Final Management Report

IEA Wind Task 23

Offshore Wind Technology and Deployment

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Preface

This Final Task Management Report completes the obligations of the operating agents to "summarize Task or Working Group accomplishments and lessons learned at the end of a Task." This report is intended for the IEA Wind Executive Committee, Task participants, and the IEA secretariat in Paris.

The final technical report for IEA Wind Task 23, Offshore Wind Energy Technology and Deployment, is made up of two separate reports*: Subtask 1: Experience with Critical Deployment Issues* and *Subtask 2: Offshore Code Comparison Collaborative (OC3).* The Subtask 1 report provides background information and objectives of Task 23. It specifically discusses ecological issues and regulation, electrical system integration and offshore wind, external conditions, and key conclusions for Subtask 1. The Subtask 2 report covers OC3 background information and objectives of the task, OC3 benchmark exercises of aero-elastic offshore wind turbine codes, monopile modeling, tripod modeling, and floating spar buoy modeling.

Recognizing the interest and challenges of offshore development of wind energy, IEA Wind Task 11 Base Technology Information Exchange sponsored a Topical Expert Meeting (TEM 43) in early 2004 in Denmark on Critical Issues Regarding Offshore Technology and Deployment. The meeting gathered 18 participants representing Denmark, Finland, the Netherlands, Sweden, the United Kingdom, and the United States. Presentations covered both detailed research topics and more general descriptions of current situations in the countries. After the meeting, the IEA Wind ExCo approved Annex 23 (Task 23) to the Implementing Agreement as a framework for holding additional focused workshops and developing research projects. The work would increase understanding of issues and develop technologies to advance the development of wind energy systems offshore. In 2008, 10 countries had chosen to participate in this task, and many research organizations in these countries are sharing their experiences and conducting the work (Table 1).

Table 1. IEA Wind Task 23 Participants in 2008

Country	Participants
Denmark	Danish Energy Agency/Risø DTU (OA)
Germany	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Republic of Korea	Government of Korea/ KEMCO
The Netherlands	We@Sea
Norway	Norwegian Water Resources and Energy Directorate
Portugal	INETI
Spain	CENER
Sweden	Chalmers University Goteborg
United Kingdom	Department for Business, Enterprise & Regulatory Reform
United States	U.S. Department of Energy / NREL (OA)

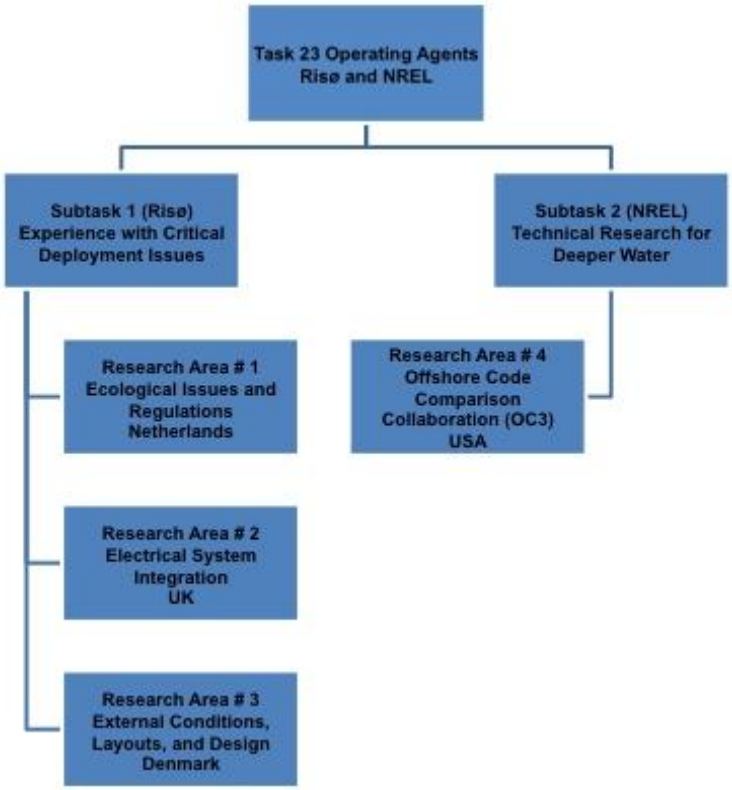

Figure 1. Organization of Task 23 Offshore Wind Energy Technology and Deployment

This annex was organized into two subtasks to (1) give the participants experience with critical deployment issues and (2) conduct technical research for deeper water applications. The results of this work are presented in the supporting two volumes of the technical report and this Final Task Management Report.

Contents

Executive Summary of IEA Wind Task 23 management report

When the work of this task began, in May 2004, offshore activities were just beginning in a few countries. The operating agents funded the work of the first year to gather participants together and formulate the further activities of the two subtasks. This approach allowed many countries to participate in the first year and begin thinking about offshore wind development. Workshops for Subtask 2 were held beginning in October 2004. Subtask 1 held its first workshop in September 2005.

In May 2005, the common fund was established and ten countries officially joined. The fund was managed at Risø, which conducted the invoicing and collected fees. NREL invoiced Risø for its share of the operating funds. It was estimated that the budgeted costs represent approximately 70% of the actual costs to the operating agents, which were provided as in-kind participation. Organizations within the countries that joined could participate in any of the workshops and in the research activities of Subtask 2 OC3.

The management of Subtask 1 involved arranging workshops and the disseminating the results from these workshops through the website. In cooperation with the OA of Subtask 2, results were reported to the IEA Wind ExCo and annual meetings were held.

The management of the funds has been carried out successfully. The objectives with the workshops have however not been fully achieved due to change of personal at Risø DTU and struggles with communications with lead countries. Fewer workshops held than expected and the hoped for new research tasks were not formulated. The workshops that were carried out were successful according to participant comments.

The scope of OC3 has greatly exceeded what was originally planned for Subtask 2. Due to a lack of time and resources, the reporting of the project's status and results to IEA Wind was given a much lower priority than ensuring a successful project.

The model with shared OA management and several un-funded lead countries within the subtask has in some situations not turned out to be optimal. If similar structures are selected in the future it is recommended that a clearer commitment is secured from institutions or persons agreeing to take a lead on work. Whether this implies funds supplied by participating countries (which then need to be bigger) or though additional national funds should be discussed by the ExCo.

In some cases it was unclear who the participants were and which of these was paying the fees. It is recommended that the responsible participant should be the contracting party to the IEA Wind agreement. If responsibility is transferred by the contracting party to a national institute or company this should be done with signed commitment letters according to IEA guidelines that are sent also to the OA. This formality is especially important in cases where more than one institute from one country can participate for only one fee.

The presentation of the results to the ExCo achieved during the project time has mostly been done by the OA for Sub 1. It is recommend for future IEA Wind projects that the requirements of reporting to the IEA Wind ExCo are clearly stated to the perspective OA and suitable funding is allotted to ensure the reporting requirements are met successfully.

The spilt management and defined lead countries was supposed to support countries who wished to start activities within a new sector (offshore wind). If future tasks pursue the same model, attention should be made to the recommendations mention above.

1 Objectives

The objectives of this annex as outlines in the annex text are:

a) To conduct R&D activities of common interest relating to wind turbine facilities operating in offshore environments in order to reduce costs and uncertainties.
b) To identify a number of joint research tasks among interested countries based upon the broad range of issues identified at the Technical Experts Meeting #43 on Critical Issues Regarding Offshore Technology and Deployment, (see Appendix 1 and description in Section 3).
c) Organize several workshops relating to critical research areas relating to offshore wind deployment issues, including technical research on deeper water structures. The goal of the workshops is to identify R&D gaps in various research areas that are of interest to participating countries, publish proceedings, and identify specific joint research areas needing further investigation
d) In year one of the Annex, identify interested participants, project leads for each research area, and prepare separate Work Programmes and Budgets for each collaborative research areas.

The results expected were:
a) Published Technical Proceedings from the workshops. In addition, the results will be presented at various national and international conferences and the IEA Wind Executive Committee meetings.
b) Defined innovative collaborative research objectives under each Subtask.
c) Results from the collaborative research efforts, identified after the workshops, will be specified in their Work Programmes (the results will be coordinated by the project leads and one of the Operating Agents after year one).

1.1 Objectives of Subtask 1

The aim of Subtask 1 is to support offshore wind development by maintaining an overview of research activities with relevance to offshore wind energy by arranging workshops where participants will inspire each other and test research results in order to improve results. These workshops will make research results available to decision makers in order to pave the way for new capacity. Five issues identified in the annex text were consolidated into the following three research areas:

Research Area 1: Ecological Issues and Regulations. Goal:

- Provide a state-of-the-art overview of the knowledge of impacts of offshore wind turbine systems on the marine environment.
- Assess the consequences of regulatory frameworks, such as requirements for Environmental Impact Assessments (EIA's) and protection measures for nature reserve areas.
- Generate ideas for frameworks on how results of nature research can be used to (re)formulate regulations and legislation.
- Publish the conclusions and recommendations to stimulate both national research and policy developments and future IEA Wind activities.

Research Area 2: Electric System Integration. Goal:
At the first workshop, it was decided to concentrate on technical issues concerning the grid connections of the offshore wind farms, and the five critical issues included in the next workshops on grid integration were.

- Offshore wind meteorology and impact on power fluctuations and wind forecasting
- Behavior and modeling of high-voltage cable systems
- Grid Code and security standards for offshore versus onshore
- Control and communication systems of large offshore wind farms
- Technical architecture of offshore grid systems and enabling technologies.

A working group with representatives from Denmark, Germany, Sweden, and the UK, drafted a work program for the next 3 years which was circulated to the participants in the workshop. The following set up was decided for the program:

- Each participant must supply information from at least one national project
- The national projects should have a volume of above 100,000 Euro or 1 person-year during the period.
- Information and results from the national projects must be delivered to the OA and allowed in the final IEA report.
- Information on the project should include title, purpose of the project (5-10 line description), project period, economic volume and the total effort (person-month)
- Three workshops would be arranged in 2007 – 2008 in the UK, Denmark, and the Netherlands
- An overview of results from national projects and the results of the discussions would be published as a Task 23 report.

Research Area 3: External Conditions, Layouts, and Design of Offshore Wind Farms.
Goal:

- Exchange, validate, and evaluate wind resource data and wind maps specific to regions with high potential for wind development.
- Share databases and innovations to enhance measurement accuracy of marine buoys pertaining to long-term sea-state and MET-Ocean data.
- Exchange technical information of wave loading prediction methods and validation experience of wave loading on wind turbine structures.
- Share experience with long-term measurement techniques and instrumentation at offshore stations.
- Evaluate various turbine array configurations in large, closely spaced farms and examine critical parameters such as mutual shadow wake effects, affect on energy production, fatigue, and ultimate loading.
- Exchange technical experience with offshore forecasting to predict wind plant output.

Operation and maintenance was a high priority topic but no plans were made to hold a workshop on this topic. A task force to work on grid integration guided the design of workshops and collaborated with IEA Wind Task 25, Power Systems with Large Amounts of Wind Power. A subtask was proposed to characterize the marine boundary layer, but it never materialized.

1.2 Objectives of Subtask 2

The first workshop organized under Subtask 2 identified verification of offshore wind turbine dynamics models as a topic of utmost importance and mutual interest among the workshop's

participants. A follow workshop was held, where the topic of model verification was further explored and where a plan was developed to refocus Subtask 2 into a working group for model verification—not just for deepwater offshore wind turbines, but for shallow- and transitional-depth support structures as well. In the end, Subtask 2 became what is now known as the Offshore Code Comparison Collaboration (OC3) project.

Wind turbines are designed and analyzed using simulation tools (i.e., design codes) capable of predicting the coupled dynamic loads and responses of the system. Land-based wind turbine analysis relies on the use of aero-servo-elastic codes, which incorporate wind-inflow, aerodynamic (aero), control system (servo), and structural-dynamic (elastic) models in the time domain in a coupled simulation environment. In recent years, some of these codes have been expanded to include the additional dynamics pertinent to offshore installations, including the incident waves, sea current, hydrodynamics, and foundation dynamics of the support structure. The sophistication of these aero-hydro-servo-elastic codes, and the limited data available with which to validate them, underscore the need to verify their accuracy and correctness. The OC3 project was established to meet this need.

To test the newly developed codes, the main activities of OC3 were (1) discussing modeling strategies, (2) developing a suite of benchmark models and simulations, (3) running the simulations and processing the simulation results, and (4) comparing and discussing the results. These activities fell under the much broader objectives of

- Assessing the accuracy and reliability of simulations to establish confidence in their predictive capabilities
- Training new analysts how to run and apply the codes correctly
- Identifying and verifying the capabilities and limitations of implemented theories
- Investigating and refining applied analysis methodologies
- Identifying further research and development (R&D) needs.

To encompass the variety of support structures required for cost-effectiveness at varying offshore sites, different types of support structures (for the same wind turbine) were investigated in separate phases of the OC3 project.

- Phase I, simulated the NREL offshore 5-MW wind turbine model installed on a monopile with a rigid foundation in 20 m of water.
- In Phase II, the foundation of the monopile from Phase I was made flexible by applying different models to represent the soil-pile interactions.
- In Phase III, the water depth was changed to 45 m and the monopile was swapped with a tripod substructure, which is one of the common space-frame concepts proposed for offshore installations in water of intermediate depth.
- In Phase IV, the wind turbine was installed on a floating spar-buoy in deep water (320 m).

Code predictions were compared from load-case simulations selected to test different model features. The comparisons have resulted in a greater understanding of offshore floating wind turbine dynamics and modeling techniques, and better knowledge of the validity of various approximations.

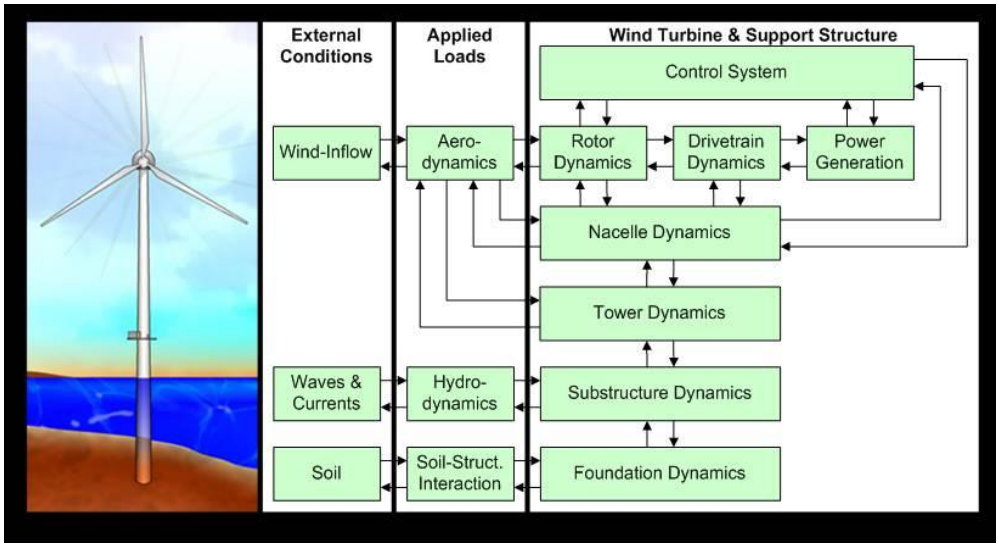

Figure 2. Codes must be verified to assess their accuracy

2 Review of Cooperative Activities

2.1 Effectiveness of national participation

Subtask 1

Although no official research efforts on the discussed critical issues under Task 23 Subtask 1 were begun, the workshops helped the participating experts with a better understanding of the needed content for future national, corporate, and institutional research programs. The workshops were well attended and the invited experts included representatives from wind turbine manufacturers and developers; utility planning, grid operators, and regulatory bodies; national research institutes; engineering and design consultants; environmental planning and regulatory bodies; universities; and wind plant operators.

It is the impression of the OA that even though a lot of experts participated the level of involvement of key persons from the lead countries could have been higher. The subtask has struggled to set up and define new cooperative research work as intended due to changes in assignments of the persons from lead countries at the beginning of the task, postponing of planned workshops, and lack of time of the needed key experts. Also the OA suffered changes in personal, making it more difficult than necessary to manage the subtask consistently.

Subtask 2

The OC3 project was performed through technical exchange among a group of international participants who came from universities, research institutions, and industry across Denmark, Germany, Korea, Norway, Spain, Sweden, the United Kingdom, and the United States. Most of the aero-hydro-servo-elastic codes that have been developed for modeling the dynamic response of offshore wind turbines were tested within OC3.

The OA of Subtask 2 tried to be as open as possible to involve all interested parties in the project. The OA feels that the national participation was excellent in both scope and depth, given

that international funding was not available to cover the labor and travel costs incurred by the project participants. While those participants directly involved in developing dynamics codes and submitting simulation results were those that most directly benefited from the project, the OA has heard numerous complements regarding the benefits of the project results from both observers who participated in meetings but did not submit results and from those who only followed the results through conference presentations and proceedings.

Most notably absent from participation in Subtask 2 was the Netherlands, who have developed dynamics codes within ECN, WMC, and TU-Delft, but did not participate in the project. These groups have interest in participating in the Task 30 follow-on project.

2.2 Participation of Industry

Subtask 1

Table 2. Industry participation in Subtask 1

Organization/Country
ABB/Sweden
ABB/UK
Airtricity/UK
Areva/UK
AWS/USA
Blue H Technol/Netherlands
Centrica Energy/UK
DEWI/Denmark
DHI/Denmark
DONG Energy Power/Denmark
Ecofys/Evelop/Netherlands
Ecofys/Germany
Econnect/UK
Elsam Engineering A/S/Denmark
Energetics/USA
Energinet/Denmark
EON/UK
Frazer-Nash Consultancy/UK
Garrad Hassan/UK
GE Global Research/Germany
GE Infrastructure/USA
IMARES/Netherlands
ISAC-CNR/Italy
National Grid/UK
Ofgem/UK
Ramboll/Denmark
Renewable Energy Systems Ltd/UK
RWE/UK
Siemens/Denmark
Siemens/UK
Sintef/Norway
Statoil/Hydro/Norway
Sunpower Renewables/USA
SWE Stuttgart/Germany

Tallisman Energy/UK
TNEI Services Ltd/UK
TU Delft/We@Sea/Netherlands
Vattenfall Vindkraft AB/Sweden
Vattenfall/Denmark
Vestas Offshore A/S/Denmark
Wea@Sea/Netherlands
WindSim/Norway

Subtask 2

Full participation: Full participation was open to all organizations in member countries of the IEA Executive Committee. Those who were actively involved with model development and load prediction could take part as full participants. Full participants participated in all meetings and exchanged information by email, net-conferencing and telecoms throughout the project. They decided the details of the project, presented on their modeling approaches, submitted simulation results, and took part in writing the conference papers, and final report.

Observers Status: There were members whose inputs were valuable but who were not actively engaged in modeling. There also were experts who were impacted by load predictions and benefited from knowing the results of the comparisons. Some of these experts were responsible for assessing risk for their companies. First hand observations of the results raised their confidence in load predictions. They added suggestions for comparisons and provide customer perspectives. Observers were invited to review the project plan and participate in meetings to discuss results.

Table 3. Industry participation in Subtask 2

Status	Organization/Country
Observer	ABS Consulting/USA
Full	Acciona/Spain
Observer	APiA XXI/Spain
Observer	CarlBro/Denmark
Full	CENER/Spain
Observer	Conwind/Denmark
Full	DNV/Denmark
Full	DONG Energy/Denmark
Full	Fraunhofer IWES/Germany
Full	Garrad Hassan/UK
Observer	GL/Germany
Full	IFE/Norway
Observer	INHA/Korea
Observer	KIER/Korea
Observer	KIMM/Korea
Observer	LAC/Denmark
Full	Marintek/Norway
Observer	MI&T/USA
Observer	MIT/USA
Full	NREL/USA
Full	NTNU/Norway
Observer	OWEC Tower/Norway
Full	POSTECH/Korea
Observer	PPI/USA
Full	Ramboll/Denmark
Observer	REpower/Germany
Full	Risø DTU/Denmark
Full	Siemens/Denmark
Observer	Statoil/Norway
Observer	Teknikgruppen/Sweden
Full	UMB/Norway
Full	University of Hannover/Germany
Full	USTUTT/Germany
Full	Vestas/Denmark
Observer	Vestas/The Netherlands

2.3 List of participating experts

The password protected web page is only available to Task 23 participants who sent letters of commitment. The announcement of this benefit and restriction helped many countries complete the process of submitting letters of commitment to the task. Participation in any part of the annex entitles the participating countries to all the parts of the annex.

Subtask 1

Table 4. Expert participation in Subtask 1

Last name	First name	Affiliation/Country
Aagaard Madsen	Helge	Risø DTU/Denmark
Alfred	Alex Schroeder	Institute for Polar and Marine Science/Germany
Allen Johansen	Nick	Risø DTU/Denmark
Anaya-Lara	Olimpo	University of Strachlyde/UK
Anton	Francois	DTU IMM/Denmark
Antoniou	Ioannis	Siemens/Denmark
Axelsson	Urban	Vattenfall/Sweden
Badger	Jake	Risø/Denmark
Baker	Phil	DTI/UK
Barthelmie	Rebecca	Indiana University/USA
Bazargan	Masoud	Areva/UK
Belloni	Clarissa	GE Global Research/Germany
Bergdahl	Lars	Chalmers/Sweden
Beurskens	Jos	ECN/Netherlands
Brand	A.J.	ECN/Netherlands
Bro	Carl	Elsam/Denmark
Brower	Michael	AWS/USA
Burges	Karstem	Ecofys/Germany
Butterfield	Sandy	NREL/USA
Byrkjedal	Øyvind	Statoil/Hydro/Norway
Carlson	Ola	Chalmers/Sweden
Carstens	Henrick	Ramboll/Denmark
Carter	Mike	Sunpower Renewables/USA
Christiansen	Merete Bruun	Risø/Denmark
Clausen	Niels Erik	Risø DTU/Denmark
Cleve	Jochen	Siemens/Denmark
Cooke	Richard	Areva/UK
Crasto	Georgio	WindSim/Norway
Cutululis	Nicolaos	Risø DTU/Denmark
Dahlberg	den Jan-Åke	Vattenfall Vindkraft AB/Sweden
Dale	Lewis	National Grid/UK
Dam	Jan	Ecofys/Evelop/Netherlands
Dimitrov	Nikolay	Siemens/Denmark
Djapic	Predrag	Imperial College/UK
Dobschinski	Jan	ISET/Germany
Downey	Raymond	Elsam Engineering A/S/Denmark
Draxl	Caroline	Risø DTU/Denmark
Duddy	Joe	Renewable Energy Systems/UK
Duden	Heinrich	Blue H Technol/Netherlands
Elkinton	Chris	University of Massachusetts at Amherst/USA
Enevoldsen	Peder	Siemens/UK
Frandsen	Sten	Risø-DTU/Denmark
Ghulmi Hanany	Hasan	DONG Energy Power/Denmark
Gravesen	Helge	Elsam/Denmark
Gribben	Brian	Frazer-Nash Consultancy/UK
Grip	Kjell	Swedish Environmental Protection Agency/Sweden
Habenicht	Gerd	Renewable Energy Systems Ltd/UK
Hair	Richard	EON/UK
Hamzah	Ham	RWE/UK
Harkema	Sjoerd	Commissie MER/Netherlands

Havsager	Jan	Energinet/Denmark
Higgins	Charlotte	TNEI Services Ltd/UK
Hoffman	Steganie	BMU/Denmark
Jeffs	Laura	Centrica Energy/UK
Jenkins	Nick	University of Manchester/UK
Jensen	Leo Enrico	Elsam/Denmark
Johansen	Niels Jacob	Risø/Denmark
Jones	Peter	ABB/UK
Jonkman	Jason	NREL/USA
Kapper	Robert	Vattenfall/Sweden
Karlsen	Elly	Statoil/Hydro/Norway
Karlsruhe	Forschungszentrum	DEWI/Germany
Knight	Matthew	Siemens/UK
Kogaki	Tetsuya	AIST/Japan
Krone	Roland	Institute for Polar and Marine Science/Germany
Küehn	Martin	SWE Stuttgart/Germany
Landberg	Lars	Risø/Denmark
Larsen	Jesper Kyed	Vattenfall/Denmark
Larsen	Gunner	Risø DTU/Denmark
Le	Nina	DONG Energy Power/Denmark
Leegaard Thomsen	Christian	Vestas Offshore A/S/Denmark
Lemming	Jorgen	Risø/Denmark
Leopold	Mardik	IMARES/Netherlands
Lindeboom	Han	IMARES/Netherlands
Lindgren	Michael	Vattenfall/Sweden
Longden	Robert	Airtricity/UK
MacAskill	Allan	Tallisman Energy/UK
Macleod	Norman	Areva/UK
Martinez	Daniel Cabezon	CENER/Spain
Mast	Eeke	TU Delft/We@Sea/Netherlands
Mikkelsen	Robert	DTU/Denmark
Mittendorf	Kim	University of Hannover/Germany
Morgan	Bridget	Ofgem/UK
Moriarty	Pat	NREL/USA
Musial	Walt	NREL/USA
Neumann	Tom	DEWI/Germany
Newton	Paul	EON/UK
Nielsen	John D.	AU/Denmark
Nielsen	Morten	Risø/Denmark
Nørkær Sørensen	Jens	DTU/Sweden
Nyhammer	Finn	Statoil/Hydro/Norway
Oester	Flemming	Risø DTU/Denmark
Olav Tande	John	Sintef/Norway
Olsen	Laust	Siemens/Denmark
Overton	John	DTI/UK
Perez-Lapena	Blanca	University Twente/Netherlands
Phillips	Joseph	Garrad Hassan/UK
Pinson	Pierre	DTU IMM/Denmark
Politis	Evangelos S.	CRES/Greece
Poon	Andy	Renewable Energy Systems Ltd/UK
Quarton	David	Garrad-Hassan/UK
Ram	Bonnie	Energetics/USA
Rathmann	Ole	Risø-DTU/Denmark

Renkema	Douwe	GE Infrastructure/USA
Rethore	Pierre-Elouan	Risø DTU/Denmark
Richards	Gerogia	DTI/UK
Riedel	Volker	DEWI/Denmark
Ris Lambers	Reinier Hille	IMARES/Netherlands
Rodríguez	Antonio Vigueras	University of Castilla-La Mancha/Spain
Sanderse	Benjamin	ECN/Netherlands
Scharling Holm	Jørn	DONG Energy Power/Denmark
Schepers	Gerard	ECN/Netherlands
Schlez	Wolfgang	ISET/Germany
Sempreviva	Anna Maria	ISAC-CNR/Italy
Skiple	Asle	NTNU/Norway
Skov	Henrik	DHI/Denmark
Son	C.Y.	INHA/South Korea
Sørensen	Poul	Risø DTU/Denmark
Stendius	Lars	ABB/Sweden
Stevens	Giles	Ofgem/UK
Stojkovska	Biljana	Imperial College/UK
Strbac	Goran	Imperial College/UK
Thomsen	Knud Erik	Vestas/Denmark
Thomsen	Kenneth	Risø/Denmark
Thresher	Bob	NREL/USA
Tleis	Nasser	National Grid/UK
Troldborg	Niels	Risø/Denmark
Trombe	Pierre-Julien	DTU IMM/Denmark
Trujillo	Juan José	University of Stuttgart/Germany
Trumars	Jenny	Chalmers/Sweden
Tuerk	Matthias	DEWI/Germany
van der Pijl	Sander	ECN/Netherlands
Veers	Paul	Sandia National Laboratories/USA
Vincent	Claire	Risø DTU/Denmark
Vindteknikk	Kjeller	Statoil/Hydro/Norway
Westra	Chris	Wea@Sea/Netherlands
White	Sara	Econnect/UK
Yao	Liangzhong	Areva/UK
Zielke	Werner	University of Hannover/Germany

Subtask 2

Table 5. Expert participation in Subtask 2

Status	Last name	First name	Affiliation/Country
Full	Anders Nygaard	Tor	IFE/Norway
Observer	Argyriadis	Kimon	GL/Germany
Full	Azcona Armendariz	Jose	CENER/Spain
Full	Bendix Nielsen	Kristian	DNV/Denmark
Observer	Bir	Gunjit	NREL/USA
Full	Böker	Cord	REpower/Germany
Full	Buhl	Marshall	NREL/USA
Full	Butterfiled	Sandy	NREL/USA
Full	Camp	Tim	Garrad Hassan/UK
Observer	Carlen	Ingemar	Teknikgruppen/Sweden
Observer	Carstens	Henrik	Ramboll/Denmark
Observer	Cermelli	Christian	MI&T/USA
Observer	Dubois	Jan	University of Hannover/Germany
Full	Fylling	Ivar	Marintek/Norway
Full	Gao	Zhen	NTNU/Norway
Observer	Graveson	Helge	CarlBro/Denmark
Observer	Hanson	Tor David	Statoil/Norway
Observer	Haugsøn	Per	OWEC Tower/Norway
Full	Hauptmann	Stefan	USTUTT/Germany
Observer	Henderson	Andrew	Garrad Hassan/UK
Full	Hogedal	Michael	Vestas/Denmark
Full	Jonkman	Jason	NREL/USA
Observer	Jorgensen	Lars	Conwind/Denmark
Observer	Jörgensen	Erik	DNV/Denmark
Observer	Juul Pedersen	Bo	LAC/Denmark
Full	Karimirad	Madjid	NTNU/Norway
Full	Kaufer	Daniel	USTUTT/Germany
Observer	Kim	Hyun-Goo	KIER/Korea
Observer	Knauer	Andreas	IFE/Norway
Full	Kohlmeier	Martin	University of Hannover/Germany
Full	Kossel	Thomas	University of Hannover/Germany
Full	Kühn	Martin	USTUTT/Germany
Observer	Kyong	Namho	KIER/Korea
Full	Larsen	Torben	Risø DTU/Denmark
Observer	Lasa Morán	Mikel	APiA XXI/Spain
Full	Lauritsen	Neils	Vestas/Denmark
Observer	Lemming	Jørgen	Risø DTU/Denmark
Full	Martinez Cia	Alfredo	CENER/Spain
Full	Matha	Denis	USTUTT/Germany
Full	Maus	Karl Jacob	UMB/Norway
Full	Melchior Hansen	Anders	Risø DTU/Denmark
Full	Merino	Daniel	Acciona/Spain
Full	Moan	Torgeir	NTNU/Norway
Observer	Moe	Geir	NTNU/Norway
Full	Morch	Christian	DONG Energy/Denmark

Full	Munduate	Xabier	CENER/Spain
Full	Musial	Walt	NREL/USA
Full	Nichols	James	Garrad Hassan/UK
Observer	Paredes Pinzon	Santiago	Ramboll/Denmark
Full	Park	Hyunchul	POSTECH/Korea
Full	Pascual Vergara	Javier	Acciona/Spain
Full	Passon	Patrik	Ramboll/Denmark
Observer	Pedersen	Keld	Siemens/Denmark
Observer	Peiffer	Antoine	MI&T/USA
Observer	Perez	Imanol	CENER/Spain
Observer	Quappen	Jan	USTUTT/Germany
Observer	Quesnel	Louis	Fraunhofer IWES/Germany
Observer	Rasmussen	Jørgen	Ramboll/Denmark
Observer	Reil	Benjamin	University of Hannover/Germany
Observer	Rix	Patrick	REpower/Germany
Observer	Roddier	Dominique	PPI/USA
Full	Rubak	Rune	Siemens/Denmark
Observer	Schaumann	Peter	University of Hannover/Germany
Observer	Schmidt	Bjorn	GL/Germany
Observer	Sclavounos	Paul	MIT/USA
Observer	Seidel	Marc	REpower/Germany
Full	Shi	Wei	POSTECH/Korea
Observer	Smid	Erik	Siemens/Denmark
Observer	Son	Coongyul	INHA/Korea
Observer	Tarp Johansen	Niels Jacob	DONG Energy/Denmark
Observer	Thesbjerg	Leo	Vestas/Denmark
Observer	Thomassen	Paul	NTNU/Norway
Observer	Thomsen	Kenneth	Siemens/Denmark
Observer	van Wingerde	Arno	Fraunhofer IWES/Germany
Observer	Vega	Rolando	ABS Consulting/USA
Observer	Veldkamp	Dick	Vestas/The Netherlands
Full	Vorpahl	Fabian	Fraunhofer IWES/Germany
Full	Wei	Shi	POSTECH/Korea
Observer	Weinstein	Joshua	PPI/USA
Observer	Whan Rim	Chae	KIMM/Korea
Observer	Winther Staerdahl	Jesper	Siemens/Denmark
Observer	Yttervik	Rune	Statoil/Norway

3 Accomplishments

3.1 Subtask 1

Unique contributions

The seven narrowly-defined workshops attracted more than 225 experts from 11 countries for 125 presentations. Significant participation from industry was achieved (Table 2 and Table 4). They shared their experiences and works in progress at these highly technical workshops. The

workshop on Ecology and Regulation in the Netherlands hosted by Wea@Sea in February 2008 generated a number of important recommendation to be included in future environmental assessments and R&D programs, but no new activities were establish directly. Within the area of Electrical System Integration of Offshore Wind, the first two workshops were hosted by DTI in the UK and played an important role for laying out the UK grid connections rules for offshore projects in round 1 and 2. The workshops in Denmark hosted by Risoe DTU identified the importance of modeling wakes and their effects the grid system. These issues are of great importance as offshore wind farms become larger.

For the identified research areas, marine boundary layer characteristics and met-ocean data and loads, a collaboration between two IEA Wind Tasks (11 and 23) resulted in a topical expert meeting (TEM) under Task 11 in January 2007. The meeting was titled the State of the Art of Remote Wind Speed Sensing Techniques Using Sodar, Lidar, and Satellites. These are very important techniques to explore boundary layer characteristics and offshore loads for wind turbines. These issues will be considered in an offshore context and separate arrangements will be offered if relevant. Additional collaboration took place when an IEA Wind Task 23 meeting was held in February 2007 in conjunction with a German Offshore Conference and the EU policy seminar on offshore wind.

Technology advances

No specific technology advances can be attributed to this task.

Technical conclusions

Technical conclusions from each workshop are summarized in the Final Technical Report for Subtask 1.

Unresolved technical issues

The work programme of Subtask 1 was designed to identify and examine critical issues and did not aim to solve specific technical issues.

3.2 Subtask 2

Unique contributions

Emphasis within OC3 was given to the verification of the offshore support structure dynamics as part of the dynamics of the complete offshore wind turbine system. This emphasis is a feature that distinguished the OC3 project from past wind turbine code-to-code verification exercises.

Widely applicable insights into the various modeling approaches available were gained through this unique collaboration among the world’s most active researchers working on design codes for offshore wind development.

Technology advances

The wind industry relies extensively on design codes for wind turbine performance, loads, and stability analyses. Improving these codes is critical for successful long-term performance, operation, and reliability of wind turbines, and increases in importance as turbines grow in size,

incorporate novel load control technologies, and are installed on offshore support platforms. While the monopile, tripod, and floating spar buoy support structures analyzed in the OC3 project were not novel technologies, nor were their designs improved within the project, the codes used to design offshore wind turbines were tested and improved over the course of the OC3 project. The accuracy of these codes will dictate the ultimate reliability of all wind turbines. If the codes are in error, turbines will fail. The results will be used for verifying all future code developments as well as testing the analyst's ability to apply them correctly.

Technical conclusions

The code-to-code comparisons in Phases I through IV have agreed very well, in general. The key reasons for the differences and the other findings from Phases I through IV are discussed in the Final Technical Report. The verification activities performed in OC3 were important because the advancement of the offshore wind industry is closely tied to the development and accuracy of dynamics models. Not only have vital experiences and knowledge been exchanged among the project participants, but the lessons learned have helped identify deficiencies in existing codes and needed improvements, which will be used to improve the accuracy of future predictions.

Unresolved technical issues

In a few situations, the reasons for differences in the code-to-code comparisons were never identified. This was most true in the last phase of the project, which ended not because the work was complete, but because the scheduled end date was reached. A proposal to continue the work of OC3 was approved by the ExCo as Annex (Task) 30 Offshore Comparison of Dynamic Computer Codes and Models. Operating agents will be the National Renewable Energy Laboratory, United States, and Fraunhofer IWES, Germany. The new annex will engage the current members of OC3—and new members who may wish to join—in further studies to benchmark at least two new coupled wind turbine and substructure systems that are relevant to the offshore wind energy industry: (1) a wind turbine installed on an offshore fixed-bottom jacket and (2) a wind turbine installed on an offshore floating semi-submersible.

4 Objectives Achieved

4.1 Subtask 1

From 2005 to 2009, *Subtask 1: Experience with Critical Deployment Issues* brought together more than 225 experts from 11 countries for 125 presentations during 7 narrowly defined, highly technical meetings to share their experiences and plan new ways to cooperate. Although no official research efforts were begun under Task 23 Subtask 1, the workshops informed the experts who went on to design national, corporate, and institutional research programs. The workshops increased awareness of the research efforts in the participating countries and organizations that will advance the technology and deployment of offshore wind development.

The invited experts included representatives from wind turbine manufacturers and developers; utility planning, grid operators, and regulatory bodies; national research institutes; engineering and design consultants; environmental planning and regulatory bodies; universities; and wind plant operators. Participants in the task determined the topics, timing, and conduct of the workshops. Three issue areas were selected: Ecological Issues and Regulations, Electrical System Integration of Offshore Wind, and External Conditions.

By the accounts of the participants in the minutes of the discussion sections, these workshops sponsored by IEA Wind provided unique opportunities for diverse disciplines relevant to development of offshore wind energy to learn about the state of the art of each other's work and to have lively discussions of the critical issues faced by the community. While it is difficult to measure, we believe that this active exchange of information at the very early stages of offshore wind deployment has helped avoid repetition of mistakes and has accelerated successful activities.

The objectives to identify specific project leaders for research areas and prepare separate Work programmes and budgets for collaborative research areas were not achieved within this subtask. Also the intention of workshop participants to write an overview of results from national projects and of the workshop discussions for a special Task 23 report was not achieved.

4.2 Subtask 2

While the original objectives of Subtask 2—i.e., holding workshops on deepwater wind R&D—were not addressed in great detail, the OA of Subtask 2 feels that what was achieved in the OC3 project greatly exceeded the original expectations of the Subtask. Not only was the project of design code verification identified in the early stages of Subtask 2, but a research plan was formed and the work was carried out at an intense pace over the course of the five-year project. Following the OC3 project plan, various modeling approaches were discussed among the project participants, benchmark models and test cases were established, simulations were conducted, simulation results were compared and discussed, and code improvements were made in each of the four phases of the project. All of the objectives of the OC3 project were achieved.

5 Information dissemination activities

The two subtask leaders prepared a poster paper presentation at the Copenhagen Offshore Conference, in September 2005, at the OWEMES conference in April 2006, and at the Global Wind Energy Conference in September 2006. Results have been summarized in chapters of the 2005, 2006, 2007, 2008, and 2009 IEA Wind Annual reports.

5.1 Subtask 1

The workshops themselves can be considered an information dissemination activity. In two of the three research areas, successive workshops explored more deeply into the issues over a period of three years. The official records of the workshops contain valuable technical detail and are now available to any interested party via the Task 23 web pages hosted at www.ieawind.org. More than 125 presentations on topics ranging from aerodynamic modeling to benthic studies to wake effects can be found there for each of the seven workshops organized under the task.

5.2 Subtask 2

One conference paper was published and presented to summarize the results and main findings of each of the four phases of the OC3 project. These included a Phase I paper presented at the 2007 Science of Making Torque from Wind conference, a Phase II paper presented at the 2007 European Offshore Wind conference, a Phase III paper presented at the 2009 AIAA Aerospace

Sciences Meeting conference, and a Phase IV paper presented at the 2010 European Wind Energy Conference. A final technical report was also written that contains a summary of the entire project, an overview of each phase of the project, and the results of each project phase, including new results that were submitted since the end of each phase. Furthermore, the presentations given at each of the 11 project meetings, the detailed minutes of each meeting, and the benchmark model and load case specifications and simulation results from each phase of the project are available on the Task 23 web page at www.ieawind.org. A journal article summarizing the activities and results of the OC3 project is also under development.

6 Management and recommendations

When the work of this task began, in May 2004, offshore activities were just beginning in a few countries. The operating agents funded the work of the first year to gather participants together and formulate the further activities of the two subtasks. This approach allowed many countries to participate in the first year and begin thinking about offshore wind development. Workshops for Subtask 2 were held beginning in October 2004. Subtask 1 held its first workshop in September 2005.

In May 2005, the common fund was established and ten countries officially joined. The fund was managed at Risø, which conducted the invoicing and collected fees. NREL invoiced Risø for its share of the operating funds. It was estimated that the budgeted costs represent approximately 70% of the actual costs to the operating agents, which were provided as in-kind participation. Organizations within the countries that joined could participate in any of the workshops and in the research activities of Subtask 2 OC3.

The management of Subtask 1 involved arranging workshops and the disseminating the results from these workshops through the website. In cooperation with the OA of Subtask 2, results were reported to the IEA Wind ExCo and annual meetings were held.

The model with shared OA management and several un-funded lead countries within the subtask has in some situations not turned out to be optimal. The model with shared OA management and several un-funded lead countries within the subtask has in some situations not turned out to be optimal. If similar structures are selected in the future it is recommended that a clearer commitment is secured from institutions or persons agreeing to take a lead on work. Whether this implies funds supplied by participating countries (which then need to be bigger) or though additional national funds should be discussed by the ExCo.

In some cases it was unclear who the participants were and which of these was paying the fees. It is recommended that the responsible participant should be the contracting party to the IEA Wind agreement. If responsibility is transferred by the contracting party to a national institute or company this should be done with signed commitment letters according to IEA guidelines that are sent also to the OA. This formality is especially important in cases where more than one institute from one country can participate for only one fee.

The presentation of the results to the ExCo achieved during the project time has mostly been done by the OA for Sub 1. (Jørgen Lemming). It is recommend for future IEA Wind projects that

the requirements of the IEA Wind ExCo are clearly stated to the perspective OA and suitable funding be provided to ensure the reporting requirements are met successfully.

6.1 Subtask 1

The management of Subtask 1 was focused on arrangement of workshops and the dissemination of the results from these workshops through the website and in cooperation with the OA of Subtask 2 reporting to the Wind ExCo at the annual meetings.

The management of the funds has been carried out successfully. The objectives with the workshops have however due to change of personal at Risø DTU (Peter Hauge Madsen, Jørgen Lemming, and Flemming Øster) and struggles with communications with lead countries not been fully achieved. The number of workshops has been to low according to the aim and it was hoped that at least one or two new tasks had been formulated. The held workshops have been carried out successfully.

The intention with the spilt management and defined lead countries was supposed to support countries who wished to start activities within a new sector. If future task pursue the same model attention should be made to the recommendations mention above.

6.2 Subtask 2

The OA representative at NREL of Subtask 2 changed from Sandy Butterfield to Jason Jonkman over the course of the project. Jonkman focused his effort on leading the day to day activities of the OC3 project to ensure that the OC3 project objectives were met successfully and on schedule. Walt Musial managed the financial details of the project and assisted in reporting the activities and results to the IEA Wind ExCo. Due to a lack of time and resources, given that the scope of OC3 greatly exceeded what was originally planned for Subtask 2, reporting of the project's status and results to IEA Wind was given a much lower priority than ensuring a successful project. It is recommend for future IEA Wind projects that the requirements of the IEA Wind ExCo are clearly stated to the perspective OA and suitable funding be provided to ensure the reporting requirements are met successfully.

7 Benefit to Participants

Participants received benefits well in excess of their contributions to the common fund of the task and their in-kind labor efforts. The cost per country to participate in the task was 6,225/USD/yr (5,221 Euro) for three years (2005 exchange rates). This totaled 18,675 USD (15,663 Euro) for each country. In addition, each participant covered travel expenses and the labor of its experts who participated in meetings or completed work plans. Table 6 and Table 7 present rough estimates of the multiplier effect of participating in this task. The exchange rates used come from 31 December 2005, www.x-rates.com.

Table 6. Subtask 1 In-kind labor (person months)*

	National effort participating in workshops					Related projects					Total in-kind labor					
	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	total
Denmark	5,8	2,6	0,5	1,3	6,8	36	18	2	8	30	41,8	20,6	2,5	9,3	36,8	111,1
Germany	2,2	0,8	0,2	0,9	1,1	12	6	0	4	6	14,2	6,8	0,2	4,9	7,1	33,2
Korea	0,2	0,0	0,0	0,0	0,0	0	0	0	0	0	0,2	0,0	0,0	0,0	0,0	0,2
NL	0,9	0,3	0,3	2,6	1,4	4	2	2	6	12	4,9	2,3	2,3	8,6	13,4	31,5
Norway	0,0	0,0	0,3	0,0	1,0	0	0	2	0	2	0,0	0,0	2,3	0,0	3,0	5,4
Portugal	0,0	0,0	0,0	0,0	0,0	0	0	0	0	0	0,0	0,0	0,0	0,0	0,0	0,0
Spain	0,0	0,3	0,0	0,0	0,7	0	2	0	0	6	0,0	2,3	0,0	0,0	6,7	9,0
Sweden	1,9	0,0	1,2	0,3	0,5	10	0	6	2	2	11,9	0,0	7,2	2,3	2,5	23,9
UK	6,2	0,5	6,3	0,0	0,7	24	2	20	0	0	30,2	2,5	26,3	0,0	0,7	59,8
US	0,7	1,0	0,0	0,5	1,1	4	6	0	4	8	4,7	7,0	0,0	4,5	9,1	25,3
Total	19,1	5,6	8,9	5,6	13,4	94	36	32	24	66	113,1	41,6	40,9	29,6	79,4	**304,6**

***** This table was filled out by estimating the time spent by participants participating in the workshops per country (30 hours including travel time plus 20 hours extra for those who had presentations), plus additional 2 person-months spent on of related projects presented at the workshops. One person-month is 150 hours.

Table 7. Subtask 2 In-kind labor (person months)**

	National projects					Related projects					Total in-kind labor					
	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009	total
Denmark	15	15	6	6	6	15	15	6	6	6	30	30	12	12	12	96
Germany	3	3	9	9	9	3	3	9	9	9	6	6	18	18	18	66
Korea	0	0	3	3	3	0	0	3	3	3	0	0	6	6	6	18
NL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Norway	0	0	12	12	12	0	0	12	12	12	0	0	24	24	24	72
Portugal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spain	0	3	6	6	6	0	3	6	6	6	0	6	12	12	12	42
Sweden	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2	2
UK	3	3	3	3	3	3	3	3	3	3	6	6	6	6	6	30
US	6	6	6	6	6	6	6	6	6	6	12	12	12	12	12	60
Total	27	30	45	45	46	27	30	45	45	46	54	60	90	90	92	**386**

** This table was filled out by assuming 3 person-months of effort directly related to the project per active partner, plus additional 3 person-months of related projects per active partner. These numbers were doubled for the OA. Only 1 month was given to Sweden, who contributed very little, and 0 to Portugal and the Netherlands, who did not participate in Subtask 2.

If a person-month of effort expended on this work is valued at 12,000 USD (8,328 Euro), then each country received the results of 3.66 million USD (2.54 million Euro) of labor for Subtask 1 and 4.63 million USD (3.2 million Euro) of labor for Subtask 2 for its investment of 18,675 USD (12,960 Euro) in fees plus in-kind labor and travel. The value of the information received by experts that participated in meetings is positive, but impossible to measure.