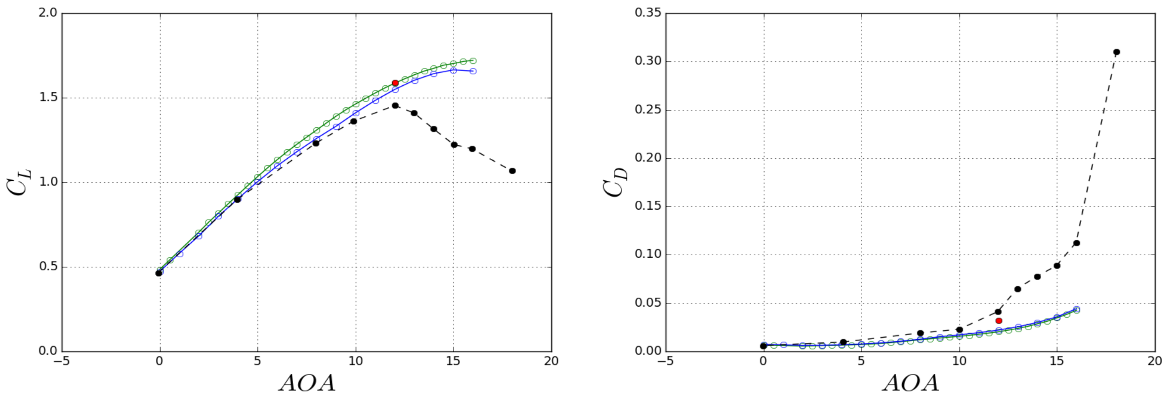

Figure 2: NACA4412 comparison of computational lift and drag (XFOIL: green, RANS: blue and WMLES: red circle) to Wadcock experiment (black circles).

- reduction of CPU cost by use of Wall-Modeled LES compared to LES--> 50% reduction of the mesh degree of freedoms for a case at Re=1,000,000.

KPI achieved, results presented in the Torque2016 paper. The use of WMLES approach permitted to reduce the mesh size even further with wall normal refinement requirement of the LES of y+~1 and for the WMLES y+~100.

Improvement of the collaboration between BERA and DTU Wind:

- establish complementarity → list of complementary activities/projects between BERA and DTU Wind in the Aerodynamic field

This KPI was too ambitious and, although there were many discussions on the complementarity between the two organizations and although some researchers were put in contacts, the process did not go far enough to be able to agree in a list of projects that could be done in collaboration. However, Ariane 3 month stay will for sure strongly facilitate the collaboration between the institutions.

- future collaborations → at least one clear following project between BERA and DTU Wind

As presented earlier there will be for sure a continuation of the collaborative project on the simulation of airfoils and VG. There will be as well a possible collaboration on crack propagation.

Description of the benefit for the researcher, the host and home organization and IRP programme.

The researcher and home institution gained from the deep expertise of the DTU team in Wind Energy to be able to transfer their CFD methodology from the turbomachinery to the Wind Energy field. The researcher managed also to develop a long term collaboration between DTU Wind and BERA and she created a strong network of researchers active in her field. This will for sure help her and BERA for future research project. The researcher has been interviewed by the IRPWind team on the benefits of the programme, see the following figure.

The DTU team gained from the knowledge transfer from the aircraft industry (the sent researcher presented three seminars with large audience) and the comparison test cases on 2 experiments: the E387 and NACA4412 airfoils.

DTU and BERA team gained as well on having a common accepted peer reviewed article.

The IRP programme gained from the advancement of the EERA Wind sub-programme Aerodynamics strategy goals "2-Improved aerodynamic design modeling" and "5-Development and evaluation of new aerodynamic concepts". Being the first participation of BERA in the Wind IRP and Mobility scheme, this project was clearly also a step forward in the integration of Belgian activities at European level.

Figure 3: Interview of the sent researcher about the benefits of the IRPWind mobility programme (available on https://www.youtube.com/watch?v=6nyAGRsCDzQ)

Future perspectives. (Future research, availability of databases to other parties, expected publications and dissemination activities.

The collaborators of the current grant plan to continue the work on the comparison of the WMLES to the state-of-the-art tools. The results with improved wall-model will likely permit to submit the work to a journal.

There is already an accepted peer-reviewed paper based on this collaboration. The paper has been accepted for the Torque 2016 conference (5th October 2016), paper published online with a high visibility for the Wind research community:

"Discontinuous Galerkin methodology for Large-Eddy Simulations of wind turbine airfoils", A. Frère, N. N. Sørensen, K. Hillewaert, P. Chatelain and G. Winckelmans.

A. Frère has during her stay presented the DG and WMLES approaches in for large audience seminars:

- Eccomas 2016 conference (08/06/2016) (~40 people)
- DTUWind Seminar (20/05/2016) (~15 people)
- DTU Wind Fluid group seminar (15/06/2016) (~15 people)
- DTU Wind LES group meeting (21/06/2016) (~15 people)

A. Frère will present two posters on this collaborative work at the Torque 2016 conference and at the BERA Wind conference.

Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**IV** **4-26 WEEKS** **FRERE/DTU**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	☐ yes
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	☐ yes
Was the used methodology effective ? Please comments if NO	☐ yes
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	☐ yes
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	☐ yes
How do you evaluate the report?	4
Is any missing information in the report? Please comments if yes	☐ No
Rate the overall experience as described in the final report.	4

Other Suggestions?
………
The collaboration proved to be valuable for the subprogramme wind energy in the EERA JPWind. The connection between institutes showed that long-lasting relations have been built and knowledge transfer from both institutes to each other has been performed.
From ECN I would have loved to have such visitor in the exchange programme to ECN: the application to higher ReNumbers is important to consider.

[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Application form for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	**Teresa**
Applicant Surname	**Lo Feudo**
Home Institution	**CNR-ISAC**
IRP Partner? *(yes/no)*	**Yes**
Home Institution Postal address	**Area Industriale Comp. 15-88046 Lamezia Terme (CZ) Italy**
E-mail	**t.lofeudo@isac.cnr.it; t.lofeudo@gmail.com**

B) Host institution details

Institute name	**DTU Wind Energy**
IRP PARTNER?	**Yes**
Contact person	**Anna Maria Sempreviva**
Country	**Denmark**
E-mail	**anse@dtu.dk**

TITLE OF THE PROJECT

Research collaboration on use of wind LIDARs in Coastal Areas.

1 Description of work and major results

1.1 Introduction

For one month, from 10th May to 7th June I stayed at DTU in order to render possible a jointly paper on new analysis in the joint campaign, between DTU and CNR, during summer 2009, and to study relations and similarities in two coastal sites: Lamezia Terme (South Western coast of Italy) and the Høvsøre (West coast of Jutland, Denmark). This in the optics to strengthen the network between CNR and DTU

1.2 Activities and results

The goals to reach during the mobility period are the following:

1. To write a joint paper on an intensive campaign during summer 2009 adding further analysis of the database of a LIDAR WLS7 WindCube (LEOSPHERE), and a ceilometer CL31 (VAISALA) based on new insight from the experience of DTU colleagues at a similar experimental facility in Denmark
2. Exploring similarities and differences between the CNR-ISAC costal site of Lamezia Terme and the site of Høvsøre at the west coast of Jutland, on the base of results obtained from the analyses of the campaign. At the Høvsøre site at 1km from coastline, the terrain is fairly flat and homogeneous and the background flow blows from the west; Lamezia Terme site is located at 600m from coastline in flat surrounded by complex terrain where local breeze regimes (W-E-W) modulate the background flow mainly from west.

To reach these objectives, during mobility period, I had a series of meetings with DTU colleagues expert in remote sensing instrumentation and coastal meteorology. We carried out the following discussions on :

- methodology and techniques to discriminate noise of raw signal from the Ceilometer , as a function of the stability parameters, and to analyze the Carrier-to-Noise Ratio, (CNR), of the laser signal of the WindCube LIDAR in breeze regime and background flow; and test of the algorithms;

- test of algorithms on boundary layer height; and

- studying differences and similarities of the two coastal areas in different atmospheric conditions.

In the following paragraphs a summary of the work and results of main activities is given.

1.2.1 Activity 1. The intensive campaign of 2009 at CNR-ISAC

The 2009 summer campaign (01/07/2009 - 06/08/2009) at CNR-ISAC experimental site of Lamezia Terme (figure1) is described in [1,2]

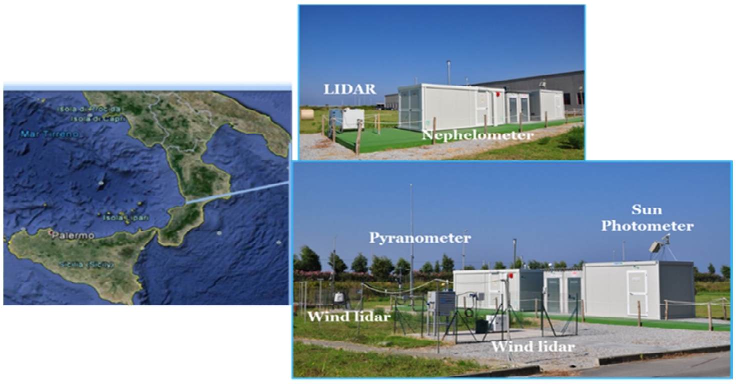

Figure 1 GAW regional WMO site-Lamezia Terme

The following sensors were present during the experiment: a wind LIDAR (WLS7 Windcube), a SODAR (DSDPA.90-24-METEK) and a ceilometer (CL31, Vaisala). At the surface, mean and turbulent meteorological parameters where sampled by standard meteorological instruments and by a METEK Ultrasonic anemometer respectively at the height of 10 m.

The focus was on the optimization of several algorithms in MATLAB language to investigate the development of the vertical structure of the coastal wind flow and the PBL (Planetary Boundary layer) layering under different meteorological conditions performing the analyses with different methodologies from different instruments. In particular, a technique to reduce the noise in the ceilometer data and a methodology to classify the lidar signals in stability classes was applied. The results obtained in earlier studies [1, 2] have led us to focus on the response of the WindCube using the CNR signal, when the sea breeze is fully developed and the vertical layer is non homogeneous in terms of aerosol content due to the presence of the Internal Boundary Layer (IBL) with marine aerosols above. Finally a comparison between the WindCube measurements and output of the Weather Research and Forecasting (WRF v.3.5.1) [3] mesoscale model was also performed.

To perform the analysis during the experimental campaign in 2009, for classifying the weather conditions and stability classes, we have taken into account the data collected by a surface meteorological station including a METEK Ultrasonic anemometer at the height of 10 m. We focused on days with a sea breeze well developed (15, 16, 17, 24, 28, 29, 03 July/August 2009, (W-E-W)) and days with a background flow from west that typically prevented the full development of the sea breeze (19, 20, 21 July 2009, (W)).

1.2.1.1 Analysis of the ceilometer in different atmospheric stability conditions:

In a previous study, we used the Range Corrected Signal (RCS) methodology, developed for aerosols lidars such as ceilometers [1, 4], in order to reduce the noise in the backscatter signal. The Mixing layer height (MHL) was then estimated in different weather conditions, with different methodologies: minimum gradient method (GM), and idealizing backscatter profile (IBM).

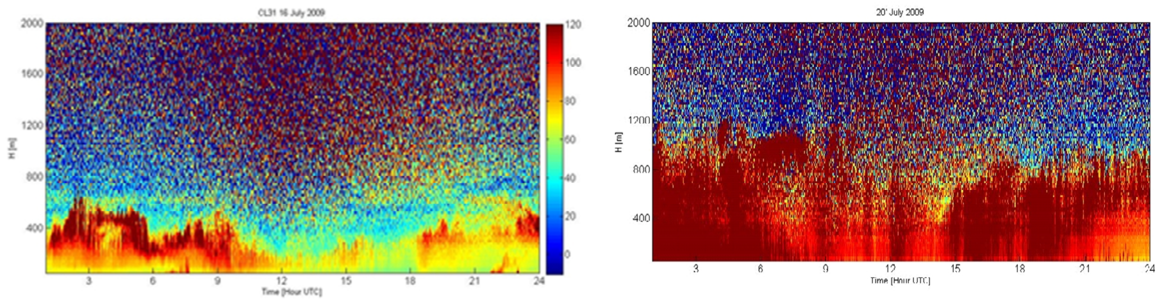

Figure 2 Ceilometer CL31- data mean every ten minutes during the breeze day -16.07.2009 (left) and background flow day 20.07.2009 (right). The intensity of volume backscatter coefficient is in arbitrary units.

Figure 2, shows an example of 10 minutes average profiles of backscatter volume coefficients for sea breeze and background flow respectively.

On the left side non homogeneous backscatter is evident for lower height (near surface) due to incursion of marine aerosols (from 10:00 am to 19:00 pm) due to sea- breeze regime. While on the right more homogeneous layer is present due to synoptic and constant flow.

During my stay, I discussed with Alfredo Peña on the most suitable methodology to reduce the noise in the ceilometer raw signal. He suggested to analyze the noisy signal performing the analyses classifying the signal according to atmospheric stability conditions estimated by the sonic anemometer [5,6]. This methodology was applied to the 10 minutes average of the backscatter profiles measurement in breeze and background flow condition separately.

Table 1 shows the Mixed Layer Height, Z, estimated in both background flow and breeze regime, during night and day, using GM [7,8] IBM [7,8], and the IBM method classified in stability classes [9]. Here, we reported only the results using, IBM [5, 6, 7], in fact the shape of the ideal backscatter profile is similar at the average profile for each stability class.

	Background flow		**Breeze regime**	
	Z-Night (m)	**Z-Day (m) (9-18 (UTC))**	**Z Night (m)**	**Z-Day (m) (9-18 (UTC))**
GM (mean all backscatter profiles during hourly night/ day)	680	580	180	460
IBM (mean all profiles during hourly night/day)	660	570	160	420
IBM (classified in stability classes)	640 **Stable**	590 **Near Neutral**	140 **Very Stable**	400 **Unstable**
n° profiles	106	43	34	56

Table1 Estimated averages of Z from ceilometer data for background flow and breeze conditions in separated night and day hours by the GM and IBM method and IBM method classified in stability classes.

For values obtained in Table 1, in order to compute algorithms, we needed to fix some parameters. The start values choose to GM method we have considered a sliding averaging of 10min and with a height interval of 80m. For the IBM method, we need to fix the first parameter of s (coefficient related to the Entrainment layer) at 100m, Bm (mean backscatter coefficient above the entrainment layer) and Bu (mean backscatter coefficient in stability classes), [5,6], 40*10-5 and 20*10-5 respectively.

But for the Z-night profiles, during background flow, the number of other profiles are less than 50% of previous ones.

Heights show small differences, lower in the background flow than in the breeze regime where differences are above 10%. Always IBM method calculate smaller heights than obtained with GM algorithm.

Figure 3, below shows an example of the analysis of the ceilometer data of volume backscatter coefficients, b,(average every ten minutes), for different stability conditions. In this case, the backscatter profiles in very stable, near unstable and neutral stability classes were analyzed during breeze and background flow days. The daily cycle was observed during the background flow conditions, in fact how to the solar radiation started the thermal effects on surface have a tendency to bring the atmosphere at the instability but due to the effects of the wind from the west, we observed a condition of neutrality during the day and near stability (here not reported) during the night. The study was performed on the breeze circulation regime with the same considerations. During the sea breeze regime the instability of atmosphere reach in the central hours of the day and during the night have a tendency to reach a stability conditions.

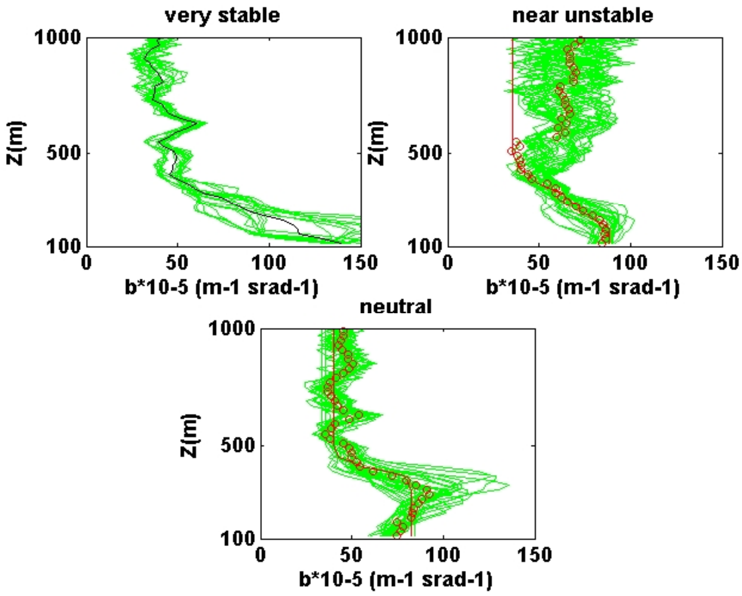

Figure 3 Volume backscatter coefficients, b for different stability conditions: Breeze day (up), stability classes: very stable (up-left) and Near unstable (up- right); Background flow neutral class (down). The backscatter coefficient are shown in green lines, the mean of all signals in red circles and the mean of all signals for “very stable” class in black line. The fit using IBM profiles [9] is shown in red line.

1.2.1.2 Carrier to Noise Ratio analysis from WindCube

In previous studies [2] we had shown that the maximum height measured of WindCube was correlated with the concentration of aerosols along the laser beam path. Therefore, the instrument cannot measure at particular height if the aerosol concentration in not homogeneous in height decrease. Figure 4 below, shows an example of the WindCube maximum obtainable measuring heights in breeze condition day, due to the presence of the Internal Boundary Layer (IBL) with marine aerosols above, the aerosol concentration is not homogeneous and the signal decrease.

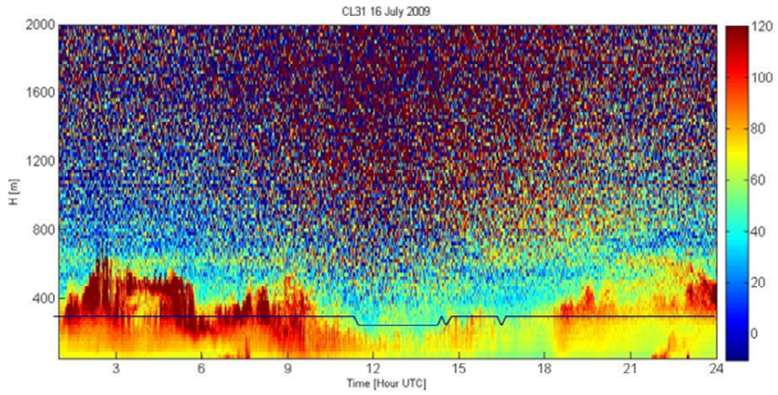

Figure 4 Backscatter profiles (mean of every ten minutes) in a.u. and WindCube maximum obtainable measuring heights (blue line) (16.07.2009).

During days of stationary sea-land breeze regime (15, 16, 17, 24, 29, 31 July), after the on-set of the sea breeze at around 10:00 UTC in figure 4, the WindCube maximum obtainable measuring height is often limited to 180m. However, as the sea breeze intensity increases and become stationary around 14:00 UTC, the maximum height reached by the WindCube increases again.
These preliminary results have suggested to focus on the response of the WindCube in days when the breeze is well developed and at its onset. The main hypothesis is that during these events, concentration of aerosols in the vertical layer is not homogeneous, therefore the signal is weak. We started the analysis from the availability of the WindCube measurements defined by the CNR of the laser signal, which depends on atmospheric conditions, such as: aerosol backscatter (β), relative humidity (RH) and precipitation (P). The WindCube disregards all measurements for which the CNR < -22 dB.

The focus is on to determine situations of suitable data availability for future field deployments by quantifying WindCube performance with respect to the aerosol backscatter distributions, in different atmospheric conditions and coastal site with complex orography. In order to investigate the influence of aerosol backscatter on CNR, in particular during the well-developed sea breeze, we performed preliminary analysis and we reported in figure 5 an example of the average CNR, for the breeze day, in function of the heights. The sector analyzed are W-E. Figure 5, shows the availability data from WindCube instruments above the station of Lamezia Terme.

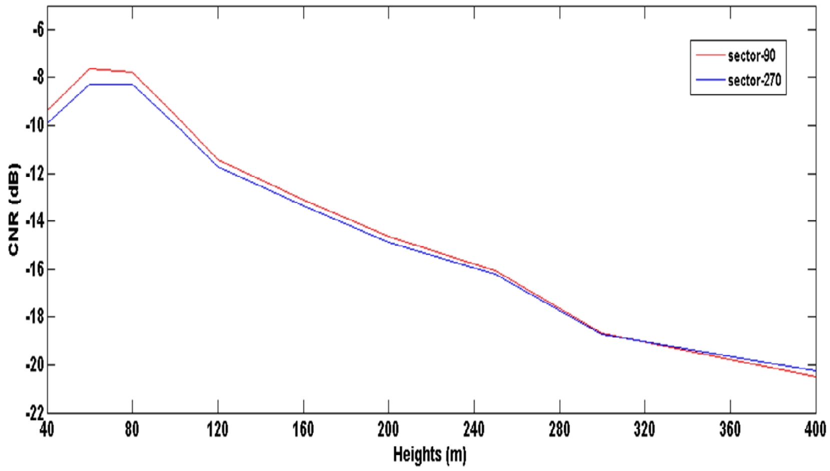

Figure 5 CNR average of day breeze from sector 90° and 270° on function of the heights.

Figure 6 shows the diurnal cycle of CNR at different heights for the breeze day (sector 270°) the aerosol lifted by convection after sunrise and increase the boundary layer entrains cleaner air from above. Up to 100m the shape of signal results similar, but the signal between 80m to 100m shows a different trend which might indicate the front of the breeze. Further analysis will be performed on the CNR of other antennas and can be inserted in a second paper.

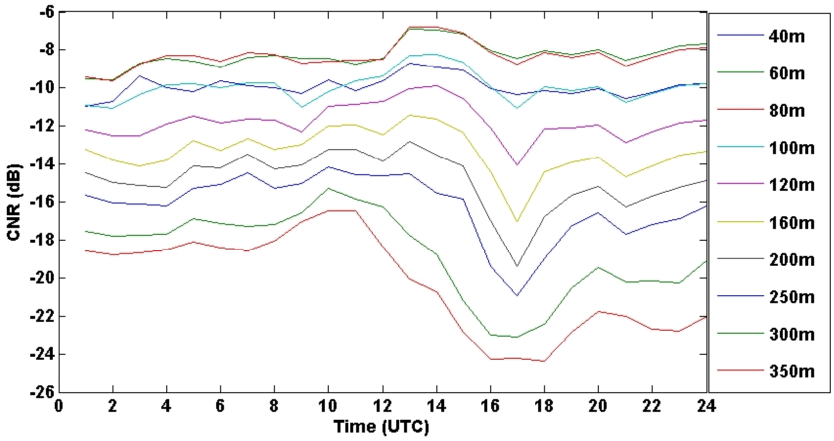

Figure 6 Diurnal cycle, hourly mean of CNR signals at different heights (sector 270°)-breeze regime.

1.2.1.3 SODAR reflectivity in different meteorological conditions

The SODAR used during the experimental campaign (DSDPA.90-24-METEK) is an acoustic sounder and provide wind and turbulence vertical profiles in the lower parts of the atmosphere. A back-scatter signal, a small fraction of the acoustic energy from density fluctuations of the backscatter atmosphere, whose frequency is shifted according to the wind component parallel to the propagation of the acoustic waves (Doppler effect). It operates ranging from 45m to 405m height with a working frequency of 1280Hz. Sampled data are averaged every 10 minutes. In previous study [1,2] we compared the wind speeds and directions measured by the Wind Cube and the SODAR during the experiment performed in July/August 2009 both to validate the profile data of wind measured and to study the variability of the phenomena that affects the boundary layer at different height. Since, the working principle of the SODAR is based on density fluctuations due to the thermal structure of the Boundary Layer, in this report we computed the reflectivity in different meteorological conditions, in order to highlight the thermal effects on surface. Reflectivity surface plots, or sodargrams, present the time series of the profiles measured for the vertical beam direction (zenith=0°) and a frequency of 1.3 kHz.

Figure 7 show the Sodargram of backscatter profiles (mean of every ten minutes) in Db of the reflectivity of the radial 3 antenna (vertical), during day and night time, in sea breeze and background flow .Measurements that have not passed the error checks successfully, are left blank.

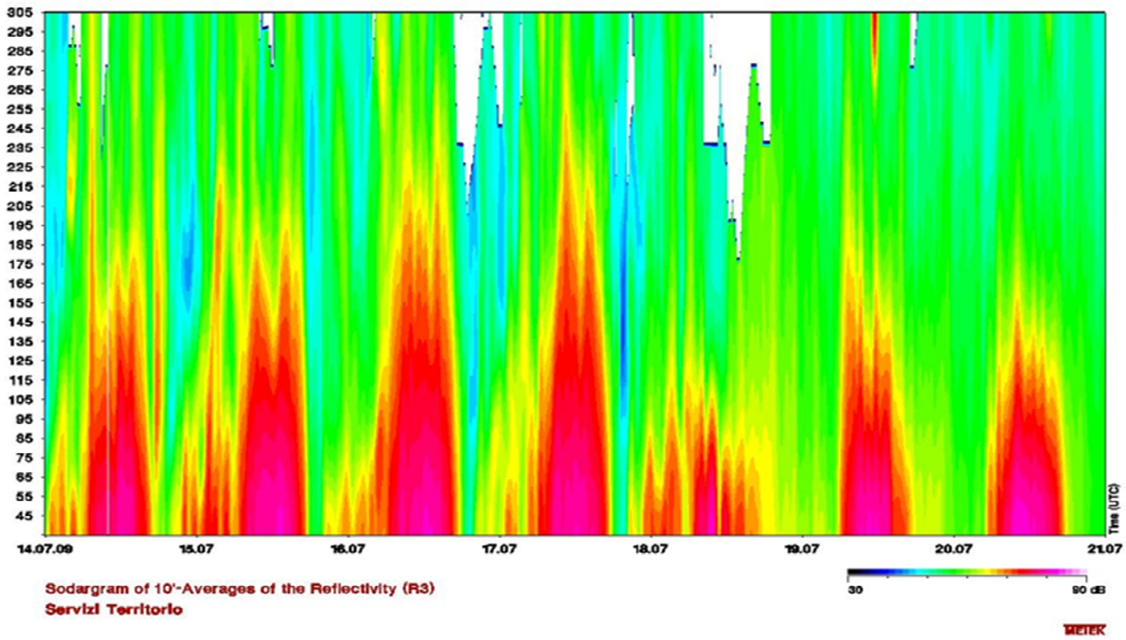

Figure 7 Sodargram of reflectivity from 14/07/2009 to 21/07/2009 during sea breeze (15, 16, 17 July) and background flow(19,20 21 July) at Lamezia Terme site.

Generally, during day time, when the solar radiation starts, the SODAR reflectivity is not disturbed by the aerosol advection and the reflectivity signals are very strong. In breeze regime in the early hours of the morning, during night- day transition, a strong variability of reflectivity signal is observed when the breeze starts, in these conditions the surface layer gradually becomes unstable and the mean wind speed decrease. We observed that near-surface the transition from night to day is coupled with numerous effects on the wind flow and the stability. During the night weaker reflectivity signals are observed and after solar heating ceases, the stratification of the surface layer gradually becomes stable.

1.2.1.4 Comparison WindCube vs WRF model

We compared the wind speeds measured by the WindCube and WRF model outputs at different heights during the experiment in 2009. We used the WRF v.3.5.1 [3] with three two-ways nested grids at horizontal resolutions of 27km, 9km and 3km respectively. Thirty vertical levels are adopted, from the surface up to 16300m of altitude in the terrain following vertical coordinates. Atmospheric initial and dynamic boundary conditions are derived from Global Forecast System (GFS) operational forecast/analysis cycle. WRF model outputs were stored hourly, and each run lasts 78 hours. Statistics used to quantify the performance of the models are: RMSE (Root Mean Square Error), MAE (Mean Absolute Error) and BIA (Bias). Here, we show in figure 8 The RMSE (Root Mean Square error) of the wind speed measured by Windcube vs WRF model outputs at different heights. In this analysis we considered the all data set of the campaign. The maximum error was calculated at the height of 200m.

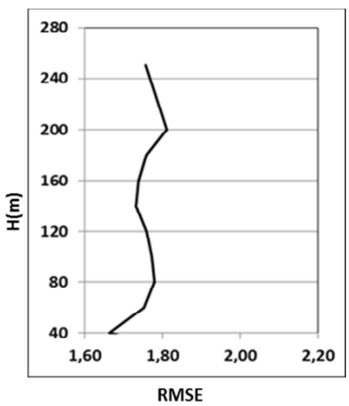

Figure 8 RMSE (Root Mean Square Error) between wind speed measured by the Windcube at different heights with wind speed WRF model simulation.

Forecast model, in general, overestimate wind speed with respect to the WindCube measures due to model low temporal and spatial resolutions (1hour, 3km).

1.2.2 Activity 2

The second activity was to explore similarity and differences between the site of Lamezia Terme and the site of Høvsøre at the west coast of Jutland. Two coastal sites are different in terms of terrain: fairly flat and homogeneous the Høvsøre and flat with complex orography Lamezia Terme. However, the orientation of the coastline is North-South therefore in both sites the sea breeze regime is west- east; furthermore, the main large scale flow is blowing from the west.

1.2.2.1 Results Activity:

We agreed to focus on the development of the sea breeze in Høvsøre during the period from April to December 2011 where ceilometer raw signals and wind LIDAR were available.

To single out suitable days with background flow and a sea breeze regime, time series of different parameters i.e. wind speed, wind direction, solar radiation, temperature, pressure, CNR signals and ceilometers signals have been inspected using the web data center of DTU–RODEO (http://vind-ponline01.win.dtu.dk/rodeo/projectlistmap.aspx). We choose several days: 9, 11 April, 31 July, 22 August with background flow and 10 April; 26, 27 July, 1 October with breeze regime at the Høvsøre station. All days are cloud free and with radiation (W/m2) well developed.

These datasets will be analyzed together with a hindcast performed by DTU using the WRF model to explore the large scale conditions. We will focus on the response of the wind LIDAR when the sea breeze is fully developed applying the methodology used for Activity 1. The results will be compared with the similar analysis in Lamezia Terme.

2 Compliance to the expected results, Key Performance indicators KPIs and the advancement of Technological Readiness Level according to the application.

The first joint paper has been drafted containing the new results from the analysis and will be submitted after the first review from all authors and published in Open access for direct transfer to the scientific community.

Different algorithms has been developed and optimized to compute Z and to analyze on the LIDAR backscatter signals, the CNR signals and SODAR reflectivity.

Discussing the two sites, it came out that a less explored issue that is worth investigating is the development of sea breeze circulation in Denmark. Sea breeze cells can be important on the near shore wind energy development in Denmark where the wind farms can be placed few kilometers offshore the coastline. Furthermore sea breeze cell can influence solar energy production inland from the coast due to cloudiness development inland due to the closing of the cell. Therefore, a new study has been elaborated in order to investigate the mechanism of the development of breezes at the two sites of Lamezia Terme and Høvsøre. Days during Summer 2011 has been singled out and run from a model will be extracted during those day to investigate the development of the sea breeze at Høvsøre.

These preliminary analysis of the second activity will lead us to write a second paper. The results of the two activities will be presented at the IRPWind Conference in Amsterdam in September 2016.

Since the research planned is related to the wind development in coastal areas, it is heavily linked to EERA Sub-programme ***Wind Condition*** as the wind LIDAR technology allows the fundamental understanding of wind flow within the atmospheric boundary layer in coastal areas.

3 Description of the benefit for the researcher, the host and home organization and IRP programme.

I have benefited from the stay in a variety of ways. I saw the differences in the priorities between CNR-ISAC and DTU Wind Energy. The historical and experienced research on wind conditions of DTU helped me in increasing understanding of the wind flow analysis from remote sensing devices Together with Anna Maria Sempreviva, I had a series of meetings with Alfredo Peña Diaz, Andrea Vignaroli, LIDAR experts on ceilometer data analyses and CNR raw signal respectively and Andrea Hahmann and Xiaoli Larsén on WRF Model performance.

I will benefit from the network I was able to establish with a number of DTU researchers for future collaboration. DTU will have access to a coastal area database in a similar site but in a different geographical and orographical area than Denmark.

4 Future perspectives

During my stay several opportunities for further collaboration has been foreseen to enhance research cooperation between CNR-ISAC and DTU Wind Energy.

I was able to establish personal contacts with my DTU colleagues that I expect will be very valuable for future cooperation and efficient implementation of common projects. Especially the paper on differences and similarities between the two experimental infrastructure of Lamezia and Høvsøre is expected to be give a unique insight on the development of the flow in coastal areas with different orography.

The achievements were made possible through the warm hospitality, welcoming atmosphere and cooperation at DTU. I am most grateful to the DTU colleagues for their many suggestions I have received from them.

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Mobility Call N°: **Mobility scheme:** **Granter Name/Hosting Institution:**	**4** **IRPWIND 01 A (4 weeks)** **LOFEUDO/DTU Wind Energy**

Evaluation of the final report [1]

Were the goals described in the proposal reached? Please comments if NO	X yes ☐ No
Does the report include major results? i.e. **highlights and new insight** and advancement of the state of the art? Please comments if NO	X yes ☐ No
Was the used methodology effective ? Please comments if NO	X yes ☐ No
Are future perspectives clear? (Future research, availability of databases to other parties, expected publications and dissemination activities). Please comments if NO	X yes ☐ No
Has the work been a benefit for the researcher, the host and home organization and IRP programme? Please comments if NO	X yes ☐ No
How do you evaluate the report?	5
Is any missing information in the report? Please comments if yes	☐ yes X No
Rate the overall experience as described in the final report.	5

Other Suggestions?
The results of Teresa Lo Feudo scientific work on use of wind LiDARs in coastal areas to survey the sea breeze are presented comprehensively. It is also obvious that DTU and CNR-ISAC both benefitted from her stay and that the collaboration between the two institutes will be sustainably strengthen.
……

[1] 1 (negative) - 2(Poor) - 3 (Sufficient) - 4 (Good) -5 (Excellent)

Funded by EU

Application form for Mobility grants within IRPWIND

NOTE

- **All documents must be named as follows:**

Sub Programme letter, Scheme no., Surname, Document type. Ex: A_2_Smidt_cv
See Table C) below.

- **The application must be max. 6 pages, ex tables, figures and references.**

A) Applicant details

Applicant Name	**Ayman Bakry Taha**
Applicant Surname	**Attya**
Home Institution	**University of Strathclyde (UoS)**
EERA/IRP Partner? *(yes/no)*	**Yes**
Home Institution Postal address	**Royal College Building, University of Strathclyde, 204 George Street, Glasgow, G1 1XW, UK**
E-mail	**ayman.attya@strath.ac.uk**

B) Host institution details

Institute name	**Catalonia Institute of Energy Research (IREC)**
EERA/IRP PARTNER?	**Yes**
Contact person	**Dr Jose Luis Dominguez-Garcia , Deputy Head of Power Systems Group**
Country	**Spain**
E-mail	**jldominguez@irec.cat**

C) Relevant Programme and scheme

CORE PROJECT? YES/NO *(Please erase the non-relevant)*	**(B) Wind Integration**	**RELEVANT EERA SUB-PROGRAMME Max 2** (Please erase the non-relevant)	**(A) Offshore Wind Energy** **(F) Research Infrastructures**
Length of the grant scheme *(Please erase the non-relevant length)*	**Scheme:** **(02) 4-24 weeks**	**Number of weeks:** **Start date:**	**12 weeks** **22/10/2016**

D. Project description

Multi-disciplinary study on the wind power plants as a provider of frequency support in the future power systems

1. Introduction

1.1 Research scope and novelty

The foreseen high penetration levels of power electronics (PE) coupled generation [1-3], including wind energy into the power systems will excavate many challenges to maintain the system stability. The retirement of conventional generation will imply additional strict requirements from wind power plants (WPP) during frequency and voltage excursions. Thus, the provision of ancillary services (AS) including frequency and voltage support by WPPs will be mandatory [4].

The sudden miss-match between generation and load demand causes the system frequency to deviate from its nominal value, which is more possible at high penetration levels of intermittent renewable generation. Hence, this planned research will have higher focus on frequency support among other AS. The rate of frequency deterioration and its nadir are determined based on several factors, namely, system inertia, miss-match severity, and load dynamic behaviour. The conventional synchronous generators are able to provide two critical responses, namely, inertia, which is a natural behaviour to maintain the synchronous speed, and primary response, which is governed by the droop value of the generator. However, the WPP are *naturally* incapable of providing both responses as they are de-coupled from the frequency dynamics due to the very fast reactions of the PE converters. Several theoretically mature methods are developed in the literature to emulate the inertia and primary responses [4-8]. Limited efforts are executed to develop an integrated techno-economic study of the dynamic interactions between the changes of the power reserve market and the responses of the power system [9-11]. In addition, there is a missing nexus between the electrical side, namely power system stability and WPP and the mechanical side including the impact of AS provision on the wind turbine structure.

The planned research work aims to develop a compact and provisional techno-economic study, which is dedicated to investigate the mutual impacts of frequency support provision. The economic side will acknowledge the widely applied/proposed approaches to receive bids and allocate incentives to renewable energies so that they can provide fast frequency response (FFR). On the other hand, a highly detailed power system will respond to different frequency events according to the available intermittent power reserves (i.e. decided by the market mechanisms). In addition, the drawbacks on wind turbine mechanical stability will be roughly assessed. Different scenarios will be examined to highlight the impacts of wind power penetration, event severity, and the adopted market approach among other parameters. The proposed research work will be developed and demonstrated through a virtual environment. However, there is a potential to conduct lab-scale limited demonstrations to test the real responses of wind turbines during frequency support provision (e.g. inertial response including the wind turbine deceleration pattern to extract kinetic energy). This will be an additional asset to get the benefit of the advanced lab facilities in the host institute. The expected overall TRL is 3-4.

1.2 KPIs

- Defining whether the AS provision should be technically or economically driven (Prioritization)
- Initial quantification of the impact of market mechanisms and the corresponding prices on the power system dynamics and stability
- Crossing the bridge between the wind turbine electrical and mechanical stability
- Exploitation of the techno-economic challenges that will face an interconnected energy system with different market mechanisms and mutual provision of AS

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

The proposed joint experiment is foreseen as the natural extension of some of the work that has been developed under the IRPWind WPs 8.1 and 8.2. For example in WP8.1, some control strategies for providing AS support to the grid including frequency support by WPPs. Moreover, the proposed project not only has links to IRPWind but also to several sub-programmes as EERA SP Grid Integration, SP Offshore wind and SP Research Infrastructures. Additionally, the project is clearly coherent with the ”nature” of EERA Wind in general which is expected to create, strengthen and foster research exchange among the European countries.

Finally, this project will lead to significant progress in some EERA Sub Programmes besides the fruitful collaboration amongst IREC and UoS. The project will extend and enforce the synergies between these two research organisations’ and their long-term objectives aligning them with the IRPWind and EERA JP Wind main goals. This research could be also considered as an extension and completion for the fruitful Knowledge Exchange activities between UoS and IREC consolidated by the recent stay of Dr Jose Luis Dominguez-Garcia in UoS in the context of IRPWind Mobility.

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

Please consider that at least one of the partners should have a national project relevant to the proposal.

2.1 Description of national projects from the receiving institution

Emerge Spanish Government - INNPACTO (MICINN)
General Description: The study and development of electrical engineering associated with deep water offshore wind power: generation, generator design and transmission, AC-DC line types, connection to the coast, etc.
Roadmap and Design of DC wind power plants (Alstom Wind SLU)
General Description: The scope of this project is to define a roadmap and the first steps to develop the future DC wind power plants (WPP) for offshore applications.
Design of a Modular Power Converter for AC and DC wind power plants (Alstom Wind SLU)
General Description: This project relies on providing conceptual designs of modular and adaptable power converters for their use in both AC and DC wind power plants; carrying out studies to evaluate their performance and comparison determining the best power converter option. Finally, a detailed technical specification of the most advantageous power converter design that enables further studies on the construction of a prototype will be produced.

2.2 Description of national projects from the sending institution

SUPERGEN -- Wind Energy Technology

Academic full partners:
University of Strathclyde (coordinator), University of Durham, Loughborough University, University of Manchester, STFC-RAL, University of Cranfield,
Industry partners and advisors:
AREVA, CEFAS , Clipper Wind , EA Technology, Eon Climate and Renewables, GL GarradHassan, MLS, Mott MacDonald, NaREC, Nordic Windpower, QinetiQ, Rolls Royce, Romax, Scottish Power, Siemens Wind Power, TNEI, Vestas, Wind Prospect, 3M
General Description: Integrates the research efforts of all the partners to address the medium term challenges of scaling up to multiple wind farms through building, operating and maintaining multi-GW arrays of wind turbine
Contribution in Grid Integration R&D

- Better understanding to the impact of whole wind farms on AC networks
- Integration of new technology with onshore legacy systems on UK and European scale
- Assessment of UK economic impact

2.3 Foreseen European added value of national alignment

- Solid contributions to the European leadership to wind energy industry
- A step to enable the provision of AS by wind power, which paves the way to secure and stable power systems under high penetration of wind power
- Exchange of knowledge and experience between participating institutes
- Fruitful collaboration accredited by high calibre conference and journal publications
- Opportunity to excavate further research challenges and ideas that could be robust pillars for further R&D proposals to attract national and European funds
- Development of the backgrounds and skills of the involved researchers

2.4 Description of the host institute: e.g. infrastructure, experience etc.

IREC Energy SmartLab is the electrical engineering area laboratory in Barcelona. It provides unique emulation and testing facilities. It is currently operating with a number of configurable units. The units can be configured to work as energy generators (i.e. wind power), energy storage nodes or energy consumption nodes. Also, real storage systems (flywheel, super-capacitors and batteries), wind turbine emulators (SCIG, DFIG and PMSG) and PEV charging point are integrated. Finally, there is a grid emulator allowing studying different grid perturbations and configurations. A schematic representation of IREC's laboratory is shown below and a descriptive video can be found in the following link: https://vimeo.com/111393514.

3. Work plan

The research plan splits into 5 tasks:

3.1 Task 1 (Weeks 1-4): Literature survey and encompassing background

A general techno-economic review on the provision of frequency support by WPPs will be made. This comes as a preliminary stage to acquire better understanding of the foreseen challenges at high wind power penetration. The survey will focus on the mechanical and economic aspects as the applicant holds an adequate background on the electrical perspectives. This task is a corner stone in the knowledge exchange between the two institutions due to the remarkable contributions of IREC to this scope of research.

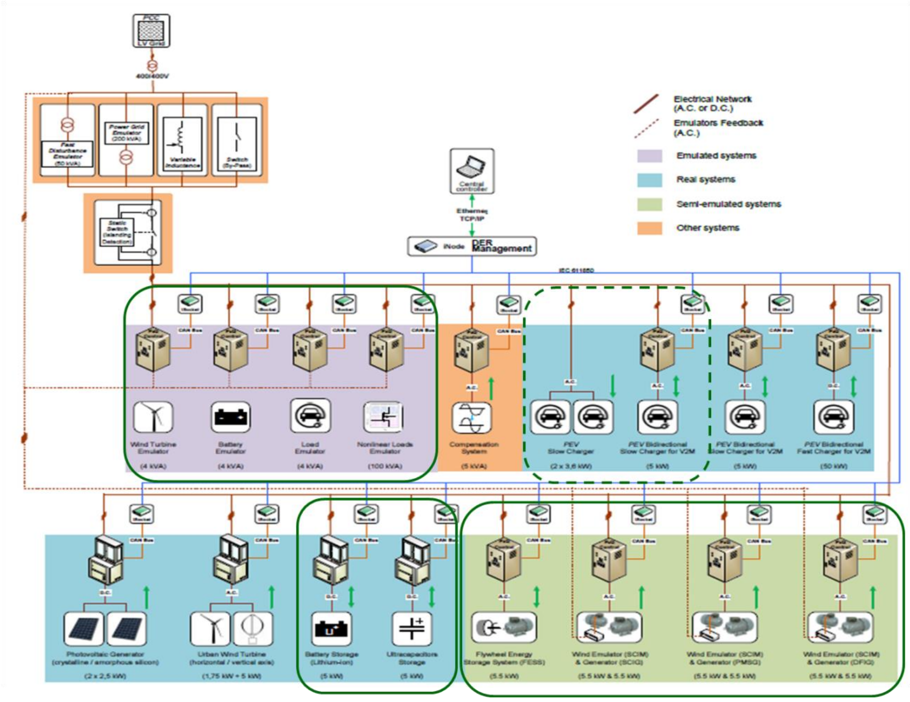

Figure 1. IREC Energy SmartLab schematic

3.2 Task 2 (Weeks 3-6): Building benchmarks in credible environments

The relevant benchmarks will be developed and aggregated to reach a simplified test system in suitable virtual and possibly hardware environments with acceptable level of accuracy. The major benchmarks will acknowledge the dynamics of the power system, FFR market and the major mechanical components of the wind turbine.

3.3 Task 3 (Weeks 4-9): Setting and running the most revealing scenarios

Scenarios will be designed and tuned to emphasis the impacts of the critical parameters of the previously mentioned benchmarks. The penetration levels of wind power will be increased to push the power system to its stability limits. In addition, through each scenario, the power system will suffer bottlenecks (e.g. loss of generation, sudden drops in WPP generation) imitating the foreseen challenging situation in future power systems.

3.4 Task 4 (Weeks 5-11): Results analysis and concluding recommendations

This task will commence as soon as initial results are obtained. The conducted analysis will have major impacts on the tuning of the scenarios as well as development of the benchmarks parameters. The conclusive analysis will lead to solid recommendations that touch upon grid codes, control and operation parameters as well as prospected risks and barriers.

3.5 Task 5 (Weeks 8-12): Dissemination

The conducted research work and the obtained results will be shared and communicated through different channels and methods. The initiation of a joint high-quality publication(s) is a major target of this task, which will also assure the continuity of the synergies between the involved researchers, and, generally the two institutes. A closing seminar will be conducted by the grant holder to a wide range of audience including students, researchers and other interested parties. In addition, condensed efforts will be conducted to attract industry participation. The preparation of the final report is also in the context of this task. The main investigated topics and the interchangeable links among them are described in Figure 2.

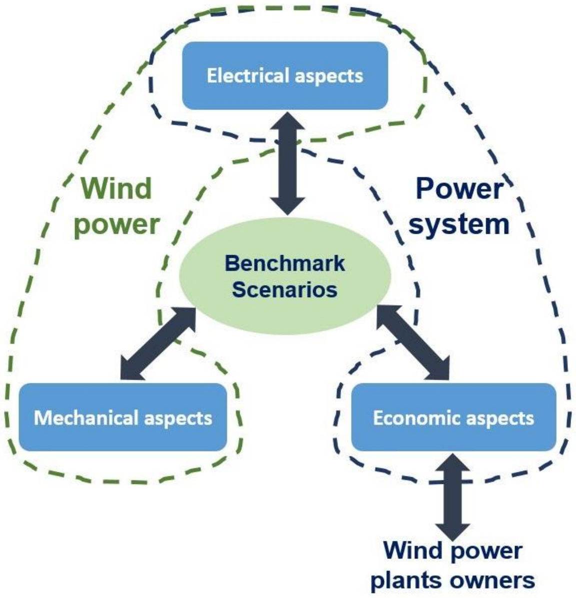

Figure 2 the main scopes to be considered in the planned research

Apart from these tasks, continuous *internal and external communication* activities will be maintained. Internal communication includes technical meetings with the involved research teams. Meanwhile external visits will be organized to industry parties, which have strong collaboration with the host institute, and other research centres (e.g. CIRCE (www.fcirce.es/) that is a partner in IRPWIND and works, together with IREC and UoS in WP8.1).

4. Benefits to EERA objective advancement

The first objective is to strengthen the present and future collaboration among the two partners. High visibility to the rest of EERA JP Wind partners is expected due to the key roles played by the proposed project partners who are very active members in EERA wind, including SP Grid Integration, and they are also leaders/coordinators in IRPWind WP8 and 8.1. Additionally, the planned dissemination actions on the different EERA JPs as Grid Integration will raise more interest on the topic and further studies may be developed with other partners. Finally, this project will act as a successful example to encourage stronger commitment to develop joint European project proposals in the field, especially that it crosses the bridge between technical and economic challenges.

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

A dissemination plan will be developed including joint publications as well as contributing to international conferences and workshops. The high expectations that the project results will have direct impact on all wind power stakeholders, will make the closing seminar open to all audience and industry (e.g. wind turbine manufacturers, wind farms developers, DSOs and TSOs). The final report will be available to EERA Wind partners (potentially, fully open access), the foreseen joint publication(s) will contribute to IRPWind and EERA Wind track record.

6. Expected results

6.1 Methodologies and/or databases and/or best practices functional to the activities of the IRP and EERA strategic agenda objectives

The developed research is expected to yield robust and practical market mechanisms that could adapt the mature methods that enable the wind power to provide AS. A methodology for comparing results under the conventional mechanisms and the developed ones will be developed and examined. Also, some best practices/guidelines will be presented for the interconnection of different large power systems across Europe as a part of the foreseen pan European energy system. And last but not least, some data from the experimental tests, and some models of the test cases will be available.

6.2 Assessment of the advancement of the TRL

The state of the art of the considered scope assures that no mature or theoretically complete studies are proposed to examine the dynamic short-term impacts of AS provision by wind power on system stability in the light of mechanical security and market mechanisms. Hence, this research work will promote the studied prospects to higher TRL (3-4) through a highly detailed benchmarks and case studies.

6.3 Assessment of the KPIs

The development of this project will contribute to the achievement of IRPWIND and particularly WP8.1 KPIs as follows:

- The influence of the multi-disciplinary research to develop emerging grid code regulations for large-scale wind integration
- The adoption of some proposed guidelines and recommendations for operation and control of European-scale wind power plants in the light of the adapted AS markets
- MS-EC support alignment
- Percentage of support spent in different countries
- Number of participants in the networking actions
- High prospects for joint publications

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Mobility Call N°: **Mobility scheme:** **Home Institution:**	OPEN 4-26 weeks **University of Strathclyde (UoS)**

Evaluation[1]

S1. EXCELLENCE	0 1 2 3x
Observations: Good research focus and continuation of previous mobility. Good use of IREC lab. Topic fits well with Irpwpind WP8 and SP4.	
S2. IMPACT	0 1 2 3x
Observations: ambitious plan for a short visit of 12 weeks – relative to the length, I think that even if part of it will be realized it is good. Depending how you want to score these, this could also be a 2. For sure improves research collaboration and transfer of knowledge between research institutions. Improving European research and innovation potential – has chances for that if successful.	
S3. IMPLEMENTATION	0 1 2 3x
Observations: Good plan of work, looks feasible, aims at using the IREC laboratory well. The people/institutes already have previous collaboration and work will benefit both institutes that already have shown good commitment.	
S4. OVERALL EVALUATION	0 1 2 3x

Suggestion?

……

Mobility Call N°: **Mobility scheme:** **Home Institution:**	OPEN 4-26 weeks **UOS**

Evaluation[2]

S5. EXCELLENCE	3
Observations: Clear and excellent description of the foreseen work and the added value due the mobility action.	
S6. IMPACT	3
Observations: There is significant impact on the progress of IRPWIND WP 8.1 and 8.2. UoS is leader of WP8.1 and IREC is member of 8.1. The foreseen work is in line with the workplan of the IRPWIND WPs.	
S7. IMPLEMENTATION	3
Observations: The results of the work will contribute to the work of IRPWIND WP8.1-8.3 and to the work of the Sub-Program Grid Integration.	
S8. OVERALL EVALUATION	3

Suggestion? The applicant shall present his work results on the next IRPWind meestings or the annual conference.
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Funded by EU

Application form for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	**Luca**
Applicant Surname	**Greco**
Home Institution	**CNR - National Research Council of Italy (Institute: INSEAN)**
EERA/IRP Partner? *(yes/no)*	**Yes**
Home Institution Postal address	**Via di Vallerano 139, 00128 – Rome, Italy**
E-mail	**luca.greco@cnr.it**

B) Host institution details

Institute name	**ECN - Energy research Centre of the Netherlands**
EERA/IRP PARTNER?	**Yes**
Contact person	**Koen Boorsma**
Country	**The Netherlands**
E-mail	**boorsma@ecn.nl**

C) Relevant Programme and scheme

CORE PROJECT?	**(A) Offshore Wind Energy**	**RELEVANT EERA SUB-PROGRAMME**	**(E) Aerodynamics**
Length of the grant scheme	**Scheme:** **4-26 weeks**	**Number of weeks:** **Start date:**	**13** **9 January 2017**

D. Project description

TITLE OF THE PROJECT:

Fast and Advanced Rotor Wake modellING (FARWING)

1. Introduction

- Research topics, originality

The project herein proposed aims at enhancing wind turbine rotor wake modelling. Aerodynamics formulations that already proved their effectiveness for helicopter rotors applications will be adopted and further developed. The implementation of these models into a comprehensive aeroelastic solver will provide a numerical tool beyond the current state-of-the-art codes widely used by the industry for preliminary design as well as control and farm optimization purposes.

The guidelines of EERA JP WIND Sub-Programme on Aerodynamics identify the improvement of unsteady wake modelling as one of the key objectives and research themes to be pursued by the scientific community. Aim of the research activity on this topic is twofold. On one hand, the enhancement of aeroelastic predictions accuracy through advanced wake modelling will help designing future large cost-effective turbines. On the other hand, a better understanding of the behaviour of rotor wake will enable the tailored optimization and control of wind farms to reduce power losses resulting from the influence of the upstream turbines.

The outcomes of the collaboration herein described will be the development and validation of novel accurate and computationally efficient rotor wake models within the framework of inviscid flow aerodynamics for aeroelastic analyses. State-of-the-art aerodynamics codes for wind turbines design involve well-assessed engineering methods based on enhanced Blade Element Momentum Theory (BEMT) techniques. More recently, CFD tools have shown the capability to achieve a physically consistent description of turbine flow-field. Nevertheless, because of the high computational costs, they are not well suited for aeroelastic analyses in practical preliminary design and aero-servo-elastic applications. In this scenario, three-dimensional, potential-flow methods represent an advanced convenient solution to overcome the limitations of BEMT codes concerning wake dynamics and unsteady aerodynamics modelling, as well as to fill the gap with complex and time-consuming CFD simulations. From this point of view, ECN and CNR-INSEAN can share a long-time and complementary expertise. ECN Aerodynamic Wind Turbine Simulation Module (AWSM) is based on a generalized lifting line theory [1 – 3], whilst CNR-INSEAN code is based on a Boundary Element Method (BEM) solver for unsteady, three-dimensional flows around lifting bodies [4]. Both methodologies are combined with suitable free wake alignement procedures to describe the potential wake evolution through a nonlinear algorithm where wake points are aligned to the local flow-field. Thus, an accurate time-dependent description of rotor wake shape and of the downstream field as well as accurate blade loads predictions are achieved [4]. Figure 1 depicts the NASA Ames Phase VI rotor wake shape predicted by CNR-INSEAN aerodynamic solver, whilst AWSM wake modelling capabilities are shown in Figure 2.

The present project aims at reducing the computational costs related to free wake computations by developing novel efficient wake models that still capture the required flow physics. The basic idea is to split the rotor wake into a near (1-2 diameters downstream) and a far portion [5, 6]. The near wake will be described through the above mentioned free wake approaches or through advanced deformed wake models that identify its relevant features and describe the dominant effects with suitable accuracy [7].

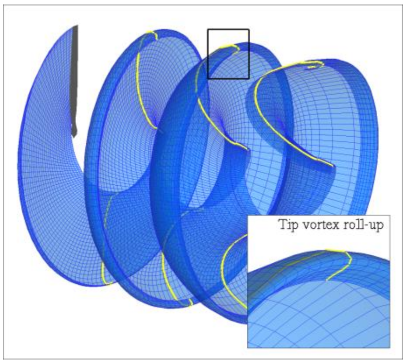

Fig. 1: NASA Ames Phase VI rotor wake shape prediction by CNR-INSEAN Boundary Element solver

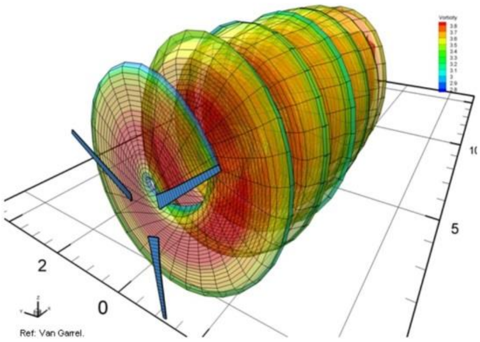

Fig. 2: Three-bladed rotor wake shape prediction by ECN AWSM code

These models are widely used for the aeroelastic analysis of helicopter rotors in forward flight where a good compromise between accuracy and computational costs is mandatory [7, 8]. On the other hand, the far wake can be described through a cylindrical wake model which takes into account only the trailing vortices emanating from the tip and the root of the blade [9] or by vortex merging techniques.

The proposed project will gather together, for the first time, ECN and CNR-INSEAN in a joint research activity. The exploitation of the complementarity of the two institutes will start a collaboration on the research objectives identified by EERA JP WIND roadmap. In details, ECN strong expertise on wind turbine modelling and experimental analysis can be integrated with CNR-INSEAN numerical tools and experimental facilities. This will allow a multidisciplinary approach to offshore wind turbines research taking into account all the interactions of the machine with the environment (wind, sea waves, moorings, floating platform, ...).

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

ECN and CNR-INSEAN aerodynamics solvers have been developed independently by the two institutes during the last 15 years of scientific activity. The ECN Aerodynamic Windturbine Simulation Module (AWSM) has been developed by van Garrel [1]. It has been extensively validated through comparison with data concerning the NASA-AMES and MEXICO rigid-bladed rotors and has also been successfully coupled to a structural dynamics solver to achieve a full aeroelastic wind turbine simulation in time domain [2]. On the other hand, CNR-INSEAN Boundary Element solver has been applied to study a variety of rotating wing devices (marine propellers as well as wind and marine currents turbines) and has been validated through comparison with several numerical and experimental databases. In details, the capability of CNR-INSEAN rotor aerodynamics code to describe the wake past a propeller has been extensively validated in [4] whilst its application to wind turbine aerodynamics and aeroelasticity is discussed in [10, 11]. These numerical tools are available as a sound basis for the development of a novel wake model and will be used also for validation purposes. They are considered as TRL 5/6 (technology validated/demonstrated in relevant environment) whilst the wake models that will be implemented are TRL 2 (technology concept formulated).

- Definition of Key Performance Indicators (KPIs).
    1. Identification of the most suitable wake models within the framework of inviscid flow methods for wind turbine aeroelastic analysis
    2. Improvement of rotor aerodynamics modelling through cost-effective wake models

3. Planning of a research collaboration between ECN and CNR-INSEAN:
    - identification of common research interests (aerodynamics, aeroelasticity, aeroacoustics, …)
    - definition of future cooperation plans (exchange of tools, implementation of common simulation platforms, integrated numerical/experimental analysis of offshore wind turbines, …)

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

The enhancement of rotor wake unsteady modelling for aeroelastic applications will contribute to the EERA Wind sub-programme Aerodynamics in the following research themes identified by the Medium to long term Research Strategy and Roadmap (2015):

RT 1: Improved aerodynamic design modelling

- Analysis of experimental data and validation of aerodynamic and aeroelastic codes. (IEA Mexnext and OC5)
- Development of advanced aerodynamic modelling (CFD models and engineering models) that can accurately calculate the future large (>20MW) wind turbines (EU AVATAR)

RT 2: Improving the design process

- Development and validation of advanced and accurate aeroelastic and aeroacoustic design tools

RT 5: Improved unsteady wake modelling

- Study of wake characteristics, length scales, turbulence conditions, turbulent mixing with atmosphere, meandering, recovery of velocity deficit

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

- Description of national projects from the receiving institution.
  ECN has a long-time expertise in participation and coordination of R&D collaborative projects in the field of wind energy. These projects have been directly commissioned by industry or supported by national or international funding. The list below includes the most recent current national projects that are relevant to the present application.
  Far and Large Offshore Wind (FLOW) is a joint research programme involving 13 Dutch businesses and knowledge institutions cooperating on innovations with the aim of reducing offshore wind power cost. The most important outcomes of the project are: improvements in wind turbine technology (blades, controllers, etc.), wind farm production (farm control systems) and in wind energy integration into the grid.
  Design for Reliable Power Performance (D4REL) aims at developing innovative technology and tools for reducing uncertainty in both the design and operation of offshore wind farms. The major outcome of the project is the improvement of design tools to address the next generation longer and lighter blades reducing the engineering safety factors to achieve a less conservative and cheaper turbine design.
  DAISY4OFFSHORE is a project dealing with smart monitoring for the reduction of offshore wind farms maintenance costs.
  High Yields Low Loads Enlarged Rotor (HYLLER) is a project aiming at increasing wind farms energy production by equipping the turbines with different rotor diameters.
  Moreover, ECN wind energy department has been 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 aim of the programme is to provide more accurate wind data and make it available to the public and developers of offshore wind farms.

- Description of national projects from the sending institution.
  CNR-INSEAN has a long expertise in participation and coordination of R&D collaborative projects under national and international funding schemes. Currently, CNR-INSEAN is involved in the RITMARE Flagship Project funded by the Italian Ministry of University and Research. RITMARE is the leading national marine research project for the period 2012-2016; the overall project budget amounts to 250 million euros, co-funded by public and private resources. This project is coordinated by the National Research Council (CNR) and involves an integrated effort of most of the scientific community working on marine and maritime issues, as well as some major industrial groups. Within this project, CNR-INSEAN is responsible, among other activities, for the development of experimental techniques and numerical tools for the analysis and design of renewable energy devices to exploit wind and marine currents.

- Foreseen European added value of national alignment.

  The wake models that will be considered for the project have demonstrated their effectiveness in the field of helicopter rotors aerodynamics and aeroelasticity. A technological transfer of these methodologies to wind turbines applications will set a step forward in the development of enhanced aeroelastic tools able to overcome the limitations of those widely used for preliminary design. This will lead, in the medium/long term, to an enhancement of European industrial community capabilities to address wind turbine cost-effective design.

  The proposed project represents a first step in the cooperation between ECN and CNR-INSEAN on offshore wind turbines research topics. Specifically, ECN has a strong expertise on wind turbine modelling and experimental characterization that can be exploited for a better integration of CNR-INSEAN activities in the field of renewable energy devices at European level. CNR-INSEAN rotor aerodynamics solvers and waves/structures interaction modelling tools can be used for a comprehensive numerical investigation of wind turbines aero/hydroelastic behaviour. Moreover, CNR-INSEAN world class facilities allow to test, in a controlled environment, model scale offshore wind turbines installed on a floating platform. The present project will increase the communication and the research alignement between the two institutes by establishing a strategic collaboration.

- Description of the host institute: e.g. infrastructure, experience etc.

  The Energy research Centre of the Netherlands (ECN) is the largest energy research institute in the Netherlands. With about 500 members of staff, it focuses on the development of new technology and conducts pioneering research to achieve an efficient sustainable energy management in joint effort with the industry, government authorities and research institutes. ECN activity on wind energy aims at reducing offshore wind energy production costs through improved design of farms, turbines and turbine parts as well as through programmes for more efficient maintenance and by integrated application of wind farm system expertise. Within this core activities, ECN plays an active role in EERA JP WIND and coordinates the Sub-Programme on Aerodynamics.

  The R&D programme on wind energy at ECN focuses exclusively on offshore wind power plants through an integrated approach covering aspects such as support structures, optimization, internal electrical network and grid connection, operations & maintenance, socio-economic aspects and experimental facilities and testing.

  ECN experimental and numerical expertise on wind turbines aerodynamics is widely recognized by the scientific community. As an example, ECN has coordinated the European project MEXICO (Model rotor EXperIments under COntrolled conditions) aiming at an in-depth analysis of a wind turbine in a controlled environment. From the numerical simulation standpoint, ECN has developed a comprehensive tool in which state-of-the-art BEM enhanced aerodynamic solvers and advanced vortex line methods (AWSM) are implemented into a rotor aerodynamics module (ECN-Aero-Module). This module is then coupled with a suitable structural dynamics solver to predict rotor aeroelastic response. Finally, ECN is the coordinator of the EU FP7 founded project AVATAR (AdVanced Aerodynamic Tools for lArge Rotors) aiming at the development and validation of advanced aerodynamic models, to be used in integral design codes for the next generation of large scale wind turbines (up to 20MW).

3. Work plan

- The project herein proposed is divided into the four tasks described below. For each task, an estimate of planned duration is indicated.

TASK 1 – Modelling requirements definition and literature survey (10 %)

Definition of the specific modelling requirements for the rotor wake models to be used within inviscid flow methods for wind turbine rotors aeroelastic analysis. A literature survey on available theoretical models will be performed to identify the most promising methodologies in terms of accuracy and computational costs.

Milestone 1.1 :: Selection of promising rotor wake models.

TASK 2 – Development and implementation of selected wake models (60 %)

A novel rotor wake model will be developed on the basis of the outcomes of TASK 1. The theoretical methodology will provide a suitable time-accurate prediction of (near and far) wake shape and a description of rotor wake inflow. Interfaces with ECN-AWSM and CNR-INSEAN BEM codes will be developed and tested.

Milestone 2.1 :: Novel rotor wake model developed and implemented

TASK 3 – Wake models validation (28 %)

The proposed rotor wake model will be validated by comparison against the outcomes of ECN and CNR-INSEAN aerodynamic solvers in terms of turbine performance (loads) and flowfield features predictions. To this aim, suitable experimental databases (such NASA Ames Phase VI and MEXICO campaigns) will be used.

Milestone 3.1 :: Novel rotor wake model validated

Deliverable 3.1 :: Technical report describing results of Tasks 1 – 3 (available to EERA partners)

Deliverable 3.2 :: Journal/conference paper on wind turbine rotors wake modelling

TASK 4 – Collaboration strategy between ECN and CNR-INSEAN (2 %)

The proposed project will highlight ECN and CNR-INSEAN complementarity within the offshore wind turbines research theme. This will help setting up a collaboration among the two institutes and will lead to the definition of common research interests.

Deliverable 4.1 :: Presentation of CNR-INSEAN activities to ECN researchers

Deliverable 4.2 :: Definition of common research interests

4. Benefits to EERA objective advancement

- Contribution to the advancement of the EERA strategy goals, gaps addressed.
  The proposed project will set a step forward in the development of enhanced aeroelastic tools to overcome the limitations of those currently used for wind turbine preliminary design purposes.
  Moreover, the startup of a research cooperation among ECN and CNR-INSEAN will contribute to the integration of capacities and resources within the IRPWIND and EERA JP WIND programmes with the aim of exploiting the strong complementarity of the two institutes.

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

As described in section 3, the proposed project will lead to a journal (or a conference) paper and a technical report on wind turbine rotors wake modelling. The technical report will be available to EERA partners. Moreover the presentation of CNR-INSEAN research activities to ECN researchers and the development of a plan for future research cooperations will help the integration of CNR-INSEAN with EERA JP WIND partners working on offshore wind turbines.

6. Expected results

- Methodologies and/or databases and/or best practices functional to the activities of the IRP and EERA strategic agenda objectives.
  The development of enhanced rotor wake unsteady modelling for aeroelastic applications will contribute to several EERA Wind sub-programme Aerodynamics research themes. Specifically the proposed project will provide the assessment of the proposed methodologies accuracy and computational costs, thus contributing to research themes RT1 (Improved aerodynamic design modelling), RT2 (Improving the design process) and RT5 (Improved unsteady wake modelling).

- Assessment of the advancement of the TRL.
  The validation of the proposed wake models coupled to the ECN and CNR-INSEAN rotor aerodynamics solvers will enhance the TRL of the selected methodologies from 2 to 5, whilst ECN – AWSM and CNR-INSEAN codes will consolidate TRL 6.

- Assessment of the KPIs.
  1. Identification suitable wake models for inviscid flow aerodynamics solvers: list of candidate models and description of pros and cons for each model
  2. Improvement of rotor aerodynamics modelling through cost-effective wake models: implementation and validation of a least one model describing near and far wake shape and flowfield features
  3. Establish a collaboration between ECN and CNR-INSEAN: list of common research interests & complementarities, definition of future cooperation plans on offshore wind turbines research topics

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11. Greco L, Testa C, Salvatore F. Design oriented aerodynamic modelling of wind turbine performances, *Journal of Physics: Conference Series*, **75,** 2007.

Mobility Call N°: **Mobility scheme:** **Home Institution:**	Continous Open Call 4-26 weeks **CNR**

Evaluation[1]

S1. EXCELLENCE	2
Observations: - Improving the models for predicting wakes is a crucial research topic - As it is not my field of expertise, I cannot judge of the innovative aspect of the suggested approach.	
S2. IMPACT	2
Observations: - This project will develop new collaboration between ECN and CNR and permit a technology transfer from the helicopter to the wind industry.	
S3. IMPLEMENTATION	2
Observations: - Although I think that the wind energy sector would gain from technology transfers from other sectors (especially helicopter), I doubt that it is straightforward to pass from a helicopter to a wind turbine wake model. In that perspective I think that the planning/increase of TRL is a bit exaggerated (3 months is a too short period to jump from TRL 2 to 5)	
S4. OVERALL EVALUATION	2

Suggestion?
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1

Mobility Call N°: **Mobility scheme:** **Home Institution:**	Continous Open Call 4-26 weeks **CNR**

Evaluation[2]

S1. EXCELLENCE	0 1 2 3
Observations: Grade 2 The project and method is a medium fidelity approach, which will enable more accurate handling of special operating condition than used in present aeroelastic codes. It addresses the IRPWING Aerodynamic target regarding improved aerodynamic design modelling as main goal. It is an interesting combination of strength from the helicopter area from CNR with the wind turbine experience at ECN and both organizations are considered to have high excellence within their areas.	
S2. IMPACT	0 1 2 3
Observations: Grade 2 The new approach suggested is expected to be important for design of future rotors operating in non-uniform loading conditions, yaw error, and for new design including partial pitch strategies and other innovative designs. Most of the work is dedicated to development and implementation and it is not clear how a direct impact on this will be gained during this short stay. It is however very possible that this work could initiate a collaboration between the two organizations, that later on can cause increased knowledge and impact. One paper is planned to be published based on the work.	
S3. IMPLEMENTATION	0 1 2 3
Observations: Grade 2 It is a bit surprising that the first part of the stay is dedicated to a literature survey about the most promising approach. As the stay is very short (13 weeks) it was expected that a clear approach was already chosen at this stage. The plan is very rough and most of the time is devoted to development and implementation. There is no information about which benchmark cases will be addressed in the stay and therefore on which specific areas increased knowledge is expected to be gained. There is a significant risk that the model will not be finished within the timeframe of the stay and therefore no results can be achieved. This has not been addressed in the application.	
S4. OVERALL EVALUATION	0 1 2 3

Suggestion?

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Funded by EU

Application form for Mobility grants within IRPWIND

*****NOTE*****

- **All documents must be named as follows:**

Sub Programme letter, Scheme no., Surname, Document type. Ex: A_01_Smidt_cv
For "Offshore Wind Energy", Scheme 01 "2-4" weeks. See Table C) below.

- **The application must be max. 6 pages, ex tables, figures and references.**

A) Applicant details

Applicant Name	Julia
Applicant Surname	Kirch Kirkegaard
Home Organization	Technical University of Denmark, Department of Wind Energy
EERA/IRP Partner? (yes/no)	Yes
Home Organization Postal address	DTU Wind Energy Frederiksborgvej 399, 4000 Roskilde
E-mail	jukk@dtu.dk

B) Host Organization details

Institute name	NTNU (Norwegian University of Science and Technology), Department of Interdisciplinary Studies of Culture, Faculty of Humanities
EERA/IRP PARTNER?	Yes
Contact person	Margrethe Aune, Head of Department
Country	Norway
E-mail	margrethe.aune@ntnu.no

C) Relevant Programme and length scheme

CORE PROJECT? ***NO*** ***(Please erase the non-relevant)***	**Wind Integration**	**RELEVANT EERA SUB-PROGRAMME** **Max 2** **(Please erase the non-relevant)**	**(G)Wind integration – economic and social aspects**

Length of the grant scheme *(Please erase the non-relevant length)*	**Scheme:** (02) 4-26 weeks	**Number of weeks: 10** Start date: 08-01-2017 --- 18-03-2017	

D. Project description

The application should take into account the following structure. Further sub-heading might be added.

TITLE OF THE PROJECT: AMBIGUOUS WINDS OF CHANGE – OR FIGHTING AGAINST WINDMILLS IN CHINESE WIND POWER

1. Introduction

With an interest in the economic and social aspects of wind integration in society, my research project will build on my PhD research from Copenhagen Business School (Department of Business and Politics, and the Sino-Danish Centre for Research and Education) (2015), which provided an analysis of the contested sustainability and acceptability of wind power development and integration in a Chinese context. With a book contract currently in hand with Routledge (deadline ultimo March 2017), I therefore plan to focus my research stay at NTNU on turning my PhD thesis into a book. Whilst my book project explores some of the economic and social aspects of wind integration in a developmental context of China, I will during my stay at NTNU also present some of my postdoctoral research at DTU Wind Energy, where I work on projects related to the social acceptability of wind power in Denmark (in particular, the Wind2050-project).

In regard to the book-project (based on my PhD monograph), I will unfold a methodological framework based on Actor-Network Theory (ANT) and the Anthropology of Markets within Science&Technology Studies, which can help map controversies over sustainable transitions and wind power development in a Chinese developmental context. By mapping controversies around wind power development and integration in a developmental context, the book will provide an integrated understanding of technology, politics, and society, as well as of market construction and science, shedding light on the economic and social aspects of wind integration in to society. This can provide foundation for cross-country comparisons of contestations over wind power integration in society.

Whilst China has a reputation for rapid growth and environmental degradation, a competing narrative on Chinese development is China's emerging role as a global leader in green industries. China's wind power market has experienced unprecedented rapid growth within the last decade. Whilst this has made China number one worldwide in terms of installed wind power, the initial years of exclusive focus on quantity and price in China's wind turbine industry have now also led to extensive quality and grid connection issues as well as resistance from incumbent fossil fuel technologies. These problems are now, paradoxically, threatening to question the very 'sustainability' of China's emerging wind power market in comprehensive terms of economic, environmental, social 'sustainability', and even in what the book terms scientific, technological, developmental and political 'sustainability'.

As China faces severe quality issues as a consequence of the focus on rapid catch-up and industrial upscaling and upgrading in wind power, the legitimacy (and 'acceptability' and 'sustainability') of wind power is increasingly being questioned and debated in China (and beyond). In this sense, China now risks to be '*fighting its own windmills*'. The book illustrates how the Chinese Government in agile, creative ways has responded to this emergent quality crisis, through what I term a potential 'turn to quality', which can re-qualify wind power as 'sustainable'. In the book, I trace the potential turn to quality, which is e.g. reflected in the introduction of new certification requirements, an increased focus on indigenous innovation and research into core technologies and scientific issues, and increased centralised control of wind farm development and integration. Doing so, I map out how this potential turn to quality has changed the dynamics of Sino-foreign collaborative relations around core technologies such as control systems, software tools, and aerodynamics, and how it has produced controversy over issues of IPRs and standardisation.

The volume will be informed by the view that in order to manage Sino-foreign industrial relations and understand China's socio-economic development and wind power integration, it is necessary to grasp the relational and micro-processual qualities of collaborations as well as how wind power technology and industry and market development are deeply entangled in politics, in particular in a Chinese context of a strategic wind power sector and a highly state-supported, -controlled and –owned power sector.

Research topics

The narrative of the book is conveyed through a mapping of dynamics of Sino-foreign collaborations around the wind turbine's core technology of software, in particular software in control systems and simulation tools. Literally mapping how relations are configured and changed around the software's core algorithms that have become critical for Chinese upgrading and for aligning with the Chinese government's doctrine of Scientific Development through indigenous innovation, the book sheds light on current power games and global collaboration and competition in the wind turbine industry. The volume in particular dives into four different 'sites' of socio-technical controversy, namely that of *IPRs, standards and certification, money and liquidity, and cost and price calculations.*

Using China's wind power market – and in particular software core-algorithms in wind turbine core technologies, e.g. as they are critical for the optimisation, design, and certification of wind turbines – as a window, the book seeks to explore the following main topics:

- First, a main theme of the book is controversies inherent to socio-technical transitions where there may exist not only technological, but also social, economic, scientific, and political barriers to the integration of renewable energy sources into the overall energy system.
- Second, the book attempts to address the issue of China's overall integration into the world economy and today's increasingly globalised industries, and what implications this has for the configuration of global value chains and the emergence of global innovation networks. Further, it puts emphasis on how these changes impact Sino-foreign collaborative relations.
- Third, it attempts to address China's specific mode of socio-economic development, looking into how China's particular mode of variegated capitalism and matrix muddle makes the seemingly paradoxical path of Chinese wind power 'logical' in a Chinese developmental perspective. This is done by putting the book into a framing of China studies.

Using core technologies – in particular software tools and their algorithmic contents – as a vehicle for shedding light on the economic and social aspects of wind integration, the book illustrates controversies over the sustainability of wind power, and how China's struggle to frame wind power as 'sustainable' through a 'turn to quality' has produced a new strategic and more complex power game between Chinese and foreign actors (e.g. companies, universities, certification agencies). In Sino-foreign relations, simultaneous dynamics of collaboration and competition coexist and collide. In these paradoxical relations, software programmes have become the centre stage of contestation. Understanding the underlying reasons and dynamics of these new industrial dynamics is critical for managing and governing Sino-foreign collaborative relations in wind power as well as in other strategic sectors of China. Further, by diving into the 'turn to quality', the book illustrates what it dubs a specific Chinese mode of market construction, namely a particularaly fragmented and experimental '*pragmatics of (green) market construction*'. Paradoxically, while it is China's 'pragmatics of green marketisation' that has produced a quality crisis - threatening to delegitimise the Chinese pragmatics of marketisation - it is also the same pragmatics of green marketisation that is likely to enable the agile 'turn to quality' and experimental learning.

Originality

The book will be one of the only works, which analyses how the development of China's wind industry has changed micro-dynamics of global collaboration and competition over wind turbine technology, at the same time as it sets this into a broader picture of China's socio-economic development, greening processes, and catch-up processes. Through a case-study on the development of China's market for wind power, the volume offers a unique and holistic account of China's 'green turn' and the inherent socio-technical controversies and struggles in building renewable energy industries in a developmental context of China where technology is deeply entangled in politics.

The book is based on ethnographic fieldwork in China and beyond in 2012-2013, and 2015. In addition, the volume is based on extensive analysis of China's policies and Five-Year-Plans regarding wind power and Science & Technology. The volume will reflect some of the most intriguing and paradoxical challenges and opportunities that exist in the simultaneously collaborative and competitive Sino-foreign relations, in a current situation where China upgrades and challenges its role as a technology follower, and puts it into a broader account of China's socio-economic development.

In theoretical and methodological terms, the book is informed by a constructivist *marketization*/market construction lens within Science & Technology Studies (STS) and in particular the lens of Actor-Network Theory. The proposed book hereby contributes and relates to a number of academic fields, hereunder in particular **New Economic Sociology and Science&Technology studies** (STS) (in particular marketization studies and ANT) (e.g. Callon and Çalişkan, 2009; 2010a; 2010b; Garud et al., 2010; Callon, 1986; 1991; 1998; Latour, 1992; 2005; Law, 2009), **China studies** (Lieberthal, 2004(1995); Heilmann, 2008; Brødsgaard, 2002; 2012; Mertha, 2009; Peck and Theodore, 2007; Zhang and Peck, 2014; Peck and Zhang, 2013; Fligstein and Zhang, 2010; Naughton, 2007; Saich 2011; Shambaugh, 2013; Nolan, 2001; Breznitz and Murphree, 2011; Korsnes, 2014; 2015), **Industrial policy and industry studies** (e.g. Evans, 1995; Wade, 2004; Amsden, 2004; Johnson, 1995; Steinfeld, 2004; Dongsheng and Fujimoto, 2004; Nahm and Steinfeld, 2012; Brandt and Thun, 2010; Herrigel, 2010; Herrigel et al., 2013; Breznitz and Murphree, 2011), **Economic geography** (e.g. Gereffi 1994a; 1994b; Bair, 2005; Gereffi et al., 2005; Ponte, 2009; Coe et al., 2008; Hess and Yeung, 2006), and the **literature on sustainable transitions and social acceptability of wind power** (e.g. Batel et al., 2013; Geels, 2011). The marketization programme has looked into market construction in developed countries. Yet, there exist no studies on developing countries like China or on the construction of a wind power market. This book contributes to ANT's marketisation programme by extending the scope and reach of the approach to a context of an emerging and transitional economy.

<u>Technological Readiness Level (TRL) of the proposed concept.</u>

(TRL – not relevant).

Concept has been developed, and is through the project made ready for dissemination to a broader public.

<u>Definition of Key Performance Indicators (KPIs).</u>

a) Book, to be published by Routledge spring/summer 2017
b) Presentation of PhD regarding the contested sustainability of wind power in China
c) Presentation of research related to Wind2050 regarding social acceptability of wind power in Denmark
d) Network building; list of project ideas and relevant scholars within the area related to the EERA sub-programme 'Wind Integration - Economic and Social Aspects'

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

The project and research stay is linked to the EERA Sub-programme of '*Wind integration – economic and social aspects'*. At the moment, not a lot of research has been conducted within the Mobility Scheme on this EERA sub-programme. With its social science perspective on the issue of wind integration in a developmental context of China, as well as in the context of Denmark, the project will help fill out this gap and moving the EERA Sub-Programme further. The research project and network-building activities will lay the foundation for future comparative work related to sustainable transitions and the socio-economic aspects of wind integration in a Danish and Norwegian context. The project further contributes with critical knowledge on changing dynamics and underlying rationales of the Chinese wind power market, and on the current legitimacy crisis of Chinese wind power. Whilst the Chinese 'quality crisis' can potentially threaten the legitimacy of wind power on a global scale, it is critical for EU member countries to understand the rationale and different agendas behind China's wind power trajectory, in order to engage in more fruitful Sino-foreign collaborations that can contribute to enhanced wind power deployment and social acceptability of wind power, whilst also protecting own competitive advantages.

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

Please consider that at least one of the partners should have a national project relevant to the proposal.

<u>Description of national projects of receiving Organization</u>

With research ongoing at the *Department of Interdisciplinary Studies of Culture, Faculty of Humanities*, NTNU, within my fields of research interest – i.e., Science&Technology Studies (STS), renewable energies, public engagement, science communication, and social acceptance of post-carbon strategies (e.g. wind power and other green technologies) – NTNU's research profile relates nicely to mine, as well as to my book project and my ongoing postdoctoral research at DTU.

NTNU will therefore be of great benefit to my research project, since NTNU's ongoing research within STS and controversies over wind power can help inform my work on the book project, and provide a fruitful environment for synergies, discussions of findings and research areas, for network building and building ideas for project proposals. For example, I have already established contact with Sara Heidenreich at NTNU who shares interests with me regarding controversies over wind power.

In this way, the stay at NTNU will help inform my work and make comparative studies possible regarding differences in market development not only in a Chinese and Scandinavian (Denmark, Norway) context but also in a European context. Both Denmark and Norway are, in comparison, small countries that look for fruitful collaborations with Chinese companies within wind power, and this project can help build the knowledge that can benefit Denmark and Norway. Given their similar size and common history, Norway and Denmark have comparable interests with regard to improving collaboration with China within renewable energies. In this way, there is plenty of room for synergistic learning, which can also be broadened out to an EU-level.

Description of national projects from the sending Organization.

At the sending organization (the Department of Wind Energy, DTU), a nationally funded project (Strategic Research Council of Denmark/Innovationsfonden) is being undertaken in collaboration with other Danish universities on the subject of social acceptance of onshore wind power in Denmark (Wind2050; www.wind2050.dk). The project looks into the social acceptability and socio-technical contestations over onshore wind power development in Denmark. The project looks at the issue from multiple perspectives, in particular local communities, municipalities, and wind farm developers. In the project, I am doing research on the wind farm developer's perspective on social acceptability of wind power and the wind farm developer's practices in terms of handling public engagement and participation. In another nationally funded project (CORAL, funded by the EUDP), we look into the impact of visual pollution from obstruction lights at the National Test Centre for large wind turbines in Denmark.

The two nationally funded research projects reflect an ongoing attempt at DTU Wind Energy to create synergies between natural (engineering) and social sciences. Hereby, the research project and its perspective on the contest sustainability of wind power in Chinese (and Danish) context will help strengthening DTU Wind Energy's profile in the area.

Foreseen European added value of national alignment.

The foreseen European added value of national alignment between DTU Wind Energy and NTNU in terms of this research field is the way in which the research project and the research stay can help build bridges between natural and social sciences, and the way in which it through insights from different cases of contested sustainability of wind power in different contexts can result in knowledge sharing and formulation of joint research projects and project proposals. By presenting and discussing the different cases of China, Denmark, and Norway, it will be possible to draw out similarities and differences between the cases and the institutional contexts. This will help shed light on different dynamics of controversies. The added European value in this regard will be the improved understanding of how to manage controversies over wind power integration, through a more holistic socio-technical and socio-economic-political perspective. The work work will thus also involve discussions on how to translaste the Chinese experience to countries with very different cultures and political institutions, i.e. inquiring into what the main differences are between China and the Scandinavian countries, and whether there are similarities and differences to take into account regarding the Scandinavian.

Further, by learning from the case of China, the research project will contribute with European added value because it will help refine strategies for collaboration with Chinese wind turbine companies and research institutes, understanding the Chinese agenda(s) in such collaborations, and ensuring more fruitful collaboration. This is of vital importance for the long-term competitive advantage of the European wind turbine industry and research community, as China is upgrading rapidly and increasingly integrating into global innovation networks in wind power.

Description of the host institute: e.g. infrastructure, experience etc.

During the research stay, the host institute will provide office space, Internet access, and library privileges, which is necessary for the research project. I will contribute to and participate in departmental meetings, and present my research based on my PhD and upcoming book as well as my current postdoctoral work at the department The department has experience in research founded in Science & Technology Studies (STS), science communication, and controversies over the integration of renewables (hereunder, wind) into society, whereby the department will fit perfectly to my work. This provides a fertile ground for joint discussions of common research interests as well as for discussing the potential for future collaborations.

3. Work plan

Deliverables, milestones etc.

Taking outset in my PhD thesis and my book proposal, I will re-write my thesis in to a book to be published by Routledge (book contract in hand). The deadline for the book submission to Routledge is March 31 2017, which fits well with the planned research stay at NTNU. I will present my work in the beginning and end of my research stay at a seminar for the department, to receive comments that can facilitate the framing and strengthen the argument of the book.

4. Benefits to EERA objective advancement

Contribution to the advancement of the EERA strategy goals, gaps addressed.

With its focus on socio-technical implications of the transition to renewable energies, the project will contribute to the EERA objective (EERA strategy goals and gaps) with its insight into the social and economic impacts of wind power integration, seen from a more holistic social science perspective. There is a lack of social science perspectives on the socio-economic impacts of wind power integration, which this research will address, and since only little research has been undertaken within the EERA sub-programme ‘economic and social aspects of wind power integration’, the project will help fill in this lacuna, bringing the field forward. Through this, and through enhanced network-building, the EERA network can get a strengthened role as a platform for improved joint EU-applications which can ensure the integration of social science and natural science perspectives as well as ensure the strengthened exploration of issues related to social acceptance of wind power in future EU project proposals.

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

Explain ToK or dissemination strategies and plan of future collaboration with other IRP/EERA partners.

I will disseminate my research at NTNU as well as at DTU Wind Energy through seminars. Further, I plan to disseminate my findings in more academic articles as well as newspaper articles. I will also be happy to disseminate m findings to other IRP/EERA partners, e.g. at EERA meetings. During my stay, I will disseminate preliminary findings from Wind2050, which will lay the foundation for discussion of future collaboration, e.g. project applications (e.g. to the Nordic Research Council, EU-applications etc.)

6. Expected results

Methodologies and/or databases and/or best practices functional to the activities of the IRP and EERA strategic agenda objectives.

The expected result is a book for submission to Routledge, which will relate to the EERA sub-programme ‘Wind Integration - Economic and Social Aspects’.

Assessment of the advancement of the TRL.

e) Not relevant

Assessment of the KPIs.

f) Book will be accepted for publication by Routledge
g) Comments received from NTNU on presentation of PhD project
h) Comments received from NTNU on research findings and approach in the Wind2050-project
i) Network being established between DTU Wind Energy and NTNU;
j) Discussion of list of relevant collaboration partners within the area related to the EERA sub-programme ‘Wind Integration - Economic and Social Aspects’; including ideas for joint projects or project proposals

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Mobility Call N°:	Open
Mobility scheme:	**Offshore wind energy, 01 "2-4" weeks**
Home Institution:	**DTU – wind energy**

Evaluation[1]

S1. EXCELLENCE =3	0 1 2 3
Observations: The proposed research adopt a unique scheme, and looks really of good quality. It shows an innovative approach (deep analysis of different country human behavior on technical problem solution to investigate economical and industrial relationship & evolution in a globalized framework: Sino –foreigner relationship on wind turbine's core technical SW). An analysis focused on controversies and non technical barriers will be provided. As well a mapping of the relationships among subjects and their changes are proposed. The research results will be inserted in a book to be published, this will give to the research a well-defined target and concreteness. The research could be an opportunity to increase European knowledge on Sino socio-economical dynamics related to industrial and economy development, keeping as test case the wind energy related industry. This information could be theoretically interesting for the innovative scheme proposed, but also relevant for its relation with the EU wind energy industry, iin a globalized framework.	
S2. IMPACT =3	0 1 2 3
Observations: The proponent presents a research project that enhance research methodology presents innovative related skills. It is believable that a good and long lasting research collaboration among the sending (DTU) and hosting institution (NTNU)can derive/be strengthened by this research. The two institutions are prestigious scientific reference for the involved themes and have complementary competence (the proposed research could be a real bridge among the different competences of the two institutions. A connection and an exchange patter between Danish and Norwegian wind energy management of controversies is also welcome according to the similarity and the differences of the two situations..	
S3. IMPLEMENTATION =3	0 1 2 3
Observations: The project presents an overall excellent coherence. The proposed work looks effective, in line with EERA plans. The allocation of work phases also looks appropriate.	
S4. OVERALL EVALUATION =3	0 1 2 3

Suggestion?
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Mobility Call N°:	OPEN
Mobility scheme:	4-24 weeks
Home Institution:	**DTU**

Evaluation[2]

S5. EXCELLENCE	0 1 **2** 3
Observations: The researcher's introduced concepts in her proposal are obviously of interest to EERA's mobility scheme on economic and social aspects of wind power integration; however, there are too many focuses and objectives stated throughout the proposal that creates a bit of confusion. It is clear that through this mobility opportunity the researcher primarily aims at translating her PhD thesis into a publishable book. The PhD research looks at the barriers linked to socio-economic-political as well as technical to the integration of renewable energy sources. Being said that, the thesis mainly looks at China's overall integration into the world economy, global innovation networks, global value chains, etc. and China's socio-economic development. This is quite a generalized framework that **may or may not** generate meaningful outcomes specifically for the "socio" aspect of wind energy. Additionally, the researcher aims at sharing research findings related to Wind2050 that focus on social acceptability of wind power in Denmark. From the researcher's CV, we understand that she has taken a part in this process. Although it is not stated as a key performance indicator, in different other parts of the proposal (e.g., Description of national projects of receiving organization, description of national projects from the sending organization, foreseen European added value of national alignment, etc.), the researcher implies an objective of conducting a comparative study on socio-technical, socio-economic-political perspective. The researcher's PhD research and DTU's Wind 2050 seem to have different focus. And it is not clear, how Norwegian case will be generated.	
S6. IMPACT	0 1 2 3
Observations: The publication of the book may have an impact in the long-run. Presentation (sharing) this knowledge with the NTNU community can also contribute to networking. But networking works when partners do something together to change the current state to a better one. In that sense, the proposal inhibits limitations. It is clear that most of the mobility time will be devoted to writing the book. Other activities aim at exchanging experiences. Then, what will be the real impact of this mobility to understand and/change economic and social aspects of wind power integration? This is a bit unclear in the proposal. Do exchanging ideas require a visit for 10 weeks? Or the researcher also aims at engaging into an already ongoing inquiry process on economic and social aspects of wind power integration in Norway?	
S7. IMPLEMENTATION	0 1 2 3
Observations: The proposal puts forward a book project to be re-written from the researcher's PhD thesis. This is a concrete stated outcome of the proposal. The rest of the activities are limited to presentations. If the researcher needs such a mobility to accomplish this is unclear. What will be the concrete outcomes of being at NTNU and collaborating via one-and-one interaction need to be further elaborated.	
S8. OVERALL EVALUATION	0 1 2 3

Suggestion?

The proposed tasks (other than the book project) to be undertaken at NTNU need to be further elaborated. Considering the capability of the stated tasks, what such a mobility can contribute to the hosting institution as well as to the accomplishment of the mobility scheme (economic and social aspects of wind power integration) is questionable. Constructing together through action (this can be an inquiry or something else) is more powerful than exchanging ideas when the concern is to change the current state of wind power integration. And to exchange ideas we only need to come together at meeting settings. It does not require long-term mobility.

Considering this, the proposal can be revised to include mutual (shared) (the hosting and sending institutions) opportunities (action) that can directly contribute to the mobility scheme.

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Funded by EU

Application form for Mobility grants within IRPWIND

*****NOTE*****

- **All documents must be named as follows:**

Sub Programme letter, Scheme no., Surname, Document type. Ex: A_01_Smidt_cv
For "Offshore Wind Energy", Scheme 01 "2-4" weeks. See Table C) below.

- **The application must be max. 6 pages, ex tables, figures and references.**

A) Applicant details

Applicant Name	Julia
Applicant Surname	K. Kirkegaard
Home Organization	Technical University of Denmark, Department of Wind Energy
EERA/IRP Partner? (yes/no)	Yes
Home Organization Postal address	DTU Wind Energy Frederiksborgvej 399, 4000 Roskilde
E-mail	jukk@dtu.dk

B) Host Organization details

Institute name	NTNU (Norwegian University of Science and Technology), Department of Interdisciplinary Studies of Culture, Faculty of Humanities
EERA/IRP PARTNER?	Yes
Contact person	Margrethe Aune, Head of Department
Country	Norway
E-mail	margrethe.aune@ntnu.no

C) Relevant Programme and length scheme

CORE PROJECT? ***NO*** ***(Please erase the non-relevant)***	**Wind Integration**	**RELEVANT EERA SUB-PROGRAMME** **Max 2**	**(G)Wind integration – economic and social aspects**
Length of the grant scheme ***(Please erase the non-relevant length)***	**Scheme:** (02) 4-26 weeks	**Number of weeks: 12** Start date: 10-01-2017 --- 04-04-2017	

D. Project description

TITLE OF THE PROJECT: SOCIETAL ACCEPTABILITY OF WIND POWER – the case of China

Introduction

The aim of the project is to provide deep insight into the market conditions and opportunities as well as issues of wind integration in China. This will be done in my own research project as well as in collaboration with post-doctoral scholar at NTNU, Marius Korsnes who is currently working on parallel project in the area using the same Science and Technology Studies (STS) theoretical approach as I apply. The project will provide opportunities for European business as well as findings with relevance for European research. The project is aligned with the EERA JP WIND sub-programme on W*ind integration – economic and social aspects* and will thus contribute to substantiate activities in this area. Furthermore, the focus on China will contribute to the IRPWIND strategy for international cooperation (INCO strategy). While the IRPWIND INCO strategy emphasises collaboration with Japan and the US for technological collaboration, understanding market conditions of the world largest wind energy market, i.e. China, can contribute to complement these elements of the INCO strategy in the area of economic and social aspects.

With an interest in controversies over the societal acceptability of wind power integration, I hereby apply for a Mobility grant within IRPWIND, under the sub-programme of '*wind integration – economic and social aspects*'.

Firstly, the aim of this project is the completion of a Routledge-publication which will be founded on my PhD monograph from Copenhagen Business School and the Sino-Danish Centre for Research and Education (SDC) (2015) regarding the development of China's wind power market, and the related difficulties and economic and social aspects of wind power integration in China. The book is to be published in 2017 (book contract with Routledge in hand). The book is founded on Science & Technology Studies (STS) (e.g. Latour 2005; Callon 1998; Callon and Caliskan 2009), and therefore discussions and interactions with STS-scholars at NTNU about my findings will contribute substantially to this work.

Secondly, I will collaborate on a joint academic paper with NTNU-postdoctoral STS-scholar Marius Korsnes, on a comparative study of the development of Chinese onshore and offshore wind power markets, and social and economic issues of wind power integration. While my doctoral research was focused on the integration of onshore wind power into the energy system (Kirkegaard 2015; 2016; forthcoming), Korsnes' work (2014; 2015; 2016) has been focused on China's offshore market. Based largely on the same theoretical perspective (STS), and reaching some complementary conclusions, a comparative study will be of high merit to our work, but also to European business and research.

Thirdly, the collaboration with NTNU-scholars will strengthen the social science group at DTU Wind Energy as well as DTU Wind Energy's participation in the research within the Sino-Danish Centre for Research and Education in Beijing (SDC). Whilst DTU Wind Energy boasts a world-wide reputation in wind power, there are at present only two social scientists employed at DTU Wind Energy, of which I am one. It is DTU Wind Energy's recent strategy to enhance DTU Wind Energy's profile in social science, through a focus on issues related to the societal acceptability and sustainability of wind power. However, to realise such strategy hinges on the development of cross-country and cross-departmental networks and collaboration, in order to build bridges between social and natural, and engineering sciences. A research stay at NTNU would therefore form an important part in the realization of this strategy. Strengthening DTU Wind Energy's contribution in social science will also enhance wind power integration in Denmark, as well as internationally. Further, DTU Wind Energy is part of the Sino-Danish Centre (SDC) in Beijing, and I am currently an SDC-affiliated researcher within both social and natural science (1) *Global Innovation theme*; 2) *Sustainable Energy theme*). Collaboration with STS-scholars at NTNU will be of critical importance to my further research at DTU Wind Energy and within the SDC, and in particular on the ongoing nationally funded project Wind2050 (Wind2050; www.wind2050.dk) at DTU on the subject of social acceptance of onshore wind power in Denmark, as well as the SDC's research themes on *Global Innovation* and *Sustainable Energy*. Lastly, engaging in scholarly discussions about societal acceptability of wind power in a European (Denmark and Norway) and Chinese context can build a platform for future research trajectories, shedding light on institutional (e.g. cultural, political) differences and similarities.

Research topics

China today constitutes the world's biggest market for wind power, and China still leads annual growth in terms of installed capacity. Understanding the dynamics and growth trajectories of the Chinese market is therefore of critical importance to the survival and competitiveness of European business and research within wind power. The project's focus on China will provide an insight into the development and rationale of China's wind power development, and today's persistent curtailment issues. China's curtailment issues and issues of wind power grid integration have resulted in contestation over the societal 'acceptability' and 'sustainability' of wind power in China, due to the large amounts of wasted (economic, social, and environmental) resources. The curtailment issues – largely a result of a 'quality crisis' in Chinese wind power – have led to a political call in China for higher turbine quality, for the extension of the power grid, as well as for the realization of an 'Energy Revolution'. The 'Energy Revolution' is part of China's credo of a 'One Belt One Road' strategy. These recent developments bode well for enhanced market conditions, and for improved wind power generation and distribution (Kirkegaard 2015; Garcìa 2013; Martinot 2010; Meidan, Andrews-Speed, and Xin 2009; Lema and Ruby 2007; Lema, Berger, and Schmitz 2013; Korsnes 2014, 2015; Lema, Haakonsson, and Kirkegaard forthcoming), as well as for enhanced Sino-European research and business collaboration.

Understanding the underlying reasons for issues of the social and economic aspects of wind power integration in China is of critical importance to the further development of China's wind power industry, but also to understanding collaborative opportunities for European countries, and ensure societal acceptability of wind power in a Chinese and global context. The project work at NTNU will build on data from my PhD and recent fieldwork in China under the SDC and DTU as well as from NTNU postdoctoral research Marius Korsnes' fieldwork in China. During my research stay, collaboration and knowledge-sharing with other STS-scholars will be highly beneficial to my current research at DTU Wind Energy, but also provide a fertile ground for making future joint projects and academic paper contributions. Discussion with NTNU-scholars within STS will help inform my analysis of my field findings, which have e.g. detected an ongoing 'paradigm shift' in Danish wind power deployment. The interview data from Wind2050 is in 2017 going to be digested and analysed, and written into articles, and I will lead two articles based on an STS-perspective, namely on the ongoing paradigm shift in Danish wind power development, and the role of landownership. With no other STS- or social science scholars at DTU Wind Energy, the strong NTNU research environment on STS, interdisciplinary cultural studies, and renewable energy will contribute to discussing the findings on the underlying reasons for increased resistance against wind power, which are much broader than issues of 'Not-in-my-backyard' (NIMBYism) or issues of 'social acceptance' (Batel, Devine-Wright, and Tangeland 2013). A holistic perspective of STS can help disentangle matters of concern of local communities, and to open the black-box of the social and economic aspects of wind power integration. Further, it will help open up discussions of potential joint comparative studies between a European (Norway, Denmark) and Chinese context, shedding light on the role of different institutional contexts - e.g. political and cultural - for wind power deployment and dynamics of societal acceptability. In China, pragmatism and experimentalism seem to have been driving forces of the wind power development, as stated in the quote below:

"We are facing this problem [of quality issues], so it will force us to have the solutions. This is good" [...] "In China [it's] very strange, maybe different from Europe, but in China every...we first do it – then to solve it! 先做，才解决! (Xian zuo, cai jiejue! [first do it, then solve it!]). Then you have the problems to force people to solve them [...] If the problem had not appeared, nobody would have considered about that [...] That is not strategy...that is a [...] reality. To learn from the practice is much better than learn from the theory or learn from imagination [...] It's the Chinese way (Chinese wind power expert and government advisor 2013, in Kirkegaard 2015).

Indeed, whilst this Chinese trial-and-error approach seems to have produced a quality crisis and pursuant contestation over the societal acceptability of wind power in China, it will be interesting to inquire into the European approach of technological industry development and deliberative democracy versus China's experimentalism and authoritarian regime. These factors, along with Chinese cultural factors of the importance of personal relations (*guanxi*) etc. would form the basis for new research collaborations and contributions.

Originality

The book will be one of the only works, which analyses how the development of China's wind industry has changed micro-dynamics of global collaboration and competition over wind turbine technology, and its problems with wind power integration, at the same time as it sets this into a broader picture of the societal acceptability and sustainability of wind power deployment in China. The book is based on ethnographic fieldwork in China and beyond in 2012-2013, and 2015-2016, with almost 100 interviews conducted (in Chinese, English, and Danish). The joint paper will be the only study that sets a comparative study of China's onshore and offshore industries into the context of China's imminent 'Energy Revolution' and Chinese fragmented authoritarianism, experimental governance, and variegated capitalism (Kirkegaard 2015; forthcoming; Korsnes 2014; Lieberthal 2004; Oksenberg and Lieberthal 1988; Heilmann 2005; 2008; 2009; 2011; Peck and Theodore 2007; Peck and Zhang 2013). Lastly, establishment of collaboration with STS-scholars at NTNU on issues related to integration of wind power and cultural differences in regard to wind power integration and societal acceptability will advance the research at a European level about the societal acceptability of wind power integration, constituting one of the only projects within the EERA network with a social science focus. The research project will overall enhance possibilities for European business and for international cooperation.

Technological Readiness Level (TRL) of the proposed concept.

(TRL – not relevant). Concept has been developed, and will through the project be made ready for dissemination to a broader public. The book is the most mature of the products, whilst the joint paper with Marius Korsnes will be submitted in fall/winter 2017. Regarding the joint collaboration and network building on STS and wind power integration and formulation of research topics on cross-cultural differences, this is the least mature, but one with a lot of future potential for future contributions and projects, and for strengthening European collaboration in the field.

Definition of Key Performance Indicators (KPIs).

The project and research stay is linked to the EERA Sub-programme of '*Wind integration – economic and social aspects'.* To date there has been little research conducted through the Mobility Scheme under this EERA sub-programme. With its social science perspective on the issue of wind integration in a context of China, which is the world's largest market for wind power, as well as in the pioneering context of Denmark, the project will help fill out this gap and moving the EERA Sub-Programme further, and extending the IRPWIND INCO (international cooperation) strategy to China. The research project and network-building activities will lay the foundation for future collaborative research between DTU Wind Energy and China- and STS-scholars at NTNU, related to the societal acceptability of sustainable transitions and the socio-economic aspects of wind integration. In concrete terms, the KPIs of the project are:

- Book, to be published by Routledge 2017.
- Joint paper with Marius Korsnes: comparative study of China's onshore and offshore industries; to be published in Research Policy, Energy Policy, or The China Quarterly in 2017
- Presentations and discussion of STS-contributions and findings:
    - book and PhD project; Wind2050
    - Presentation of the project at the IRPWIND conference 2017
    - 2 LinkedIn articles to be published on my profile (500+ connections) and shared with the IRPWIND LinkedIn group.
- Cooperation strategy document
    - list of relevant collaboration partners in Denmark and Norway
    - list of overlapping STS-related research topics within the area related to the EERA sub-programme 'Wind Integration - Economic and Social Aspects'
    - list of ideas for joint papers, e.g. on comparative studies across Europe (Denmark and Norway) and China and the role of the institutional context (culture) on wind power development.

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

Description of national projects of receiving Organization

With research ongoing at the *Department of Interdisciplinary Studies of Culture, Faculty of Humanities*, NTNU, within my fields of China studies, Science&Technology Studies (STS), culture, and the societal acceptability of wind power, NTNU's research profile relates perfectly to mine, to the research project, and my ongoing postdoctoral research at DTU Wind Energy. Projects e.g. include:

- SHAPE-ENERGY - Social Sciences and Humanities for Advancing Policy in European Energy (Horizon 2020) - project start 02/2017;
- CenSES (Center for Sustainable Energy Studies), work package 1.3. "Public engagement to build energy citizenship" in Research Area 1 "Policy making and transition strategies";
- Public Acceptance of Post Carbon Strategies.

NTNU will be of great benefit to my research project, since NTNU's ongoing research within STS and controversies over wind power and other renewables, as well as its profile in interdisciplinary culture studies, can help inform my work on the book project, result in a joint paper, and provide a fruitful environment for discussions of findings, for network building and building ideas for future academic articles and project proposals. I have already agreed with postdoctoral researcher Marius Korsnes, whom I know from my doctoral research, to work on a comparative paper, but also to discuss the book findings, and setting them in to a new framing of recent field findings from 2015 and 2016. Additionally, other relevant scholars within the fields of STS, China, and societal acceptability of renewables are Professor Marianne Ryghaug and researchers Jøren Solli and Sara Heidenreich.

Description of national projects from the sending Organization.

At the sending organization (the Department of Wind Energy, DTU), the nationally funded project (Strategic Research Council of Denmark/Innovationsfonden) Wind2050 is being undertaken in collaboration with other Danish universities on the subject of social acceptance of onshore wind power in Denmark (Wind2050; www.wind2050.dk), in order to understand the reasons of increased social resistance against wind power in Denmark. In the project I have conducted extensive fieldwork on the imminent 'paradigm shift' in Danish wind power deployment. The paradigm shift is closely linked to the changing nature of wind power as a community-owned power source to large commercial development. These changes in the Danish developer landscape have co-evolved with institutional changes in the support schemes, technological changes, and changes in ownership and business models. In another nationally funded project (CORAL, funded by the EUDP), I am looking into the impact of visual pollution from obstruction lights at the National Test Centre for large wind turbines in Denmark. These two nationally funded research projects reflect an ongoing attempt at DTU Wind Energy to create synergies between natural (engineering) and social sciences. Further, DTU Wind Energy is partner in the Sino-Danish Centre for Research and Education (SDC) in Beijing, and through this project, DTU Wind Energy can become better linked to the SDC research. Hereby, the research project and its perspective on the contested acceptability of wind power in a Chinese and Danish context will help strengthening DTU Wind Energy's profile in the area. During my stay at NTNU, I will discuss overlapping interests and research findings about the integration of wind energy and renewables in general in society, which will lay the foundation for potential future collaboration.

Foreseen European added value of national alignment.

The foreseen European added value of national alignment between DTU Wind Energy and NTNU in terms of this research field is the way in which the research project and the research stay can help build bridges between natural and social sciences, and the way in which it through insights from different cases of contested sustainability of wind power in different contexts can result in future joint papers, knowledge sharing, and formulation of joint research projects and project proposals. This will enhance the IRPWIND strategy for international cooperation (INCO strategy). By learning from the case of China, the research project will contribute with European added value with refined advice for Sino-European research and business collaboration in wind power, e.g. by understanding the Chinese agenda(s) in such collaborations, and by understanding the development trajectory and political underpinnings of this. This will promote enhanced Sino-European collaborations and better market opportunities for European businesses. This is of vital importance for the long-term competitive advantage of the European wind turbine industry and research community, as China is upgrading rapidly. Overall, by providing insights into controversies over the acceptability of wind power, the project and the collaboration will contribute to enhancing wind power deployment in Europe, and thus to the fulfilment of EU's renewable energy and climate targets.

Description of the host institute: e.g. infrastructure, experience etc.

During the research stay, the host institute will provide office space, Internet access, and library privileges, which is necessary for the research project. I will contribute to and participate in departmental meetings, and present my research based on my PhD and upcoming book, of the joint academic paper with Marius Korsnes, as well as my current postdoctoral work at the department. The department has experience in research founded in STS, China studies, China's wind market, social acceptance of renewable energy, and interdisciplinary culture studies, whereby the department will fit perfectly to my work and to building a strong research network.

3. Work plan

Deliverables, milestones etc.

10.01.2017 – 31.3.2017 Book publication work

Book writing based on my PhD thesis, to be published by Routledge. Collaboration with Marius Korsnes on refining my arguments, conclusions, and recommendations.

15.01.2017 Presentation of my work plan to NTNU department to receive input and frame discussions
20.01.2017 Milestone: Book structure and contents scoping complete
20.02.2017 Milestone: First draft ready for review

25.03.2017 Presentation of my book work to NTNU department
31.03.2017 Milestone: Book (deliverable 1) to Routledge for publishing

10.01.2017 – 04.04.2017 Joint article work

Joint paper, a comparative study of China's onshore and offshore industries. Collaboration with NTNU researchers at the department, including Marius Korsnes.

20.01.2017 Milestone: abstract written
02.04.2017 Milestone: presentation of the paper argument (deliverable 2)

01.02.2017 – 04.04.2017 Strategic exchange and collaboration work

Explore the opportunities for enhancing the STS-focussed collaboration between DTU and NTNU. Ongoing exchange concerning the research at NTNU on role of technology in society, the social science activities current and envisaged at DTU Wind Energy, and identification of research opportunities on institutional and cultural differences between a Scandinavian (Denmark, Norway) and Chinese context of wind power deployment.

25.03.2017 Milestone: Document on research collaboration possibilities, common project work and applications (deliverable 3).

4. Benefits to EERA objective advancement

Contribution to the advancement of the EERA strategy goals, gaps addressed.

With its focus on socio-technical implications of the transition to renewable energies, the project will contribute to the EERA objective (EERA strategy goals and gaps) with its insight into the social and economic aspects of wind power integration, seen from a more holistic social science perspective, and through insights into issues of wind power curtailment and integration in a Chinese context. This research will address the current research gap on the socio-economic impacts of wind power integration. Since only little research has been undertaken within the EERA sub-programme 'economic and social aspects of wind power integration', the project will help fill in this lacuna, bringing the field forward. Through this, and through enhanced network-building, the EERA network can provide a strengthened platform for improved joint EU-applications which can facilitate the integration of social science and natural science perspectives as well as ensure the strengthened exploration of issues related to social acceptance of wind power in future EU project proposals. The project will also extend the IRPWIND strategy for international cooperation (INCO strategy), extending focus to the world's largest wind power market China, which is of vital importance for the future of global wind power development and integration.

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

Explain ToK or dissemination strategies and plan of future collaboration with other IRP/EERA partners.

I will disseminate my research at NTNU as well as at DTU Wind Energy through seminars at NTNU. Further, I plan to disseminate my findings in more academic articles, one of them with NTNU-research Marius Korsnes. I also plan to present my findings at the IRPWIND conference 2017, and to disseminate through Social Media, i.e. LinkedIn articles/blogging to be published on my profile (500+ connections) and shared with the IRPWIND LinkedIn group. The findings of the project will lay the foundation for future collaboration (e.g. EU-applications etc.) with NTNU, but also other IRP and EERA Wind participants.

6. Expected results

Methodologies and/or databases and/or best practices functional to the activities of the IRP and EERA strategic agenda objectives.

The expected result is a book for submission to Routledge, which will relate to the EERA sub-programme 'Wind Integration - Economic and Social Aspects', e.g. through a list of implications for the management of Sino-European collaborations in wind power. Further, an academic paper comparing controversies over China's onshore and offshore wind power markets will result from the work. A strategy paper for joint collaborations between DTU Wind Energy and NTNU will be produced.

Assessment of the advancement of the TRL.

Not relevant.

Assessment of the KPIs.

a) Book will be accepted for publication by Routledge in 2017.
b) Joint paper on comparison of Chinese onshore and offshore wind energy submitted 2017.
c) Comments received from NTNU on presentation of PhD project and book.
d) Comments received from NTNU on research findings and STS-approach in the Wind2050-project.
e) Discussion of cooperation strategy document and of overlapping research topics within the area related to the EERA sub-programme 'Wind Integration - Economic and Social Aspects'.

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Funded by EU

Application form for Mobility grants within IRPWIND

A) Applicant details

Applicant Name	**Francisco**
Applicant Surname	**Lahuerta Calahorra**
Home Institution	**Knowledge Centre WMC**
EERA/IRP Partner? *(yes/no)*	**Yes (*IRP Partner*)**
Home Institution Postal address	**P.O. Box 43** **1770 AA Wieringerwerf** **The Netherlands**
E-mail	**f.lahuerta@wmc.eu**

B) Host institution details

Institute name	**Danmarks Tekniske Universitet**
EERA/IRP PARTNER?	**Yes (*IRP Partner*)**
Contact person	**Lars Pilgaard Mikkelsen**
Country	**Denmark**
E-mail	**lapm@dtu.dk**

C) Relevant Programme and scheme

CORE PROJECT? YES/NO *(Please erase the non-relevant)*	**(C) Structures and Materials**	**RELEVANT EERA SUB-PROGRAMME Max 2** (Please erase the non-relevant)	**(C) Structures and Materials**
Length of the grant scheme *(Please erase the non-relevant length)*	**Scheme: (01) 4 weeks**	**Number of weeks: Start date:**	**4**

D. Project Description

Micro-mechanical investigation on shear and compression fatigue properties on thick laminates via 3D X-ray computed tomography using the sub-laminate technique

1. Introduction

Research topics, originality

Thick laminates (typically above 6 mm) are present in wind turbine blades, where the spar cap layout can show thicknesses between 40 to 150mm as a function of the blade length and loads. Recent research has shown that mechanical properties through the thickness show large differences [1]. Ultimate strengths and fatigue properties (S-N curves) vary through the thickness showing unexpected values in comparison with thin laminate tests. The variation of mechanical properties of thick laminates was reported as a function of the curing cycles and temperature gradients that occur during the manufacturing due to the resin exothermic curing process. Variations up the 33% in the compression ultimate strength and shear strength have been reported [2–4]. Also, safety factors between 1.3 and 1.6 regarding the thickness effect in fatigue properties have been suggested [5]. However, the influence of the curing cycles in thick laminates mechanical properties is not considered during the industrialisation of blades designs. These investigations were carried out using the sub-laminates method which allows evaluating thick laminates material properties experimentally according to a prescribed curing cycle.

While the sub-laminate technique allowed to investigate the through-thickness mechanical properties. The micro-mechanical reasons that drive this behaviour have not been investigated. With the present proposal is proposed to use the sub-laminate technique to manufacture coupons cured at different curing cycles, equivalent to the through thickness distribution that can be found in a thick laminate. Later, degrade such coupons in fatigue up to a given level. Finally, investigate in DTU premises the degraded microstructure using 3D X-ray computed tomography.

Technological Readiness Level (TRL) of the proposed concept.

Both techniques by separate have been explored previously. The 3D X-ray computed tomography has been used previously by DTU [6–9] and also the sub-laminates technique has been developed and employed by WMC [2]. Therefore, the technological readiness of both techniques by separate is high and has been drawn up and tested previously. However, the combination of both techniques to further investigate the microstructure and fatigue degradation of a thick laminate has not been explored or reported in the literature.

Definition of Key Performance Indicators (KPIs).

In case the combination of both techniques offers quantitative and qualitative insights regarding the microstructure and fatigue degradation of a thick laminate. Key performance indicators to evaluate the joint investigation would be:

- Reports:
  - On the coupon manufacturing and sub-laminates technique
  - On the coupons fatigue tests
  - 3D X-ray computed tomography observations of coupons
  - Coupling microscope observations with influence of manufacturing procedure
- Journal paper written between DTU and WMC

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

The present proposal aligns with the research topics from EERA sub-programmes on materials and substructures where fatigue on composites is considered as one of the main topics. Also, the present proposal can be framed in WP7.3 (”Material models & life predictions methods”, lead by WMC) where thick laminates and fatigue properties are investigated.

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

The current proposal is align with national projects in which WMC is participating such as:

- “Thick laminates” ADEM project
- “Load and Structural Health Monitoring of Offshore wind turbine blades” SLOWIND Project plan Wind op zee
- “Micromechanics based modelling and condition monitoring of rotor blade composites (MIMIC)” TKI-WoZ Project

3. Work plan

The work plan is divided into 6 main groups. The manufacturing of the thick laminates (60-70mm thick), the coupon extraction and preparation, the fatigue degradation and the X-Ray tomography investigation. Also, task related to data analysis and reporting are required.

Material tested, epoxy glass fiber unidirectional composite.

The entire time framework is around 12 months.
The experimental time is in the range of 6 months.
The mobility grant consists in one month in DTU premises, where the X-Ray tomography machine is located, to collaborate and fulfil task 3.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1-Thick laminatesmanufacturing (sub-laminate technique)												
2-Coupons extraction and preparation												
3-Fatigue degradation of coupons												
4-X-Ray tomography investigation (1° WMC visit)												
5-X-Ray tomography investigation (2° WMC visit)												
6-Data analysis												
7-Report												
Thick laminate manufacturing												
Coupon tests												
X-Ray tomography investigation												
Conferance paper												
Journal paper												

Figure 1: Gantt diagram with the main tasks and time frame (Total time frame 12 moths).

At DTU
At WMC
WMC /DTU

		Loading mode	
		Compression	
		R08	
Fatigue degradation at cte load (cycles)		Null	1.00E+05
Curing rate	High (150 °C/min)	2 scans	2 scans
	Low (30 °C/min)	2 scans	2 scans

		Shear	
		ASTM D7078	
Fatigue degradation at cte		Null	1.00E+05
Curing rate	High (150 °C/min)	2 scans	2 scans
	Low (30 °C/min)	2 scans	2 scans

Figure 2: Test matrix.

As indicated in the diagram, a small number of preliminary scans will be performed by another member of the WMC material research team, for whom a separate mobility application with a different research topic will be submitted. The results of such preliminary scans will guide eventual adjustments to the proposed test matrix before the visit associated with the present research project is made. Likewise, the second visit will include follow-up scans of material associated with the project conducted by the aforementioned WMC researcher. Such collaboration is mutually beneficial and falls in line with WMC's R&D goals.

During the stay at DTU, the scans and subsequent analysis of the results will be done in cooperation with the DTU PhD student Ulrich A. Mortensen and supervised by DTU personnel. Relevant training in data analysis of the obtained scans will also be provided by DTU.

4. Benefits to EERA objective advancement

The current proposal aims to investigate the structural load carrying mechanical properties of a thick laminate in fatigue. It is believed that studying the microstructure from a thick laminate will help to understand the uncertainties observed between thin and thick laminates static and fatigue mechanical properties. This approach is aligned with the EERA *sub-programme 3 Structures and materials.* The objectives of sub-programme 3 is to reduce the uncertainty in the design of structural load carrying components as well as machinery components to increase cost efficiency and reliability and allow for optimization, innovations and upscaling of future wind turbines. To deeper investigate relation between the manufacturing procedures, curing cycles and mechanical properties allow make better service life time predictions and underline the uncertinities behind the manufacturing procedures.

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

It is intended to publish the proposed investigation in first order conference and journals related to composites materials and fatigue. On conference paper and journal paper are the expected outcome.

6. Expected results

A new methodology to study the influence of fatigue on the microstructure of a thick laminate for a prescribed curing cycle is projected to be the result. Is believed that this methodology will bring further insight regarding the fatigue degraded and undegraded microstructure that can be found through a thick laminate thickness for a prescribed curing cycle. The proposed investigation will be assessed base on the reporting of the work and a peer-reviewed publication.

7. References

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Mobility Call N°: **Mobility scheme:** **Home Institution:**	Open 1-4 weeks **WMC**

Evaluation[1]

S1. EXCELLENCE	3
Observations: the candidate has a strong background in the matter, as witnessed by the articles and patents. Both institutes have a long history in the research of FRP. The intended study fits perfectly into the SP structures and materials. The combination of large-scale testing of thick laminates and tomographic scan of the results is predestined to shed new light on the failure mechanisms involved.	
S2. IMPACT	3
Observations: The combination of experience in testing thick laminates at WMC, combined with the strong role of DTU regarding microstructures and tomography is bound to produce highly valuable results. The publication of results in the reports and journal papers assures wide spread coverage of the results and might lay the basis for future standards for thick laminates, as well as for a better understanding of the mechanisms involved, important for the manufacturing of rotor blades, where increased dimensions also can lead to larger laminate thickness.	
S3. IMPLEMENTATION	0 1 2 3
Observations: The time schedule and organization seem fully adequate for the purpose	
S4. OVERALL EVALUATION	0 1 2 3

Suggestion?

……

Although understandable from the amount of effort involved, more data points, for instance at more numbers of cycles would be a useful extension to the project. At the low number of specimens involved (2 per loading mode/curing rate), statistical effects (“outlayers”) can easily obscure the observations. Very careful scrutiny of the specimens (and if necessary, discarding imperfect samples) used before testing is considered essential.

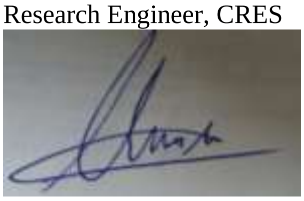
Mobility Call N°: **Mobility scheme:** **Home Institution:**	Open 1-4 weeks **WMC**

Evaluation[2]

S5. EXCELLENCE	0 1 2 (3)
Observations: **The topic of investigating the mechanical behavior of thick composite laminates and the through thickness variations is of paramount importance for the better understanding of the failure characteristics of the spar cap of the blade, especially when now days very large blades with an increased thickness are considered.**	
S6. IMPACT	0 1 2 (3)
Observations: **The specific mobility case will enhance the collaboration between WMC and DTU, two of the largest institutes in Europe for wind energy research. Knowledge will be transferred concerning material testing, composites manufacture and non destructive testing.**	
S7. IMPLEMENTATION	0 1 2 (3)
Observations: **The work plan for this mobility scheme is coherent and will also be supportive for the work of WP7 of the IRP project.**	
S8. OVERALL EVALUATION	0 1 2 (3)

Considering the above statements and the description of the work plan, I suggest that this mobility plan should proceed and mainly will support our efforts in WP7 of IRP project in increasing the reliability level of the wind turbine blade as a stepping stone in the better understanding of mech

Andreas Makris
Research Engineer, CRES



Funded by EU

Application form for Mobility grants within IRPWIND

NOTE

- **All documents must be named as follows:**

Sub Programme letter, Scheme no., Surname, Document type. Ex: A_2_Smidt_cv
See Table C) below.

- **The application must be max. 6 pages, ex tables, figures and references.**

A) Applicant details

Applicant Name	**Lukas**
Applicant Surname	**Pauscher**
Home Institution	**Fraunhofer IWES**
EERA/IRP Partner? *(yes/no)*	**Yes**
Home Institution Postal address	**Königstor 59, 34119 Kassel, Germany**
E-mail	**lukas.pauscher@iwes.fraunhofer.de**

B) Host institution details

Institute name	**Technical University of Denmark**
EERA/IRP PARTNER?	**Yes**
Contact person	**Jakob Mann**
Country	**Denmark**
E-mail	**jmsq@dtu.dk**

C) Relevant Programme and scheme

CORE PROJECT? YES/NO *(Please erase the non-relevant)*	**(B) Wind Integration**	**RELEVANT EERA SUB-PROGRAMME Max 2** (Please erase the non-relevant)	**(D) Wind Conditions** **(F) Research Infrastructures**
Length of the grant scheme *(Please erase the non-relevant length)*	**Scheme:** **(02) 4-26 weeks**	**Number of weeks:** **Start date:**	**13** **03.10.2016**

D. Project description

Wind Statistics from multi-lidar measurements: Improving turbulence measurements and reducing uncertainties

1. Introduction

The characterisation of wind and turbulence conditions is one of the major challenges for wind energy developments at complex terrain sites. Mast bound measurements are confined to one location and classical remote sensing approaches often suffer from errors (Bingöl et al. 2009; Bradley et al. 2015; Klaas et al. 2015). Moreover, they are not able to measure turbulence with the desired accuracy for wind energy applications (Sathe et al. 2011; Sathe et al. 2015a).

Multi-lidar measurements offer a promising way to overcome these problems. Using the WindScanner technology multiple lidar systems can be centrally steered and synchronised to intersect their beams in a single measurement location. This way, turbulence measurements can be improved and the complex terrain error of profiling lidars can be overcome. Moreover, the technology allows spatially resolved probing of the wind field and thus opens up completely new possibilities for research applications building the fundamental understanding of the wind conditions. Also, in an applied context this can be of great advantage. The 3D wind vector can be measured in multiple locations at a complex site during the project planning phase to get accurate estimates of the wind resource and parameters which are important for turbine loads (e.g. turbulence intensity).

Using data from the Kassel 2014 Experiment Pauscher et al. (2016) demonstrated the high accuracy of mean wind speed measurements which can be achieved using multiple WindScanners and the advantages when compared to classical profiling lidars in complex terrain (Figure 1). Moreover, Pauscher et al. (2016) showed the great potential for measuring (second order) turbulence statistics. The analysis, however, also revealed persisting problems in turbulence measurements due to path averaging effects. Also, the results showed that the positioning of the WindScanner devices has an influence on the accuracy of the measurement – especially for turbulence measurements. A systematic evaluation of the expected uncertainties/errors is missing up to this point. This is especially important for the turbulence measurements, where the results indicated a significantly higher sensitivity to the positioning of the WindScanners.

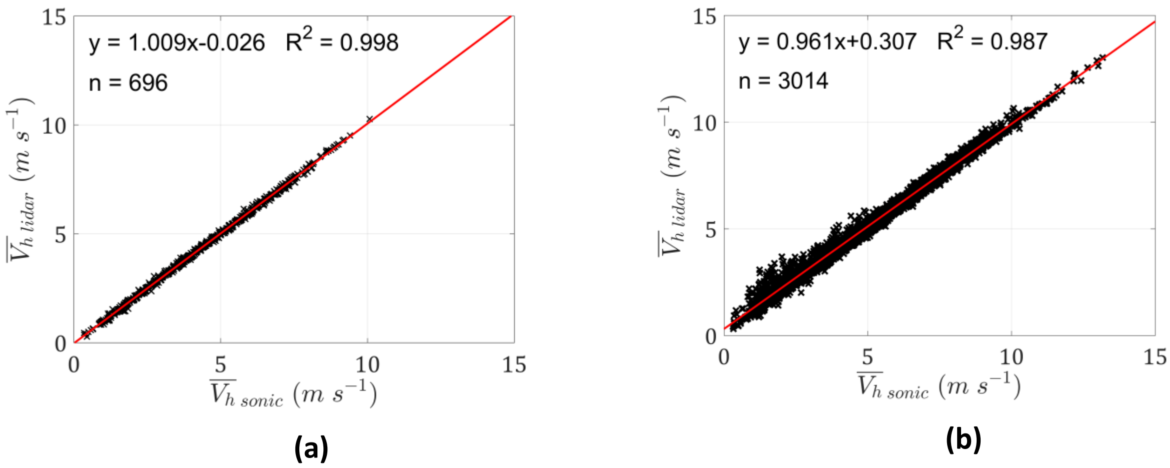


Figure 1: Comparison of (a) tripple-lidar measurement and (b) a classical DBS-proviler (windcube v2) with a reference sonic anemometer; figures taken from (Pauscher et al. 2016); $\overline{V}_h$ denotes the horizontal wind speed.

Suggested work:

This project therefore aims at:

1.) Investigating the possibility of a turbulence correction based on the spectral broadening of Doppler spectra of the WindScanner lidars. A theoretical basis has been developed by Smalikho et al. (2005) but no experimental validation/experience for the WindScanner systems exists.
2.) Developing and testing of a three-beam multi-lidar technique in analogy to the six beam technique using a single lidar (Sathe et al. 2015b) to derive second order statistics of the horizontal wind speed.
3.) Investigating, if second order statistics of the horizontal wind speed using two instead of three scanners can also be improved.
4.) Uncertainty/error quantification of different multi-lidar configurations for measurements of the mean wind speed and second order statistics and providing guidelines on the appropriate setup. This analysis will focus on configurations combining two and three WindScanners. The work of Stawiarski et al. (2013) will be used as a starting point here.

These steps would greatly improve the value of multi-lidar measurements in general and especially of the WindScanner technology in a wind energy context. One of the key shortcomings of lidars in wind energy applications is their inability to measure turbulence with the desired accuracy for wind energy applications (Sathe et al. 2015a). Points 1, 2 and 3 could help to close this gap. The reduction of the uncertainties (point 4) is key in every resource/site assessment process, but also in measurement campaigns which create experimental data sets for experimental model evaluation. The error analysis will provide guidelines on the best practice for choosing measurement locations for a synchronised multi-lidar measurement.

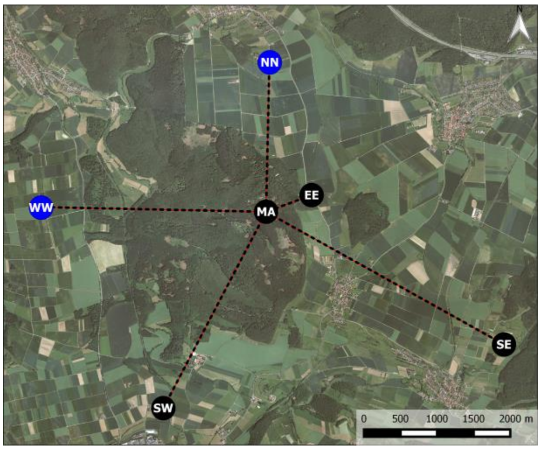


Figure 2: Positions of the different WindScanners during the Kassel 2014 experiment. MA indicates the location of the reference mast and a WindScanner positioned directly next to it.

The work suggested for this project will rely on data collected during the Kassel Experiment 2014 within the *WindScanner.eu* project. During the project measurements with six WindScanners, which were focused in a point close to a reference anemometer, were performed (Pauscher et al. 2016). The setup during the Kassel 2014 experiment is close to ideal for the suggested work, as it allows the experimental evaluation of several different WindScanner combinations with different characteristics. The project thus partly builds on the analysis performed by Pauscher et al. (2016), which was partly performed during an IPR supported exchange of Doron Callies between DTU and IWES. Also data from the *New European Wind Atlas* experiments in Østerild (Denmark) may be used. Here two horizontally scanning lidars measure the mean and turbulent winds over several square kilometers.

Links to relevant EERA Sub Programmes and/or IRPWIND Core Projects:

The proposed project is relevant to the EERA Sub Programmes *Wind Conditions* and *Infrastructure*. The use of WindScanners in multi-lidar measurements greatly enhances our ability to make spatially resolved measurements and create experimental data sets for model validation. It will thus help to increase our fundamental understanding of atmospheric motions and help to increase our measurement ability. In fact, during the ERANET+ project *New European Wind Atlas* synchronised WindScanners will be extensively used to create data sets for flow model validation in complex terrain. The proposed project will strongly benefit these experiments.

The WindScanner technology was the focus of the *WindScanner.eu* project which aims at creating a European infrastructure for the WindScanner technology. Also several European research institutes (including IWES and DTU) now operate long range WindScanners.

Key Performance Indicators:

- Answer the question whether we can use the Doppler spectra from WindScanners to improve turbulence measurements.
- The work will help provide an uncertainty frame work for the WindScanner measurements during the large scale complex terrain experiments planned during the NEWA project.
- Recommendations for the setup of WindScanners will be available.
- Outcomes of the project will be published in a journal paper.

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

The project is strongly related to the ERANET+ project *New European Wind Atlas* in which the sending and the receiving institution receive national funding. During this project several measurement campaigns in complex terrain employing multiple WindScanners are performed. The output of the proposed project would greatly enhance the value of these measurement campaigns.

2.1 Description of national project of DTU

DTU Wind Energy is the leader of the *New European Wind Atlas (NEWA)* which uses lidar technology in all its experiments. *NEWA* does not directly develop improved measurement procedures, so the proposed project would complement the *NEWA* activities very nicely. DTU is starting a project to use WindScanner for routine site assessment. It is mainly aimed at wind resource estimation in complex terrain, but the proposed project could be used to enhance the site evaluation part (that is estimation of turbulence) of that project. DTU also has projects aimed at power curve verification or wind turbine control assisted by lidar.

2.2 Description of the national project of Fraunhofer IWES

The proposed project is aligned with the national project *Windenergienutzung im Binnenland II* (Utilization of Inland Wind Power funded by the German Federal Ministry for Economic Affairs and Energy). The project centres on the characterisation of wind conditions in hilly forested terrain and implications for the wind resource and wind turbine loads. A specific focus is put on the evaluation of lidar technology for site and resource assessment in complex terrain. During the project Fraunhofer IWES acquired three Scanning lidars, which are equipped with the WindScanner software. They are used for wind and turbulence characterisation in complex terrain. These systems now form a central part of the nationally funded measurement infrastructure at Fraunhofer IWES. The use of these instruments and the subsequent data analysis would greatly benefit from the proposed project.

2.3 Foreseen European added value of national alignment.

The expected outcome of the proposed project will be directly usable in the European project *New European Wind Atlas*. Moreover, the project further develops the European infrastructure which is central in the *WindScanner.eu* project. The proposed work complements both projects and adds to the value of their outcomes.

2.4 Description of the host institute

The Technical University of Denmark (DTU) has provided a major part of the wind energy research in Denmark with Risø National Laboratory for Sustainable Energy as a major contributor. In 2012, DTU founded a new department of wind energy, DTU Wind Energy, integrating also Risø wind energy activities. DTU Wind Energy has more than 230 staff members, including 150 academic staff members and approximately 50 PhD students, and the department comprises 8 sections. Research is conducted within 9 research programmes organized in three main topics: Wind energy systems, Wind turbine technology and Wind energy basics.

DTU owns several research facilities such as the Danish National Wind Tunnel, a drivetrain facility and the two test sites Høvsøre and Østerild for large wind turbines. For wind measurements they also possess several remote sensing wind measurement devices (VAD lidar, long-range and short-range wind scanners) and focus on the application and development of the wind scanner technology. In the field of lidar measurements DTU is the leading European Institution with many years of experience with projects such as Wind.Scanner.dk, Optimizing wind energy: Investigation of atmospheric turbulence using lidars, NORSEWInD -Northern Seas Wind Index Database.

3. Work plan

The time schedule for the proposed work is 3 Oct 2016 – 1 Jan 2017 (13 weeks):

Table 1: Time Schedule for the work plan during the proposed project.

Task	Week starting												
	3 Oct	10 Oct	17 Oct	24 Oct	31 Oct	7 Nov	14 Nov	21 Nov	28. Nov	5 Dec	12 Dec	19 Dec	26 Dec
Investiagtion of the relationship between the spectral brodening of the Doppler spectra and the turbulence attenuation.													
Derivation of a correction function for the turbulence measurement in the LOS measurment.													
Analysis of the WindScanner data based on the three beam methodology and a two WindScanner combination.													
Comparison of results to turbulence estimates using the classical multi-lidar approach.													
Application and modification of the error estimation framework of Stawiarski et al. (2013) to WindScanner data													
Extending the error estimation framework to turbulence measurements.													
Validtation of error estimation framework with experimental data.													
Preparation of a draft paper.													
Buffer week													

4. Benefits to EERA objective advancement

As the WindScanner technology is currently one of the cutting edge technology developments in the area of remotely sensing wind and turbulence, the proposed work contributes the objective of providing strategic leadership for the scientific–technical medium to long term research. It thus supports the Technology Roadmap activities

The proposed work also directly benefits activities which are aimed at the strategic goals of the European Wind Initiative (EWI). Especially the EWI key research activities 1) simplifying site assessment and 2) development of new wind energy maps, would benefit from this project.

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

As the WindScanner technology is used by different European Institutions, is the central part of the WindScanner.eu project and plays a key role in the *New European Wind Atlas (NEWA)*, a dissemination of the results among the EERA wind participants is crucial.

Within the *NEWA* consortium the results of the proposed projects will be communicated in internal workshops.

IEA Task 32 LiDAR will be used to communicate and discuss the results with a wider and more industry oriented community.

The outcomes of the project will also be published in a journal publication to make it available to the general scientific community.

6. Expected results

The expected outcomes of the project can be summarised in the following points:

The proposed project advances the use of the WindScanner technology in wind energy applications as it will provide:

- An investigation on the possibilities of improvements to the WindScanner technology to measure turbulence quantities.
- Recommended practices on the WindScanner configuration for field measurements and a framework for uncertainty/error estimation.

These advancements will help the WindScanner infrastructure to become more ready for direct applications in the wind energy industry like site and resource assessment.

The outcomes of this project will be published in a journal publication.

References

Bingöl F, Mann J, Foussekis D (2009) Conically scanning lidar error in complex terrain. Meteorol. Z. 18(2):189–195. doi: 10.1127/0941-2948/2009/0368

Bradley S, Strehz A, Emeis S (2015) Remote sensing winds in complex terrain – a review. Meteorol. Z. 24(6):547–555. doi: 10.1127/metz/2015/0640

Klaas T, Pauscher L, Callies D (2015) LiDAR-mast deviations in complex terrain and their simulation using CFD. Meteorol. Z. 24(6):591–603. doi: 10.1127/metz/2015/0637

Pauscher L, Vasiljevic N, Callies D, Lea G, Mann J, Klaas T, Hieronimus J, Gottschall J, Schwesig A, Kühn M, Courtney M (2016) An inter-comparison study of multi- and DBS-lidar measurements in complex terrain. Remote Sensing (Submitted)

Sathe A, Banta R, Pauscher L, Vogstad K, Schlipf D, Wylie S (2015a) Estimating turbulence statistics and parameters from ground- and nacelle-based lidar measurements: IEA Wind Expert Report. IEA Wind Task 32, Roskilde, Denmark

Sathe A, Mann J, Gottschall J, Courtney MS (2011) Can wind lidars measure turbulence? J. Atmos. Oceanic Technol. 28(7):853–868. doi: 10.1175/JTECH-D-10-05004.1

Sathe A, Mann J, Vasiljevic N, Lea G (2015b) A six-beam method to measure turbulence statistics using ground-based wind lidars. Atmos. Meas. Tech. 8(2):729–740. doi: 10.5194/amt-8-729-2015

Smalikho I, Köpp F, Rahm S (2005) Measurement of atmospheric turbulence by 2- μ m Doppler lidar. J. Atmos. Oceanic Technol. 22(11):1733–1747. doi: 10.1175/JTECH1815.1
Stawiarski C, Träumner K, Knigge C, Calhoun R (2013) Scopes and challenges of dual-Doppler lidar wind measurements - an error analysis. J. Atmos. Oceanic Technol. 30(9):2044–2062. doi: 10.1175/JTECH-D-12-00244.1

Mobility Call N°: **Mobility scheme:** **Home Institution:**	Open Call 4-26 weeks **IWES**

Evaluation[1]

S1. EXCELLENCE	3
Observations: How to measure second order statistics of the wind speed (that is: turbulence) with lidar accurately is a technical challenge at the moment.	
S2. IMPACT	3
Observations: If turbulence could be measured accurately with lidar, lidar could replace fixed masts and a cost reduction of a wind resource assessment campaign is within reach.	
S3. IMPLEMENTATION	2
Observations: Risoe/DTU is one of the better places to be, as the lidar knowledge is big.	
S4. OVERALL EVALUATION	3

Suggestion?

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Mobility Call N°: **Mobility scheme:** **Home Institution:**	Open Call 4-26 weeks **IWES**

Evaluation[2]

S5. EXCELLENCE	3
Observations:	
S6. IMPACT	3
Observations:	
S7. IMPLEMENTATION	2
Observations:	
S8. OVERALL EVALUATION	3

Suggestion?
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Funded by EU

Application form for Mobility grants within IRPWIND

A) *Applicant details*

Applicant Name	**Iuri**
Applicant Surname	**Barcelos Carneiro Montenegro da Rocha**
Home Institution	**Knowledge Centre WMC**
EERA/IRP Partner? *(yes/no)*	**Yes (*IRP Partner*)**
Home Institution Postal address	**P.O. Box 43** **1770 AA Wieringerwerf** **The Netherlands**
E-mail	**i.barcelos@wmc.eu**

B) *Host institution details*

Institute name	**Danmarks Tekniske Universitet**
EERA/IRP PARTNER?	**Yes (*IRP Partner*)**
Contact person	**Lars Pilgaard Mikkelsen**
Country	**Denmark**
E-mail	**lapm@dtu.dk**

C) *Relevant Programme and scheme*

CORE PROJECT? YES/NO *(Please erase the non-relevant)*	**(C) Structures and Materials**	**RELEVANT EERA SUB-PROGRAMME Max 2** **(Please erase the non-relevant)**	**(C) Structures and Materials**
Length of the grant scheme *(Please erase the non-relevant length)*	**Scheme: (01) 4 weeks**	**Number of weeks: Start date:**	**4 01/04/2017**

D. Project Description

Microscopic characterisation of material degradation evolution due to hygrothermal ageing using 3D X-ray computed tomography

1. Introduction

Research topics, originality

Research on composite material usage optimization for wind turbine blades has been on the rise in the past few years, and particular focus is being given to reducing design uncertainty through a better understanding of material interaction with extreme service environments. Among many types of environmental attack, the combined influence of temperature and moisture ingression is regarded as the most critical one [1]. Upon exposure to humid environments, polymers tend to absorb water molecules through a diffusion process driven by pressure gradients. Once inside, water tends to plasticize the resin and cause swelling, as well as chemically break polymer chains Experimental observations in a glass/epoxy system used in wind turbine blades suggest that diffusion mechanics and material degradation tend to be well predictable for short duration exposure of neat resin specimens, while for composites the presence of fibres brings differential swelling stresses which do not vanish upon saturation [2]. Furthermore, when conditioned at high temperatures and for extended durations, water can chemically attack the fibres and their sizing [3].

Previously obtained experimental results on glass/epoxy composites [4,5] show significant degradation in static and fatigue material performance after immersion, with up to 50% lower interlaminar shear strength and a fatigue life three orders of magnitude shorter. Furthermore, visual inspections of specimens before and after immersion suggest the occurrence of widespread cracking along the fibre/matrix interface. Such cracking phenomenon seems to be linked to an additional water uptake phase observed during periodic weighing of the specimens, possibly linked to the creation of new absorption loci along the cracks.

The current proposal intends to further investigate the formation of interfacial cracks in glass/epoxy composite specimens after hygrothermal ageing. In order to assess the evolution of the cracking process and its link with the measured strength and water uptake, specimens immersed in water for multiple durations will be inspected through the use of 3D X-Ray computed tomography. By comparing the observations in aged specimens with those of a reference (unaged) set, the location of the first cracks inside the specimen will be determined, as well as the approximate immersion time necessary for them to develop. By coupling the results from the inspections with those of multiphysics numerical models for diffusion, the mechanisms responsible for the cracking phenomenon will be better understood.

Technological Readiness Level (TRL) of the proposed concept.

The proposed research project aims in better understanding the evolution of the microscopic material state during hygrothermal ageing in glass/epoxy composite specimens. The 3D X-ray computed tomography technique has been previously used by DTU in the investigation of fatigue damage evolution [6-9]. Regarding material characterisation after hygrothermal ageing, a combined numerical/experimental approach is currently being explored at WMC [4,5]. The use of X-ray tomography as a way to monitor hygrothermal ageing damage evolution is novel and not thoroughly explored in literature.

Definition of Key Performance Indicators (KPIs).

The Key Performance Indications (KPIs) for the current research proposal are:

- Reports:
  - Material manufacturing and ageing procedure
  - Mechanical test results before and after immersion
  - 3D X-ray computed tomography observations of reference and aged samples
  - Coupling microscopic observations with multiphysics numerical models
- Journal paper written in a collaboration between DTU and WMC

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

This research project falls in line with the objectives of the EERA sub programme on Structural Design and Materials, on which WMC is an active partner. More specifically, the topics covered in the present research proposal align with the goals of Work Package 7.3 of the IRPWind project (Material models and life prediction methods), which includes the study and modelling of environmental effects on load carrying components of wind turbines.

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

The current proposal is aligned with the TKI-WoZ Project MIMIC (Micromechanics based modelling and condition monitoring of rotor blade composites), led by WMC.

3. Work plan

The work plan of the proposed research project can be seen in Figure 1 and the preliminary test matrix can be seen in Table 1. The plan can be roughly divided in an experimental part, involving ageing the mechanical characterization of composite samples, an inspection part, involving the use of 3D X-ray computed tomography, and a numerical modelling part, involving the multiphysics modelling of the hygrothermal ageing phenomenon. The time frame for the whole project is expected to be of 9 months.

As indicated in the diagram, a small number of preliminary scans will be performed by another member of the WMC material research team, for whom a separate mobility application with a different research topic will be submitted. The results of such preliminary scans will guide eventual adjustments to the proposed test matrix before the visit associated with the present research project is made. Likewise, the second visit will include follow-up scans of material associated with the project conducted by the aforementioned WMC researcher. Such collaboration is mutually beneficial and falls in line with WMC's R&D goals.

During the stay at DTU, the scans and subsequent analysis of the results will be done in cooperation with the DTU PhD student Ulrich A. Mortensen and supervised by DTU personnel. Relevant training in data analysis of the obtained scans will also be provided by DTU.

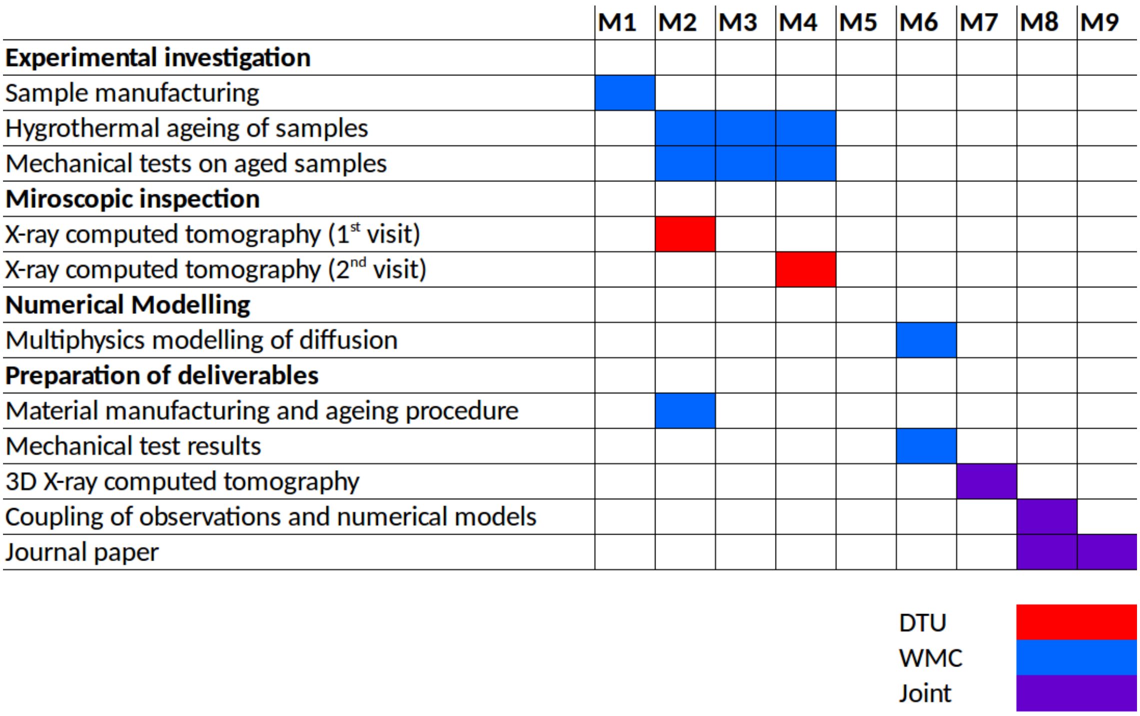

Figure 1: Project tasks and time frame.

Conditioning	Mech. test	No. of scans
Unaged	Untested	2
	Tested	2
5000h at 50°C	Untested	2
	Tested	2
2200h at 65°C	Untested	2
	Tested	2
Total number of scans:		**12**

Table 1: X-ray computed tomography plan for multiple specimen conditions.

4. Benefits to EERA objective advancement

As mentioned in Section 1, the current research proposal is aligned with the goals of the EERA sub programme on Structural Design and Materials and more specifically to WP7.3 of the IRPWind project. The main objective of WP7 is to reduce the design uncertainty of load carrying components of wind turbines. This can be achieved by a combination of better understanding of loads and service conditions experienced by such structures with advancements on numerical modelling techniques. The present mobility project can contribute to such goal by investigating the material degradation effects brought by moisture ingression in a composite material system used in wind turbine design. The deeper understanding of the underlying degradation mechanisms obtained through microscopic X-ray computed tomography investigations can then be combined with state-of-the-art multiphysics and multiscale numerical models in order to make better service lifetime predictions.

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

The results obtained in the proposed research project will be published as a journal paper. Furthermore, reports pertaining to each of the main tasks described in Section 3 will be made available to both partners.

6. Expected results

The insight provided by the 3D X-ray computed tomography observations of reference and hygrothermally aged specimens will be coupled with mechanical test results and advanced multiphysics numerical models. This combination will result in a deeper understanding of driving mechanisms of the ageing phenomenon and provide the necessary knowledge and tools to make structural health and remaining lifetime predictions of materials subjected to water ingression.

7. References

[1] White JR, Turnbull TA. Review: Weathering of polymers: Mechanisms of degradation and stabilization, test strategies and modelling. *Journal of Materials Science*, 29:584-613, 1994.

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[7] Jespersen KM, Lowe T, Withers PJ, Mikkelsen LP. Fatigue damage evolution in fibre composites for wind turbine blades. Fract. Mech. Laminated Compos. Struct., Aalborg, DK: 2015.

[8] Munk Jespersen K, Zangenberg Hansen J, Mikkelsen Pilgaard L. Micromechanical Time-Lapse X-ray CT Study of Fatigue Damage in Uni-Directional Fibre Composites. Proc. 20th Int. Conf. Compos. Mater., Copenhage: 2015.

[9] Munk Jespersen K, Zangenberg Hansen J, Mikkelsen Pilgaard L. Micromechanical investigation of fatigue damage in unidirectional fibre composites. Proc. 6th Int. Conf. Fatigue Compos., 2015.

Mobility Call N°:	Open
Mobility scheme:	1-4 weeks
Home Institution:	**Knowledge Centre WMC**

Evaluation[1]

S1. EXCELLENCE	2
Observations: Both WMC and DTU have an excellent background in FRP research. The experience of the Ph.D. student from WMC is shown by the list of articles included, and the topic fits well within the SP: “structures and materials”.	
S2. IMPACT	2.5
Observations: The hygrothermal material behavior of FRPs is not well understood and the current project could help to shed light on the issue, the possibility for publications on the result seems good, the journal paper would be a good result.	
S3. IMPLEMENTATION	3
Observations: The time schedule and organization seem fully adequate for the purpose and both organizations have cooperated before and another EERA mobility scheme proposal has been accepted, this second mobility scheme proposal fits in very well with that; no organizational problems are to be expected.	
S4. OVERALL EVALUATION	2.5

Suggestion?
A presentation on the work at a SP Workshop would be welcome, so as to show the results to other EERA partners.
………

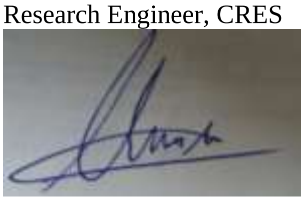
Mobility Call N°:	Open
Mobility scheme:	1-4 weeks
Home Institution:	**WMC**

Evaluation[2]

S5. EXCELLENCE	0 1 2 (3)
Observations: **The topic of investigating the degradation of the mechanical properties of composite laminates because of hygro-thermal ageing is of paramount importance, especially for wind turbine blades that face during their service life extreme weather conditions and large temperature variations. The application of a nondestructive testing method to follow up the degradation of the material will allow the comparison with available analytical and numerical material models.**	
S6. IMPACT	0 1 2 (3)
Observations: **The specific mobility case will enhance the collaboration between WMC and DTU, two of the largest institutes in Europe for wind energy research. Knowledge will be transferred concerning material testing, composites manufacture and non destructive testing.**	
S7. IMPLEMENTATION	0 1 2 (3)
Observations: **The work plan for this mobility scheme is coherent and will also be supportive for the work of WP7 of the IRP project.**	
S8. OVERALL EVALUATION	0 1 2 (3)

Considering the above statements and the description of the work plan, I suggest that this mobility plan should pro in increasing the reliability level of the wind turbine blade as a stepping stone in the better understanding of mechanical behavior of Composite materials.

Andreas Makris
Research Engineer, CRES



Funded by EU

Application form for Mobility grants within IRPWIND

NOTE

- **All documents must be named as follows:**

Sub Programme letter, Scheme no., Surname, Document type. Ex: A_2_Smidt_cv See Table C) below.

- **The application must be max. 6 pages, ex tables, figures and references.**

A) Applicant details

Applicant Name	**Gerard**
Applicant Surname	**Schepers**
Home Institution	**ECN**
EERA/IRP Partner? *(yes/no)*	**Yes**
Home Institution Postal address	**P.O. Box 1, 1755 ZG Petten, Netherlands**
E-mail	**schepers@ecn.nl**

B) Host institution details

Institute name	**Carl Von Ossietzky Unversitaet, Forwind, Oldenburg**
EERA/IRP PARTNER?	**Yes**
Contact person	**Stephan Barth**
Country	**Germany**
E-mail	**stephan.barth@forwind.de**

C) Relevant Programme and scheme

CORE PROJECT? ***YES/NO*** ***(Please erase the non-relevant)***	**(A) Offshore Wind Energy**	**RELEVANT EERA SUB-PROGRAMME** **Max 2** **(Please erase the non-relevant)**	**(E) Aerodynamics**
Length of the grant scheme ***(Please erase the non-relevant length)***	**Scheme:** **1 month**	**Number of weeks: 4** **Start date:** **October 10, 2016**	

D. Project description

The application should take into account the following structure. Further sub-heading might be added.

TITLE OF THE PROJECT: 'Influence of turbulence inflow on airfoil characteristics'

1. Introduction

- Research topics, originality

Precise knowledge of the transition location on an airfoil of a rotating wind turbine blade is extremely important since it determines the airfoil characteristics (in particular the drag) and so the power and loads to a large extent. Airfoil data used in lifiting line wind turbine codes generally originate from wind tunnel measurements which are performed at very low turbulence levels. ECN has a long history in the development and application of these lifting line design codes and often questionned the usefulness of 'smooth' wind tunnel data for the calculation of the power because it is believed that the turbulent environment in which a wind turbine operates causes a significant forward shift of the transition point on the suction side
(the so-called "by-pass transition"), where moreover unsteady aerodynamic effects like dynamic stall may lead to important deviations from the smooth airfoil characteristics. Forwind has a unique facility to answer this question, i.e. a wind tunnel which, through a controllable active grid can generate a turbulent flow representative for wind turbine conditions. In this wind tunnel measurements been performed on a DU00-W-212 airfoil. These measurements were carried out in the AVATAR project, an EU FP7 project initiated by EERA. The aim of AVATAR is to improve and validate aerodynamic models for large

off-shore wind turbines . It is coordinated by ECN with Forwind as one of the participants. Within the present mobility project the Forwind measurements are analysed to asess the effect of turbulence on airfoil characteristics.

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

    - TRL level 2-4

- Definition of Key Performance Indicators (KPIs).

  The main outcome of the study is an assessment of turbulence on airfoil characteristic: Which differences in airfoil characteristics at turbulent conditions are observed compared to the situation at low turbulent conditions and how do the airfoil characteristics at the various turbulent conditions compare mutually?

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

  Precise knowledge of airfoil characteristics as used in wind turbine codes is a key subject of the EERA sub programme on aerodynamics. It is also a main subject of the EU project AVATAR as initiated by EERA.

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

Please consider that at least one of the partners should have a national project relevant to the proposal.

- Description of national projects from the receiving institution (please erase if not actual).

  1. DFWind and ProWind:
  The projects are connected and comprise the setup up of an onshore research facility of wind turbines. In the current phase the experiments are being planned, the measurement equipment is to be developed and test and the turbine tpes are to be chosen. The turbines are planned to be of state of the art commercial wind turbine type. This research facility will therefore be unique in the field of wind turbine research. A large emphasis of the research lies on the investigation on the wind field and the wind turbine aerodynamics. For this purpose sensors are to be developed, tested in the wind tunnel and the layout of the experiments are to be detailed.
  2. Smart Blades II
  This project is a follow-up of the smart blades project which finished in February. In this projects three different types of aerodynamic and aeroelastic improvments of wind turbines have been studied: Bend twist coupling, flexible trailing edges and leading edge slats. In the second part of the project, bend twist coupled blades developed in the project are to be build and tested. Also the other technologies are to be improved, tested in wind tunnels and raised in the TRL.

3. DFG – Project PAK 780 with the research part at the university of Oldenburg called “time resolved identification of aerodynamic extreme events and unsteady effects under turbulent inflow conditions”. It mainly consists of research based on wind tunnel measurements under various unsteady inflow conditions.

- Description of national projects from the sending institution (please erase if not actual).

  Several Dutch national projects have close links to the present mobility project, e,g, the D4Rel project: http://www.d4rel.nl/ aims, amongst others, at the development of more accurate aerodynamic models for off-shore wind turbines.

- Foreseen European added value of national alignment.

  This project brings together key expertises of the host and sending institute: Atmospheric turbulence is one of Forwind’s key expertises where aerodynamics is one of ECN’s key expertises. Merging these key expertises makes it possible to assess the influence of atmospheric turbulence on airfoil characteristics.

- Description of host institute, e.g. infrastructure, experience etc.

  The university of Oldenburg has 30 year experience in wind energy research. Since 2004 these activities are carried out within the ForWind as a center for wind energy research together with the University of Hannover and Bremen (as of 2009). Furthermore ForWind, the German Aerospace Center DLR and Fraunhofer IWES form the German Wind Energy Alliance, a close cooperation with access to large and unique wind energy research infrastructure and HR resources. In Oldenburg, ForWind is part of the institute of physics. Due to this the main research focus is on the physics of the wind and the resulting forces. A special emphasis has been put on experimental research on turbulence. For this purpose a wind tunnel has been extended by fractal and active grids to generate turbulence characteristics measured in actual wind fields. In September 2016 ForWind will inaugurate a new large turbulence wind tunnel. ForWind operates its own HPC for massive CFD computations and is currently in the process of renewing and extending its computer clusters by means of 3 million € national funding. Forwind collaborates with ECN in several projects, e.g. the EU FP7 project AVATAR and IEA Task 29. In both projects the influence of turbulence on airfoil characteristics is one of the key research subjects. The already existing collaboration between Forwind and ECN will be strengthened further through the present exchange.

3. Work plan

The project aim is to improve the understanding of boundary layer processes at turbulent conditions. This holds in particular for the effect of turbulence on boundary layer transition and dynamic stall. Thereto the airfoil measurements taken by Forwind in their wind tunnel at various turbulent conditions are compared and analyzed. The conclusions drawn on the effect of turbulence will be reported at the end of the exchange period. This report will form the main deliverable and milestone.

4. Benefits to EERA objective advancement

- Contribution to the advancement of the EERA strategy goals, gaps addressed.

  The following research topics of the EERA SP aerodynamics are addressed

  - Improved engineering inflow wind field modelling to be used as input for aerodynamic design and aero-elastic simulations.
  - Improved aerodynamic design modelling including rotational effects, dynamic inflow, **transition**, turbulence structures, **unsteadiness and dynamic stall**, distributed control, variable geometries etc
  - Improving the design process of wind turbines by developing new, improved models, concepts and tools for the aerodynamic interaction with respect to the integrated system design.

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

- Explain ToK or dissemination strategies and plan of future collaboration with other IRP/EERA partners.

  The measurements considered in this mobility program are taken in the AVATAR project and distributed between the partners of that project for further analysis. The present study forms an additional contribution to these analyses. The Forwind airfoil measurements and the analyses on them (including the present one) are important discussion topics between the AVATAR partners at the project progress meetings and they are included in the AVATAR dissemination strategy which aims to disseminate results by means of presentations at conferences, papers and journal articles. Eventually the measurements will be made public by uploading them on the WindBench site which is a key dissemination platform of both IRPWIND and AVATAR.

6. Expected results

- Methodologies and/or databases and/or best practices functional to the activities of the IRP and EERA strategic agenda objectives.

  A report will be made which establishes the influence of turbulence on airfoil characteristics. The data considered in this project will be added to the AVATAR database which is uploaded on the AVATAR website and the WindBench platform

- Assessment of the advancement of the TRL.

  The TRL level is expected to remain on the same level as this is a small project in the long process of establishing more accurate aerodynamic models. Still if forms an essential contribution to reach a next TRL level in aerodynamic modelling.

- Assessment of the KPIs.

The KPI will be measured in a progress meeting of the AVATAR project where the effects from turbulence on airfoil characteristics is assessed

Mobility Call N°:	OPEN
Mobility scheme:	1-4 weeks
Home Institution:	**ECN**

Evaluation[1]

S1. EXCELLENCE	3
Observations: The proposed research topics deal with critical aspects of wind turbines rotor aerodynamics modelling. The quality of knowledge sharing and of interaction between the participant organizations is clearly described as well as the innovative aspects of the research that will improve the insight into turbulence effects on wind turbines airfoil characteristics.	
S2. IMPACT	2
Observations: The project addresses the issue of the influence of turbulence inflow on airfoil characteristics measured in wind tunnels. The Applicant points out that this topics has already been addressed in the EU-FP7 Project AVATAR, in which both the home and host institution are fully involved. In details, this mobility project seems to be focused on the analysis of airfoil measurements already carried out in the AVATAR Project. Thus the Reviewer expects that such analysis has been (at least partly) addressed in the AVATAR Project. The applicant should clarify this point to underline the enhancements he is willing to achieve with respect to the AVATAR Project outcomes. The delivery of a publicly available report on the influence of turbulence on airfoil characteristics would give the project relevant added value for codes validation and models development. I suggest that this report should be at least available to EERA partners. The applicant should clarify this aspect.	
S3. IMPLEMENTATION	1
Observations: The Project implementation should be described with more technical details in order to judge the overall coherence and effectiveness of the work plan, including appropriateness of the allocation of tasks and resources. The work plan simply describes a single task in which the measurements already achieved in a EU-FP7 Project will be compared and analysed. The Applicant should provide more details on measured quantities as well as on the numerical/experimental techniques used for data processing. The grade gained on this aspect could then be enhanced. Competences, experience and complementarity of the participating organisations and institutional commitment are fully documented and of excellent quality.	

S4. OVERALL EVALUATION	2

Suggestion?

The proposed Project is very interesting in the framework of airfoil aerodynamics modelling for the application within wind turbines analysis tools. Moreover, the Applicant CV is fully adequate to finalize the proposed activity with a clear indication of research quality and credibility.
The Reviewer suggest to enhance the technical description of the work plan to achieve a higher overall evaluation.

Mobility Call N°:	OPEN
Mobility scheme:	1-4 weeks
Home Institution:	**ECN**

Evaluation[2]

S1. EXCELLENCE	3
Observations: - Quantifying the impact of flow turbulence on airfoil aerodynamics is a very interesting research topic - Gerard Schepers is the right person to bring ECN knowledge on airfoil aerodynamics in this project - Forwind is the right place to go as it is where the measurements were performed	
S2. IMPACT	2
Observations: - I doubt that this project will develop new collaboration but it will for sure reinforce the collaboration between ECN and Forwind. - The results will be well shared to the community through the AVATAR projects and publications	
S3. IMPLEMENTATION	3
Observations: - Gerard Schepers is a very experienced researcher. - The KPI and deliverable are coherent with the time allocated to the project.	
S4. OVERALL EVALUATION	3

Suggestion?
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Funded by EU

Application form for mobility grants within IRPWind

A) Applicant details

Applicant Name	**Til Kristian**
Applicant Surname	**Vrana**
Home Institution	**Sintef Energi**
EERA/IRP Partner?	**Yes**
Home Institution Postal address	**Sintef Energi, Postboks 4761 Sluppen 7465 Trondheim, Norway**
E-mail	**vrana@sintef.no**

B) Host institution details

Institute name	**ECN**
EERA/IRP PARTNER?	**Yes**
Contact person	**Edwin Jan Wiggelinkhuizen**
Country	**Nederland**
E-mail	**wiggelinkhuizen@ecn.nl**

C) Relevant Programme and scheme

CORE PROJECT? YES	(B) Wind Integration	**RELEVANT EERA SUB-PROGRAMME**	(A) Offshore Wind Energy (B) Wind Integration
Length of the grant scheme	**Scheme:** **(02) 4-26 weeks**	**Number of weeks:** **Start date:**	**9** **2016-11-01**

D. Project description

Investment Cost Parameters for Transmission Planning Studies for Offshore Wind Integration

1. Introduction

Research topics, originality

The grid connection for remote offshore wind power plants is expensive, and accounts for a relevant part of the levelised cost of energy from offshore wind. It is therefore of high importance to study all aspects of different offshore transmission options regarding different future scenarios. To find the optimal topology of a future electricity network for offshore wind integration in the North Sea, a variety of planning studies have been performed.

A major obstacle for such offshore grid planning studies are the involved uncertainties. As regarding the uncertainty of future offshore wind power plant constructions, this can be covered by addressing a set of different scenarios. But also the uncertainty of the input data, especially the cost data for VSC HVDC transmission systems is a major problem. VSC HVDC technology has advanced tremendously in the past decade, making it a challenging task to forecast the capabilities and costs in the future. Several offshore transmission systems in the German part of the North Sea have seen cost overruns, indicating the difficulty to forecast the cost. However, the used cost model and the estimated cost parameters for the transmission infrastructure can have a significant influence on the results of such offshore grid planning studies. Comparing different past studies reveals large variations in the cost assumptions, leading to validity concern regarding the results. It is therefore highly important to focus on the cost estimates.

Technological Readiness Level (TRL) of the proposed concept

TRL scale is difficult to apply here, because it is not a technology itself in focus, but rather the deployment cost of that technology. Offshore VSC HVDC transmission systems are TRL 8-9. Offshore wind integration optimisation studies are TRL 2-3.

Definition of Key Performance Indicators (KPIs)

The proposed exchange aims to contribute to following IRPWind KPIs:

- Number of projects that cooperate actively and that exchange knowledge with IRPWind.
- Number of joint publications by IRPWind participants.
- Number of researchers and reports from these researchers involved in mobility programmes.
- Number of days of mobility and exchange.
- Number of dissemination events related to the participation in the exchange programmes.

Description of links to relevant EERA Sub Programmes (SP) and/or IRPWind Core Projects (CP):

Sintef and ECN are partners in the IRPWind project, and also in other projects, where NSON (North Sea Offshore Network) is especially relevant in this context. The activities planned during the research visit are based on WP83, where Sintef is directly involved but ECN is not (ECN is WP82). However, the subject matter of WP83 is highly relevant for ECN as well, which works on similar topics within other projects than IRPWind.

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

Description of national projects from the receiving institution

- Synergies at Sea (TKI-WindOpZee): Technical, economical and regulatory feasibility study and design of an interconnection between the UK and Dutch grids through offshore wind farms.
- Strategies towards an Efficient North Sea Energy Infrastructure "SENSEI" (NOGEPA): Study of system integration options and development strategies for system integration between offshore wind farms and oil & gas infrastructure at the Dutch part of the North Sea
- ISSWind (ESA-ARTES): development of services on resource assessment, power forecasting and O&M using satellite data.
- Harmonics in offshore wind farms (EZS-Innovation): modelling of interactions and mitigating measures

Description of national projects from the sending institution

- NOWITECH. The objective of NOWITECH is pre-competitive research laying a foundation for industrial value creation and cost-effective offshore wind farms. Emphasis is on "deep-sea" (+30 m) including bottom-fixed and floating wind turbines.
- NSON. The aim of this project is the analysis and evaluation of different market and network options for the North Sea with regard to their impact on the European electric power system. The cases considered include the connection of different synchronous areas, the planning and operation of meshed Multi-Terminal High Voltage Direct Current (HVDC) networks, the integration of new offshore storage concepts. ECN is also part of NSON and takes part in NSON proposals.

Foreseen European added value of national alignment.

The Norwegian hydropower based electricity system has good power balancing abilities. The large-scale implementation of wind power in Europe creates an increasing need for balancing resources. Norway has therefore often been considered as the future "green battery" of Europe. This European approach to power balancing offers significant advantages (e.g. highlighted by the e-Highway project).

However, such a European approach requires good coordination and alignment on a European scale. The Netherlands have progressive future plans for offshore wind energy in the North Sea. Both Norway and the Netherlands will therefore be among the countries who build the future electricity network in the North Sea.

The research visit will improve the coordination of IRPWind WP83 activities with other related projects like NSON, leading to better and more natural collaboration than possibly only by email and telephone meetings. This will lead to more efficient and fruitful cooperation between Sintef and ECN, which will benefit IRPWind WP83. In addition to the direct benefits for the IRPWind work, the knowledge exchange will be generally valuable for both sides, have positive effects on related projects at both institutes.

Description of the host institute: e.g. infrastructure, experience etc.

ECN is the largest research centre in the Netherlands in the field of energy and holds a strong international position in the field of wind energy technology. The unit ECN Wind Energy develops knowledge and technology for offshore wind energy. The research program consists of activities on wind turbines and offshore wind farm aerodynamics and control design, installation operation & maintenance and grid integration. A measurement & experiment group, which is ISO 17025 accredited, forms part of the unit. ECN has its own wind turbine test site with five full-scale 2.5MW wind turbines for experimental research. ECN has developed its models and tools in many national and international projects and its knowledge is extensively applied in industrial projects.

3. Work plan

At ECN, Til Kristian Vrana will have the opportunity to increase his knowledge and experience on the economic aspects of offshore wind power plants and their grid integration infrastructure. He will contribute to ECN providing know how on the technical details on HVDC technology and of VSC HVDC transmission systems which are in operation or under construction.

The plan is to address the following points:

- Collecting cost data estimations on different technical solutions for integrating remote offshore wind power plants
- Comparing the different data
- Collecting published cost figures from real VSC HVDC projects
- Evaluating the cost estimates against the data from real projects
- Assess how and to what extend the gathered knowledge can lead to better cost estimates
- Develop cost estimations that are based on all the gathered information
- Assess how these improved cost estimation influence the techno-economical optimal grid integration solutions for remote offshore wind power plants in the North Sea

4. Benefits to EERA objective advancement

The research visit of Til Kristian Vrana at ECN will contribute to the advancement of the EERA strategy goals on aligning European research on wind integration and on performing coordinated research. Moreover, after the mobility period, continuous interaction among the centres for further developing joint research will ensure further advancement on reaching such goals.

The research to be done during the research visit is well aligned with several research objectives within EERA JP Wind. The work deals with the Research Themes from the sub-programme Grid Integration:

- RT2: Grid planning and operation
- RT3: Wind energy and power management

The work relates also to the Research Themes from the sub-programme Offshore wind Energy:

- RT 3: Numerical tools for offshore grid and wind farm electric design

The research is also well aligned with the newly released Strategic Research and Innovation Agenda 2016 by ETIP-Wind:

- Section 1.3.a: Offshore grid design

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

The work developed will contribute to IRPWind project objectives, specifically WP83. The results will be disseminated in the deliverables of WP83. Specific results of special relevance are to be additionally disseminated in joint publications under the regime of IRPWind and EERA JP Wind SP Grid Integration. A presentation will be given at ECN to disseminate the outputs and results of the research visit and to discuss how to keep the link beyond the research visit.

6. Expected results

The results expected are :

- Specific results described in the DoW of IRPwind WP83
- At least one joint research article
- Ideas for future collaboration and joint project proposals

Mobility Call N°: **Mobility scheme:** **Home Institution:**	Open CALL 4-26 weeks **SINTEF**

Evaluation[1]

S1. EXCELLENCE	2.5
Observations: I rate excellence as very high as the proposed research is highly relevant and could certainly have significant impact in the industry practices for planning of HVDC offshore transmission for wind applications. The novelty is a bit harder to judge as there are no details on the methods to be adopted/pursued. Both, sending and host institutions have solid knowledge in the area and I am confident the stay will be productive and successful.	
S2. IMPACT	2
Observations: The proposed work is necessary to provide industry insight into cost associated with VSC-HVDC connections. It is clear that a good understanding on these aspects will be very welcome and I anticipate a significant impact. I am rating this as 2 as the applicant is not giving details on how HVDC manufacturers will be involved or approached.	
S3. IMPLEMENTATION	2.5
Observations: The plan is credible (perhaps a bit ambitious) and doable. I trust the candidate will interact with industry and have their guidance to some extent in terms of the various activities planned.	
S4. OVERALL EVALUATION	2.5

Suggestion?
The proposed work is very relevant and the activities are well designed. My olny comment to the applicant is to make sure the relevant industry is involved as convenient and possible. I certainly support Til Kristian stay at ECN.

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Mobility Call N°: **Mobility scheme:** **Home Institution:**	Open CALL 4-26 weeks **SINTEF**

Evaluation[2]

S5. EXCELLENCE	0 1 2 3
Observations: Descriptive proposal. The mobility action is in line with the IRPWIND activities in WP8 (8.2, 8.3) and in line with the SRA of the sub-programme Wind Energy Integration: 3	
S6. IMPACT	0 1 2 3
Observations: The action, foreseen in frame of the mobility action has valuable impact on the progress of the R&D topics of IRPWIND WP8 and the SP: 3	
S7. IMPLEMENTATION	0 1 2 3
Observations: In addition to the report, the applicant is invited to present the results of the work on one of the upcoming workshops of the sub-program Grid Integration. 2	
S8. OVERALL EVALUATION: 3	0 1 2 3

Suggestion?
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