

Norwegian Centre for Offshore Wind Energy (NORCOWE)

A centre for Environmental Energy Research (FME)

A joint initiative from:

Christian Michelsen Research (CMR; applicant and contractual partner);

in cooperation with

Unifob, University of Bergen (UiB), University of Agder (UiA), University of Stavanger (UiS), Aalborg University (AAU), Agder Energi, BKK, Lyse Energi, StatoilHydro, Statkraft, NorWind, Sway, Grieg Logistics, Det norske Veritas (DnV), Aker Solutions, National Oilwell Norway, Origo Engineering, Troll Power, and Bergen Group

with particular support from

Siemens, InWind, Angle-Wind, NCE-Subsea, Greater Stavanger, Norwegian Meteorological Institute (met.no), and Bergen University College (BUC).

1 Status

1.1 Vision

The Norwegian Centre for Offshore Wind Energy (NORCOWE) will be an interdisciplinary resource centre for the exploitation of offshore wind energy as a natural sustainable energy source. Key players in the development of Norwegian offshore technology join forces with leading Danish and international communities on onshore and shallow water wind energy to define the future state of the art in the field of offshore wind energy technology. NORCOWE will take the lead in the development of new innovative and cost efficient solutions for the exploitation of offshore wind energy at large water depths and in harsh offshore environments.

1.2 Focus areas

NORCOWE will enable scientific and industrial partners in the consortium to work together in developing new innovative solutions for the realisation of offshore wind energy technology, with particular focus on concepts for large water depths and harsh offshore environments. The centre will focus on research and innovations within the following five work packages (WPs):

WP1 Wind and ocean conditions

WP2 Offshore wind technology and innovative concepts

WP3 Offshore deployment and operation

WP4 Wind farm optimisation

WP5 Common themes: education, safety, environment, and test facilities and infrastructure

The exploitation of synergy effects between the key research areas will yield substantial benefits, for the consortium parties in particular, and for the society in general.

1.3 Motivation

Both the Norwegian government¹, including the Norwegian Research Council^{2,3} (NFR), and the European Commission^{4, 5} (EU), recognize offshore wind technology as an area with an enormous energy potential, in both a long-term and a climate-friendly perspective. Offshore wind energy is also an area where Norway has indigenous natural and industrial advantages over many other countries²: the best wind conditions in Europe, and well-established state of the art technology within marine activities and offshore operations².

¹ *Enighet om nasjonal klimadugnad* (Klimaforliket). The Norwegian Ministry of the Environment, January 2008.

² *A collective R&D strategy for the energy sector – Final report*. Energy 21 / NFR, February 2008.

³ *Foresight rapport: Offshore vindenergi*. NFR, September 2007.

⁴ *Offshore wind energy: action needed to deliver on the energy policy objectives for 2020 and beyond*. EU, Brussels, November 2008.

⁵ *Strategic research agenda: market deployment strategy from 2008 to 2030*. TPWind, Brussels, July 2008.

The steadily increasing global energy consumption, the limited availability of fossil fuels, and the potentially devastating consequences of a global climate change, create a definite need for new and sustainable energy sources. The vision for wind energy production from the European Wind Energy Technology Platform⁵ (TPWind) is 25 % coverage of the electricity consumption within Europe in 2030, with a total installed capacity of 300 gigawatts (GW), corresponding to an annual reduction in carbon dioxide (CO₂) emissions of about 600 megatons (Mt). According to the European Wind Energy Association (EWEA), only 1.1 out of the 56.5 GW wind power installed in the EU at the end of 2007 was offshore⁶. However, EWEA's *low*, *medium*, and *high* predictions for 2020 and 2030 are 20, 35, and 40 GW, and 40, 120 or 150 GW, respectively⁷.

EWEA emphasizes that offshore wind technology offers a significant potential for industrial development within the maritime sector, and that this activity may revitalize the maritime industry⁸. Similar conclusions can be drawn from a report ordered by Enova that estimates the annual physical potential for offshore wind energy in Norwegian waters to 14 000 terawatt hours (TWh), from which 13 000 TWh covers water depths from 60 to 300 m⁹. There are currently no offshore wind farms in Norway, and for deep-water applications, the technological status is still at the research and demonstration stage. Offshore wind power technology faces new and demanding challenges during both installation and operation, and the expertise from Norwegian offshore logistics and technology is highly relevant in this context³:

- Strong and relevant expertise from operation of oil and gas installations
- National industrial engagement on both fixed and floating turbine concepts
- Substantial potential for industrial development both nationally and internationally
- Near unlimited access to potential development sites in the North Sea
- Potentially competitive advantage since most other countries focus on shallow-water concepts
- Better wind conditions and less severe environmental impact offshore, compared to onshore

Wind turbines fixed to the seabed is a feasible solution for water depths down to about 60-70 metres (e.g. the OWEC Tower concept), but deeper waters will most likely require floating installations (e.g. the SWAY and Hywind concepts). Several initiatives along the south-west coast of Norway show that the industry considers offshore wind power a feasible business opportunity, e.g.: the emerging ARENA project in Bergen, the MetSenter on Haugalandet, the Norwegian Offshore & Drilling (NODE) cluster in southern Norway, and NCE Subsea in Bergen.

The primary objective of EU's Research and Development (R&D) initiative on offshore wind energy production is to reduce the social, environmental, and technological costs. To realize this vision, TPCWind identifies four thematic areas: wind conditions, wind turbine technology, wind energy integration, and offshore deployment and operation⁵. The suggested WPs in this centre focus on the same topics (section 1.2). Commercially reliable and cost effective solutions call for research and innovation in a collaborative effort between the research community and industry. The partners in NORCOWE represent a strong combination of scientific and technological expertise:

- *Wind and weather conditions*: UiB and Unifob host the internationally recognized centre of excellence Bjercknes Centre for Climate Research (BCCR), and the Norwegian Meteorological Institute (met.no) is an associated partner.
- *Measurement technology*: CMR Instrumentation hosts the Michelsen Centre for Industrial Measurement Science and Technology, a Norwegian Centre for Research based Innovation (CRI) established by CMR and UiB.
- *Modelling capabilities*: the Bergen Centre for Computational Science (BCCS) and the computational fluid dynamics (CFD) community at CMR GexCon represent the international state of the art in their respective fields of research.

⁶ *EU Action to promote Offshore Wind Energy*. EWEA, June 2008.

⁷ *Pure power: wind energy scenarios up to 2030*. EWEA, March 2008.

⁸ *Delivering offshore wind power in Europe*. EWEA, December 2007.

⁹ *Potensialstudie av havenergi i Norge*. Sweco Grøner, report no. 154650-2007.1 for Enova SF, October 2007.

- *Offshore technology*: UiS, CMR, and UiA represent the state of the art in mechanical engineering, components and systems, control systems, asset management, instrumentation, safety aspects and offshore deployment and operations.
- *Wind turbine and wind farm technology*: AAU is world leading in wind power systems and wind energy integration, both onshore and in shallow waters, and their active participation in the project ensures efficient and relevant transfer of knowledge from Denmark to Norwegian industry and Norwegian research institutions.
- *Environmental impact*: the strong research groups at UiB and Unifob in marine biology, oceanography, and ornithology will study the potential impact from offshore wind energy production on the marine ecosystem; the University of Glasgow (UK) and Klaipeda University (Lithuania) will actively participate in this work.

Hence, the essential philosophy behind NORCOWE is to combine the international state of the art expertise on met/ocean conditions and offshore operations in Norway with the international state of the art expertise on wind energy technology in Denmark. This combination will put the centre in a unique position to efficiently build competence and support innovation in Norwegian industry and research institutions, as well as for commissioning international research projects, including the European Framework Programmes (FP7 and beyond).

1.4 Background information about partners

CMR (www.cmr.no) is a contract research organization with expertise and experience within energy technology, mechanical engineering, instrumentation, monitoring, and CFD modelling. *CMR Prototech* focuses on R&D targeted towards concept evaluation, design and development, and manufacture and testing of innovative technology for sustainable energy production by means of a combination of advanced engineering techniques and technological research. *CMR Prototech* is currently pursuing a unique and innovative concept for high altitude wind power in cooperation with the company R&D OMNIDEA. *CMR Instrumentation* develops advanced measurement technologies for fiscal, process, and multiphase flow measurements of oil and gas, meteorological and oceanographic observations, and fisheries applications. *CMR GexCon* specializes in technical process safety, and in particular CFD modelling of fluid flow in complex geometries: the wind field within the atmospheric boundary layer, accidental releases and dispersion of flammable or toxic gas, gas and dust explosions, and jet/pool fires. *CMR Computing* develops innovative solutions for visualizing geological, oceanographic, meteorological, and acoustical data, for the purpose of visual analysis, monitoring of processes, risk evaluation, and facilitating decision support.

Unifob (www.unifob.uib.no) is among the leading R&D institutions in Norway, and a major actor within the area of climate and environmental research. Unifob has three departments within mathematics and natural sciences that will work closely with the centre. Unifob Bjerknes has relevant activities on numerical modelling of atmospheric and oceanic processes. The department is hosting partner of the BCCR Centre-of-Excellence. Unifob Natural Science has strong skills in environmental and biological monitoring, including ornithology and marine biology. BCCS focuses on computational aspects of science, i.e. mathematical modelling, software engineering, and high performance/grid computing.

The university partners have research and education capabilities in many relevant areas, such as ocean-atmosphere modelling (UiB), measurement science (UiB), materials and offshore technology (UiS), maintenance and control systems (UiA, UiS, UiB), and wind energy research (AAU):

The Geophysical Institute in the Faculty of Mathematics and Natural Sciences at *UiB* (www.uib.no) is an internationally recognized contributor to the development of marine research and weather forecasting methods, including the Bergen School of Meteorology. The institute is part of the foundation for the BCCR centre of excellence and hosts a national research school in climate dynamics. The research strategy rests upon use of own cutting-edge measurement techniques developed in collaboration with technology partners in combination with theory and modelling in geophysics.

The Faculty of Science and Technology at UiS (www.uis.no) has since 1999 had a PhD program in Offshore Technology with at present about 20 PhD students, 9 professors, and 7 associate professors. The expertise and competence of UiS lies primarily within marine technology, marine operations, design of mechanical systems, integrity, and reliability of offshore structures and mechanical systems, risk assessment, and maintenance and asset management.

The Faculty of Engineering and Sciences at UiA (www.uia.no) has several research groups and education programs of high relevance to NORCOWE. The mechatronics group has well established research projects with the NODE cluster, an established Master program, and a PhD-program that will be launched in 2010. The group that works on renewable energy focuses on integration of distributed energy sources in the main electrical grid. UiA hosts a strong research group in information and communication technology (ICT), including a separate PhD-program, and expects to find synergetic effects between the research on wireless communication and sensor technology in the centre.

AAU (www.aau.dk) has a number of research projects of high relevance for the centre funded by the European Framework Programmes (FP) and the Danish Strategic Research Council (DSRC):

- Aeolus – Distributed control of large-scale offshore wind farms (FP7)
- UpWind – Integrated wind turbine design (integrated project, FP6)
- Systems with high level integration of renewable generation unit (DSRC)
- Probabilistic design of wind turbines (DSRC)
- Reliability-based analysis for reducing the cost of energy from offshore wind turbines (DSRC)
- Concurrent Aero-Servo-Elastic analysis and Design (CASED) of wind turbines (DSRC)

AAU has also a strategic research & development alliance with Vestas Wind Systems that focuses on power electronics, power systems, and electrical energy storage for power systems. AAU offers part-time 2-year education with mechanical or electrical specialization on wind energy at the Master level (WindMaster).

Some of the industrial partners contribute expertise, personnel, and facilities: DnV (materials and testing), and NorWind (access and logistics for marine operations). NORCOWE will incorporate additional research and technological expertise on a sub-contract basis (e.g. Polytec and the Marine Energy Test Centre (METcentre) on Haugalandet for offshore testing and measurements, and Molde University College on the logistics of marine operations), and will cooperate with related research initiatives in Norway (e.g. the FME offshore power grid initiative from Sintef/NTNU).

2 Research activities

Figure 2-1 illustrates how NORCOWE plans to organize the main research activities in four main research topics (WPs), and four common themes: education and dissemination of results, safety, environment, and test facilities and infrastructure. The research activities will focus on innovation, interdisciplinary research, and sustainable energy production in a long-term perspective.

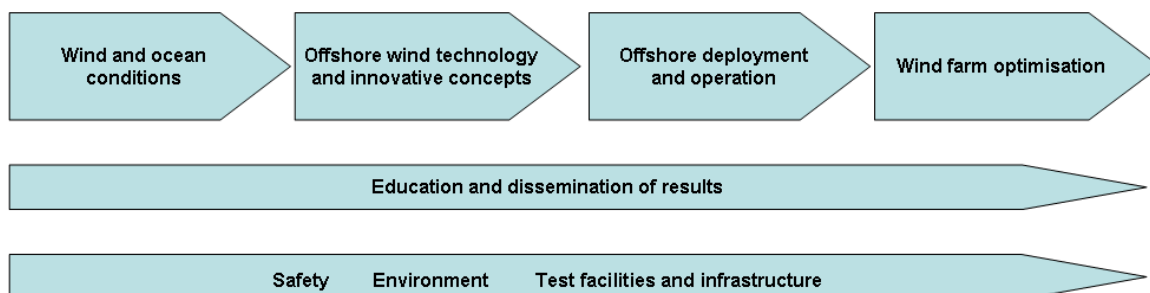


Figure 2-1 Schematic diagram illustrating the main research activities within the NORCOWE consortium.

Current operational solutions for offshore wind energy production involve conventional wind turbines fixed on foundations that rest on the seabed in relatively shallow waters. There is ongoing work on floating solutions for deep-water conditions, but these solutions are still in the developing stage. Hence, the prospective research in NORCOWE targets an entirely new industrial field where no mature technological solutions exist.

2.1 WP1 – Wind and ocean conditions

2.1.1 Climatology of met/ocean conditions

The depreciation time for offshore wind parks and associated infrastructure is comparable to the timescale of climate change. Recent results indicate that storm tracks are sensitive to changes in climate, and reliable long-term predictions of wind conditions should therefore include updated forecasts on climate change. Both BCCR and met.no have long experience in assessing the climate on regional scales, and this will ensure cost-effective placement of wind farms in a long-term perspective.

The term *reanalysis* describes a comprehensive description of the variation in the atmospheric state over time. Currently available global reanalyses of high quality have grid resolutions down to 100 km (e.g. ERAinterim), and regional downscaling of these reanalyses have already been produced (e.g. wave and wind fields for Nordic areas by met.no, and global downscaling by BCCR). The NFR-funded project *Predictive wave modelling* involved dynamical and statistical downscaling of ocean wave conditions down to a 500 m grid scale for an area west of Karmøy. The same methodology can produce local downscaling based on global reanalyses in areas considered for offshore wind farms.

The main research tasks under this activity include:

- Optimize wind farm location using recent climate change scenario studies
- Local downscaling of existing reanalyses using numerical tools

2.1.2 Modelling of the marine boundary layer

The marine boundary layer (MBL) is the atmospheric boundary layer over the ocean that forms the lower part of the flow field in the offshore wind system, and influences both the wind further aloft and the distribution of waves in the ocean. Optimal design, placement, and operation of offshore wind turbines with respect to energy production and costs require accurate descriptions of the loads from waves and wind on the individual production units, and hence intimate knowledge about the MBL. However, reliable measurements of important parameters in the MBL are scarce (e.g. vertical velocity profiles and turbulence parameters). The numerical modelling techniques rely heavily on skilful design and setup, and validation of the models requires reliable measurements of relevant physical quantities. Limited understanding of the overall physics of the MBL represents a significant limitation with respect to detailed numerical modelling of wind power applications.

Specific numerical models will describe the atmospheric conditions from planetary length scales (1000 km), down to length scales where large-eddy simulation (LES) models apply (100 m). The current approach for describing the air-sea interactions involves coupling a next-generation mesoscale model¹⁰ with a model for ocean waves from met.no. Numerical schemes for the subgrid scale in the LES modelling of the physical processes in MBL are under development. CMR will develop a special version of the CFD code FLACS (FLACS-Wind) to describe the range of length scales relevant for wind park planning and operations (1-100 m). The goal is to model the key features of full-scale offshore wind farms in realistic offshore environments. The treatment of MBL processes will be subject to validation against observational datasets.

The main research tasks under this activity include:

- Implement and validate numerical models for MBL on mesoscale
- Implement and validate the coupling between the mesoscale model and the wave model
- Implement and validate numerical models for MBL in FLACS-Wind
- Adapt results from the mesoscale models as boundary conditions in FLACS-Wind

¹⁰ The Weather Research and Forecasting (WRF) model: www.wrf-model.org

2.2 WP2 – Offshore wind technology and innovative concepts

2.2.1 Dynamic response

A clear understanding of the dynamical response of wind turbines and their operation in offshore wind farms is needed. This calls for a systematic assessment of the efficiency and stability of the wind turbines under a wide range of different wind and sea state conditions. Information on wind and turbulence profiles is a necessary requirement. A sound understanding of the dynamical response will provide valuable information for design of single wind turbines and wind parks as well as for the design of control systems. The NORCOWE consortium possesses long-term experience on developing dynamic models for fixed and floating offshore structures, and on the analysis of data from full-scale measurements on such structures.

In the first part of this subtask, the dynamics of different types of floating wind turbines will be investigated. Simplified models describing the behaviour of the wind turbine, the floating system, and the mooring subjected to different wind- and wave conditions will be established. The models must include the highly nonlinear relations between response and loads. The goal is to understand the effect of gyroscopic loads, aerodynamic and hydrodynamic forces, and hence the dynamical behaviour of the systems, in order to estimate load effects and instabilities. Experimental data from model scale experiments and the full-scale tests of concept Hywind (StatoilHydro) and SWAY (Sway) will be used to develop the simplified models. Secondly, the models will be extended to handle cases of extreme waves. To this end, they will include full nonlinear coupling, and if required, refined hydrodynamic modelling. Worst case scenarios will be investigated, and the model results may be used as input to commercial tools for structural and fluid analysis, enabling detailed predictions of load effects on machinery, structures, and mooring. The main research tasks under this activity include:

- Investigate the dynamics of wind turbines and develop appropriate nonlinear models
- Verify the models with commercial mooring and/or vessel response programs (Orcaflex, Riflex)
- Couple the models to operation and maintenance procedures, and develop strategies for reducing dynamic load effects (sections 2.2.4 and 2.2.5)
- Validate the models against downscaled experiments and full scale applications (section 2.5.4)

2.2.2 Wind energy capture

Accurate modelling of the flow field behind individual wind turbines is necessary for optimizing the layout of wind farms⁵. However, the computer capacity required for resolving the flow field around individual blades on a large-scale wind turbine is formidable, and such simulations would typically be extremely time-consuming, or require the use of a supercomputer. Hence, the approach adopted here entails the use of suitable subgrid models in FLACS-Wind to describe the wind turbine: a moving porosity pattern representing the rotating turbine blades, varying porosities in the pattern representing pitching, and the appropriate conservation laws and empirically determined efficiency factors determining the energy conversion and displacement of impulse. Details of the flow field near the turbine blade will also be studied using other CFD codes. The main research tasks under this activity include:

- Implement suitable subgrid models for wind turbines in FLACS-Wind (section 2.1.2)
- Validate the models against experimental data (section 2.5.4) or detailed numerical investigations

2.2.3 Innovative concepts

In addition to certain inventive solutions specific to offshore wind turbines, the technical solutions adopted in the initial phase of offshore wind farm developments will most likely combine existing technology from onshore wind farms with conventional offshore technology and knowledge from marine operations. In a longer perspective, it will be necessary to develop new concepts with lower development and maintenance costs, prolonged expected lifetime, enhanced power output, and increased reliability. New solutions for intervention during operation and maintenance call for new concepts, and one possibility will be to adopt design solutions from subsea systems in the petroleum industry, where the need for maintenance is minimized and all interventions are done unmanned by replacing modules.

Both CMR and other companies in the consortium work on promising innovative concepts that require thorough analytical proof of concept, pilot scale testing, and clarification regarding patents and intellectual property rights (IPR). NORCOWE intends to stimulate the innovation process by offering scientific analytical evaluation of innovative solutions, and to participate in the further development and commercialization of the most promising concepts. CMR Prototech and OMNIDEA are working on an innovative concept for high altitude wind power¹¹, where CMR Prototech contributes with specific IPR not yet published for construction of highly effective offshore installations. The available expertise in the centre will significantly increase the chances for successful development of this technology into a full-scale prototype within 3-5 years. The main research tasks under this activity include:

- Monitoring and reviewing the technological developments in the field: reliability and maintenance, capital and operating expenditures (capex and opex), risk aspects associated with deployment, interventions, and techno-economic feasibility
- Systematic analysis of new concepts, including advanced rotor design, kites, inflatable structures, and other system components (section 2.2.4)

NORCOWE will provide an arena for activities that stimulates and encourages the search for new and innovative solutions/concepts in the field of offshore wind technology.

2.2.4 Component and systems development

This section focuses on R&D activities related to existing technology and mature concepts, i.e. for solutions that have been through the initial proof of concept phase. A key challenge will be to improve the stability of floating wind turbines through lighter gearbox design, new low speed generators, and possibly by positioning the gearbox and generator at, or below, sea level. This work will benefit from the partners' expertise on marine and mechanical engineering, material technology, and electrical components. Another important topic will be to evaluate suitable cost-effective systems through optimized designs and numerical modelling. The focus here will be the optimal combination of gearbox, generator, and power electronic conversion system. This work will consider the interaction between the main components of the wind turbine, and the interaction between the main components and the surrounding environment (including the electrical grid, modes of operation, climatic conditions, and other factors). AAU in particular has long experience from work on the main electrical components in wind turbine systems, including design optimisation for various types of generator systems. In a research project sponsored by the EU, AAU developed criteria and methods for optimizing various generator concepts, including the direct-drive low speed permanent magnet generator, a combination of a single stage gearbox with a medium speed generator, and power electronic converters. AAU can also perform optimisation and site matching for wind generators. Hence, the collective experience of the partners in NORCOWE will effectively provide a strong background for the proposed project activities:

- Design models for main system components
- Analysis and comparison of the cost-effectiveness of wind turbine systems
- System design optimisation

2.2.5 Reliability and lifetime

The high cost of offshore wind turbines, combined with the potentially extreme loading conditions in harsh marine environments, introduce significant challenges when it comes to securing robust, reliable, and long-lasting designs for the wind turbine system. The NORCOWE consortium has long experience from developing models for reliability analysis of structural and mechanical systems, and in particular for offshore structures and wind turbine components. One of the main research tasks will be the development of models for the integrated system: fixed or floating structure, turbine, gearbox, generator, and single components such as turbine blades, shafts, or bearings. These models form the basis for the integrity analysis of the structure and component, maintenance planning, and concept evaluations.

¹¹ *Atmospheric Resources Explorer*. WO/2007/139412 at <http://www.wipo.int>

Cost reduction is a key prerequisite for establishing offshore wind power as a major sustainable energy source in the future. The approach adopted here entails a procedure for minimizing the costs based on probabilistic design of individual system components (i.e. consistent reliability level for all components in the system, taking into account the uncertainties associated with load, strength, calculation method, and site-specific parameters). Damage accumulation results from e.g. corrosion and fatigue, and determines the expected time to failure for both the system and the individual components in the system: structure, mooring, machine components (gearbox, brakes, turbine blades, shafts, bearings, etc.), electrical components (generator, wires, etc.).

An important research topic will be to develop models for different damage scenarios, and rates of damage accumulation for individual components, in order to estimate the overall reliability of the system. Statistical model parameters and associated uncertainties will be assessed from analysis of empirical data (e.g. the UpWind project). The reliability analysis will rely on theoretical methods such as FORM, SORM, simulation techniques, and Bayesian methods for taking into account all available information. Since the expected consequences of failures involve economic loss, and not fatalities or environmental degradation, optimisation of offshore wind power systems will primarily focus on reliability according to the following criterion: optimum reliability maximizes the economic return to the owner by maximizing the total expected benefits less the costs of construction, operation, maintenance, repair, and potential failure. The main research tasks under this activity include:

- Identifying and modelling critical failure scenarios for mechanical, electrical, and structural components in offshore wind turbine systems
- Coupling the reliability models to the work on instrumentation and forecasting
- Lifetime cost and energy optimisation
- Extreme weather precautions

2.3 WP3 – Offshore deployment and operation

2.3.1 Asset management

Costs related to operation and maintenance of offshore wind turbines are large, typically more than 25% of the cost of energy produced. For offshore wind farms with fixed support structures cost vs. maintenance strategies models are available (e.g. cost models developed by ECN, TU Delft and O2M). These models are based on experience and historic data, and are not developed to assist daily decision making for planning maintenance actions given actual data. Recent experiences from offshore wind farms indicate even larger costs due to technical problems. Studies¹² show that failures of wind power plants have many sources, ranging from sensor/control system faults, mechanical backlash, failure of gears/bearings and hydraulic leakage. Results from the recently completed 5-year EU funded project Condition Monitoring for Offshore Wind Farms (CONMOW 2002-2007), show that at present there is insufficient knowledge available to assess the condition of wind farms and to estimate how failures develop over time. This implies that a broad scope of new methods and techniques is required for management of offshore wind turbines.

The assurance of technical integrity is an inherent design challenge for offshore wind turbines, and maintenance-related challenges contribute to a major portion of the risk that the offshore wind turbines are exposed to. Development of maintenance concepts needs to be risk-based and data-driven for offshore energy sources. In the short term, maintenance identified by lifetime models and remote diagnostics will be performed by sent-out personnel. Target designs should support unmanned replacement of modules from special intervention vessels. New reliability/risk-based methods and technologies will also be developed in the areas of measurement and instrumentation, signal processing and system identification, such as fault-tolerant control methods, vibration, acoustic and fibre optic strain analysis of the blades and drive-train components, thermographic

¹² For example: Ribrant J. *et al.*, IEEE Trans. on Energy Conversion, Mar 2007

analysis of electrical components, analysis of oil quality and time and frequency domain analysis of electrical power.

UiS, with partners in USA, Finland, and Canada has acquired valuable knowledge through years of continuous work with energy systems. Some of this work includes; Mitsubishi Heavy Industry Wind Mill, Siemens, Wisconsin Energy systems. For sensor technology for offshore wind turbines, the centre will benefit from cooperation with the recently established Michelsen Centre for Industrial Measurement Science and Technology and CMR Instrumentation. UiA and Norwegian suppliers of offshore drilling equipment have active R&D activities related to condition based maintenance, which will be of significant value to the centre. Companies such as Aker Maritime Hydraulics and National Oilwell Varco have long measurement series and experience in developing lifetime models for equipment operating in harsh offshore environments. The research tasks will focus on four main challenges related to the operation and maintenance of offshore wind turbines:

- Technical integrity through systems design, with main focus on maintainability, operability, availability, and supportability
- Development of cost-optimal maintenance concepts based on real-time remote diagnostics and risk-based decisions
- Technology for performing continuous maintenance based on measurements, failure modelling, and signal processing
- Technology for repairing or replacing damaged parts (i.e. cost-optimal intervention techniques).

2.3.2 Single turbine control systems

A significant challenge for single offshore turbine control systems, compared to turbines with ground-based foundations, is the much larger movements of the turbine. Grounded towers with heights of 100 m or more can sway and generate movements in the horizontal directions of more than a metre. This sway motion influences the wind speed relative to the rotor, which in turn influences the blade pitch and turbine speed control algorithms. In the worst case, the coupled dynamics between the tower motions and the blade pitch and turbine speed can cause instabilities in the control loops. For a floating or anchored offshore wind turbine, it is most likely that there will be significant additional vertical and horizontal movements. Traditional single turbine control algorithms based on PID and feed-forward models may not be sufficient for an offshore turbine, and model-based multiple-input-multiple-output (MIMO) controller algorithms may be required. The recently started EU project, Aeolus - Distributed Control of Large-Scale Offshore Wind Farms¹³, coordinated by AAU, will focus mainly on farm-wide control. Another project at AAU, CASED – Concurrent Aero-Servo-Elastic Analysis and Design of Wind Turbines¹⁴, focuses mainly on single turbine control. Significant synergies between the Aeolus and CASED projects and the proposed project on single turbine control for offshore turbines are expected. Another topic which is at least as important as pitch and speed control, is the effect of the control algorithms on the fatigue load on the wind turbine system. Synergies with the Aeolus and CASED projects are also expected in this area. One objective is development of generic quasi-static flow models relating single turbine production and fatigue load to the map of wind speeds and wave motions. Another objective is the development of a time averaged quasi-static flow model derived from fluid dynamics and based on meteorological and wind turbine related measures. The main research activities will include:

- Pitch and speed control based on model-based MIMO controller algorithms
- Effect of control algorithms on fatigue loading
- Generic and time-averaged quasi-static flow modelling

¹³ www.ict-aeolus.eu, 2008-2011

¹⁴ www.control.aau.dk/~tk/Research/CASED

2.3.3 Remote operations

Remote operations are necessary to secure cost-efficient operation of offshore wind turbines. The required technology includes communication technology, and service platform and software tools supporting visualization, estimation and prediction. Infrastructure for energy transport will be an important part of wind farms and naturally cater for installation of optical fibres between the remote wind farm and the main operations centre. In normal operation, mobile (wireless) communications will mainly be used for sensors and data acquisition. These will primarily be local, but may also include remote sensors (e.g. buoys). At this scale we can use existing and modified protocols with appropriate solutions for reliability and security.

In connection with installation, modifications, and maintenance, there will be a need for high capacity and high quality communication between the ship, the wind turbines and onshore operation centres for video communication, retrieval of 3D models, transferring large amounts of data and other demanding applications. For these purposes, the main means of communication is still satellite connection, which is quite expensive. The MarCom-project funded by The Norwegian Research Council aims to develop new methods for broadband communication at sea. These results need to be taken into account and extended, in particular by the use of ad-hoc communication between the ships combined with medium-range wireless communication (WiMax). Offshore wind farms will be an opportunity to provide large areas of broadband access at sea for general use. Knowledge and experience from the introduction of integrated operations for oil and gas offshore installations will be important when planning remote operations. It is important to use a service oriented approach including a proper domain model for maximum flexibility. This will ensure adaptation to new technology, and the exchange of old parts will be smooth. Special emphasis must be made on the reliability and security of the communication. Relevant results from the Joint Industry Project *Integrated Operations in the High North* need to be taken into account and adapted to wind farm operations. This will make it easier for the oil and gas industry to enter the wind energy business.

In close cooperation with the activities in chapters 2.3.1, 2.3.2 and 2.4, appropriate methods for visualization, estimation, and model-based prediction will be developed. Advanced techniques for information visualization will be utilized. For instance, multidimensional scaling techniques can be used to detect meaningful underlying dimensions in a high-dimensional dataset, thus supporting data visualization for exploring similarities or dissimilarities among elements within a dataset. From a broader perspective, data visualization may involve organization of evidence, evaluation of risks, and representation of decision strategies. The main research tasks under this activity include:

- Communication infrastructure that is sufficiently flexible (cable – wireless, long range-short range, high – low capacity, real time – non real time communication) and robust service platform that is sufficiently flexible, secure, and easy to use
- Optimisation of work processes, visualization, and collaboration for remote operations
- Wind turbine management using decision support systems based on visualization techniques and performance predictions estimated from models and measurements

2.3.4 Marine operations

At present, the costs of installation, intervention, and decommissioning of offshore wind concepts are unreasonably high when using state of the art conventional technology, such as jackups or offshore crane vessels. There is thus a need for a new mindset to develop safe but less costly technologies and procedures for such operations. These operations are closely connected to the concepts developed and analysed in task 2.2.3, 2.2.4 and 2.3.1, and the technology and procedures should be developed in close interaction with the designers of these concepts and farms.

For deepwater offshore wind concepts, the state of the art is to use crane vessels for such operations, however, this might not be attractive in view of the costs of employing sufficiently large size vessels that can operate under most weather conditions. It should in this respect be noted that today's smaller crane vessels may have movement characteristics that will make such operations difficult or impossible for prolonged periods of the year.

New technologies are therefore needed for installation, intervention, and decommissioning of offshore wind energy concepts. We will in particular investigate the use of ballast procedures combined with use of offshore service vessels to perform such operations in a safe manner, but other concepts will also be investigated. The technology development will include new modules that can be handled by work procedures developed by the offshore service industry. In particular, this involves the following phases:

- *Installation*: towing the unit to the field, combined with new technology components that can be handled with offshore service vessels;
- *Intervention*: using ballast procedures combined with maintenance directly from service vessels;
- *Decommissioning*: reverse installation.

For each phase, the intention is to categorize all types of necessary operations, screen vessel types for suitability, analyse designs, categorise the different concepts, and develop logistic programs. Procedures for ballast control and technology for mooring developed for the offshore drilling industry will become central elements in these operations. The main research tasks under this activity include:

- Explore new technologies and operational concepts for installation, intervention and decommissioning
- Investigate the potential use of ballast procedures combined with offshore service vessels

2.4 WP4 – Wind farm optimisation

2.4.1 Nowcasting

When wind parks are built and operated, optimisation is primarily with respect to cost. The park units should preferably avoid extreme loads, and loads leading to severe strain and fatigue. The rotor blades and generators of the park units should also be adjusted to ensure optimum energy output. Information on the wind and turbulence conditions in the coming minute(s), so-called nowcasting, is highly advantageous in order to achieve optimal energy capture. Remote sensing information on the wind upstream of the wind park may provide a few minutes warning, so that the control system can optimize the tuning of the park units. In recent years, Lidar technology in experimental meteorology has made substantial progress, and the cost of Lidar instruments has decreased. It is proposed to install and test Lidar technology in various setups to evaluate the feasibility of this technology as a means to provide the wind information necessary to support accurate and reliable nowcasting (section 2.5.4). Remote sensing information on upstream wind conditions with simultaneous wind and turbulence measurements at the park site will be used for testing and calibrating rapid park-model calculations, to provide optimal adjustments (sections 2.2.1 and 2.2.2). The main research activities include:

- Investigate the relation between remotely observed wind and turbulence profiles, and direct turbulence measurements
- Develop practical systems that can provide 1-3 minute wind predictions for offshore wind parks

2.4.2 Short-term forecasting

Reliable 1-2 day predictions of the energy output from wind parks will generally allow better pricing of the produced energy. Accurate forecasts using mesoscale models (section 2.1.1) are the basis for prediction of energy production and extreme loads. Errors in forecasts may have different origins, such as inaccurate representation of physical processes, poor initial conditions, and inaccurate lower and lateral boundary conditions. Forecasting errors related to the MBL on small scales have not been addressed up to now, and further investigation is warranted in order to achieve accurate forecasts. Implementation of operational aspects of the forecast system will be relatively straightforward due to the long operational experience of met.no on forecasting in the MBL, and the main research activity will include:

- Identifying sources of error growth for prediction of MBL phenomena on scales down to 100 m, and correction of such errors using state-of-the art techniques

2.4.3 Power systems integration

Integration of large-scale wind power may have severe impacts on the power systems. Both installation and maintenance of offshore wind farms are more expensive than for onshore wind farms. Various kinds of configuration for offshore wind farms are possible, and the fast development of power electronics has led to a number of different design schemes for wind farms. These design schemes can have different costs, power losses, and reliability, and they may present different control and operation behaviour in power systems. Stable, reliable, and economic operation of the power system under the massive integration of wind power is a big challenge. The wind power penetration will result in variations of load flows in the interconnected systems, and re-dispatch conventional power plants, which may reduce the reserve power capacity. Hence, certain actions are required to accommodate large-scale wind power penetration: expansion of the power grid for bulk transmission of electricity from offshore wind farms to load centres, reinforcement of existing power lines, construction of new power lines, installation of Flexible AC Transmission system (FACTS) devices, etc.

The goal of this research activity is to optimise power system integration of offshore wind farms (i.e. minimise the overall system cost), and to develop robust control strategies that satisfy certain technical specifications for grid codes and grid connectivity. The Institute of Energy Technology (AAU) has extensive experience in studying wind farm performance in power systems, wind farm modelling, system optimisation, and operation and control of wind farms and power systems. AAU has conducted some relevant research projects, e.g. on the use of Genetic Algorithms (GA) to optimize the electrical systems of offshore wind farms, and to investigate the impacts of large wind power integration into power systems. The extensive experience at AAU in this field will provide a solid foundation for the proposed project activity.

- Develop suitable control strategies for cost-effective integration of offshore wind power within the constraints of the existing grid
- Test the control strategies for optimized systems using the Real Time Digital Simulator (RTDS) at AAU

2.4.4 Wind farm modelling

Power losses from wakes in wind farms are difficult to predict. This effect is also usually underestimated: the impact on the overall power output from the farm is likely to be in the region of 5-10 per cent⁵. Hence, there is an obvious need for improved predictive capabilities on the optimisation and layout of offshore wind farms. Many companies and research institutions develop specialized software and decision support systems (SDSS) for offshore wind energy exploitation, and some systems cover the entire process from project development, wind farm layout, restriction area, geological items, cable routes, grid connection, and operation and maintenance¹⁵. However, current SDSS models cannot describe the physical phenomena that govern the interaction between the MBL (section 2.2.1) and energy capture in a single wind turbine (section 2.2.2), not to mention the complex interactions between several wind turbines and the MBL in offshore wind parks.

While currently available CFD tools are too computationally expensive to simulate the interaction between the MBL and an offshore wind farm in detail, the ambition here is to perform such simulations with the new CFD tool FLACS-Wind (sections 2.1.2 and 2.2.2) that will be able to handle complex large-scale geometries through the distributed porosity concept. The modelling will describe complex wake effects in offshore wind farms with multiple turbines (20-200), for various park layouts, and under changing wind and wave conditions. This type of prediction is particularly valuable for offshore wind parks, because the performance of currently available analytical models is poor in the wake near the turbines, and because of the extended wake region in the MBL due to less intense turbulence offshore compared to onshore. The main research tasks under this activity include:

¹⁵ *Software & decision support systems for offshore wind energy exploitation in the North Sea region*. Final report from Overspeed GmbH to the EU project POWER (Pushing Offshore Wind Energy Regions), Oldenburg, May 2007.

- Parameterization: the currently used models for describing the far wake region include poorly understood tuning parameters, and it is essential to obtain reliable estimates for wind turbine design and weather conditions in the design phase of a wind farm project
- Couple the CFD code to the meteorological simulations in section 2.1.2 to include the effects of wind gusting and wake meandering
- Couple the CFD code to suitable optimisation procedures (genetic algorithms or heuristic methods) and relevant cost data
- Validate FLACS-Wind against measurements from existing onshore and shallow water wind farms (e.g. Horns Rev in the North Sea)
- Produce general guidelines for optimizing the offshore wind farm layout

Other benefits from this work include the application of FLACS-Wind to e.g. onshore wind farms.

2.5 WP5 – Common themes

2.5.1 Education and dissemination of results

NORCOWE intends to organise a *Nordic research school on offshore wind energy* for the 20-25 PhD students in the centre. The research school will be a cooperative effort between the four university partners in the centre, and with links to the existing *Norwegian research school in climate dynamics* at the Institute of Geophysics (UiB) and wind power related education programs at AAU to take advantage of synergy effects. The school will arrange both cross-disciplinary introductory field courses and indebts courses and workshops in different relevant disciplines. Teaching of the courses will take place during intensive periods, so that participants from different geographic locations can attend the same course. At Master level, the university partners will offer thesis projects connected to the research in NORCOWE.

The different Master studies at UiA, UiB, UiS, and AAU will form a major recruitment base for the PhD positions at the centre, and there will be special focus on recruiting female Master and PhD students (chapter 12). AAU in particular has extensive experiences in wind power research and education across various disciplines, including civil engineering, electrical engineering, control engineering, and mechanical engineering. AAU has established cooperative research and education relationships with wind power industry, including main wind turbine manufactures such as Vestas, Siemens Wind Power, etc. Based on the research work and industrial cooperation, AAU has developed a number of high quality PhD courses, including control, electrical engineering (generators, power electronics, and power systems), foundations, and wave loads. Furthermore, AAU has a number of master programs in full-time or part-time education that have mechanical and electrical specializations, such as ‘WindMaster’ and ‘Wind Power Systems’.

Summer schools on offshore wind energy will provide an opportunity to invite leading international researchers as speakers, promote interaction between academia and industry, create an arena for exploring innovative concepts through workshops or seminars (section 2.2.3), and function as a meeting place for researchers and students in the centre.

2.5.2 Safety

Collisions between offshore wind turbines and ships represent a certain risk for both the wind turbines and the vessels, and NORCOWE intends to analyse the ship traffic near planned installations with respect to risk of collision (including drifting) and environmental aspects. Furthermore, offshore wind farms may necessitate relocation of shipping lanes, and thus installation of navigational aids such as lanterns and buoys, and other maritime infrastructure. CMR Computing can use advanced geographic information systems (GIS) to provide developers of wind farms, as well as the approving authorities, with sufficient and accurate information¹⁰. Dynamic decision support and surveillance systems can be used to calculate the risk during operation, and ensure that emergency resources are available in time should an emergency arise. The flow of information between wind farm operators, emergency services, and public authorities should connect with the system.

CMR Computing has long experience with decision support and surveillance systems¹⁶, and is currently involved in several projects that involve risk calculations¹⁷, optimisation of resources, analysis of vessel traffic, and drift simulations. This work is performed in cooperation with institutions and public authorities such as the Norwegian Coastal Administration, the Norwegian Joint Rescue Coordination Centres, the Norwegian Directorate of Fisheries, met.no, and DnV. The main research tasks under this activity include:

- Assessment of statistical and dynamic risk related to ship traffic and offshore wind farms
- Development of GIS based planning tools for wind farm developers and authorities
- Systems for decision support, surveillance, and emergency evacuation
- Optimal management of emergency resources
- Modelling of ship drift and possibly small scale experiments

2.5.3 Environmental impact assessment

Large offshore wind farms exert a significant influence on marine environment, traffic lanes, and maritime infrastructure. Wind turbines may negatively affect bird life through collision risk, habitat change, and disturbance^{18,19}. Modification of the air-sea interaction pattern in the vicinity of the installation may produce local upwelling/downwelling phenomena, which, in turn, can affect the pelagic ecosystem. Introduction of artificial hard substrates (turbine foundations) provides a new habitat for fouling marine organisms and associated biota. Such semi-artificial ecosystems may become a stepping-stone for introduction of non-native invasive species, especially near intensive maritime traffic areas. In conjunction with alteration of hydrographical and sedimentological patterns, this may cause changes in benthic populations and their predators²⁰. Discharge of contaminants, such as copper from the slip-rings of the wind turbines, or oil spills in connection with accidents or pipe ruptures, may result in contamination of the filter-feeding benthic animals²¹. The main research tasks under this activity include:

- Characterize potential locations for offshore wind farms with respect to foreseeable environmental impacts and potential conflicts with other users of the sea at the planning stage;
- Develop monitoring protocols and indicators for acceptable change once the potential impacts have been defined;
- Investigate long-term (several years) bird flight and behavioural patterns within and around offshore wind farms; monitor collision frequencies for birds in marine areas along the coast and elsewhere in Norwegian waters for the analyses of species-specific responses to the impacts of offshore wind farms impacts.
- Analyse small-scale air-sea interaction patterns within the offshore wind farm areas and impacts on local pelagic and benthic ecosystems.
- Investigate changes caused by introducing artificial hard substrates in surrounding benthic and pelagic ecosystems, and monitor non-native and potentially invasive species.

2.5.4 Test facilities and infrastructure

Successful development of wind power should be based on reliable information on winds at each location²². To obtain such information it is important to place emphasis on new observation methods and strategies providing constraints for numerical models, addressing nowcasting issues and underpinning an improved understanding of the MBL. At present there is no available

¹⁶ "AkvaVis Brukerundersøkelse. CMR report no. CMR-2008-A52030-RA-1, November 2008.

¹⁷ Prevention of oil spill from shipping by modelling of dynamic risk. *Marine Pollution Bulletin*, **54**: 1619-1633 (2007).

¹⁸ Köller J., Köppel J., & Peters W. Eds. (2006). *Offshore Wind Energy*. Research on Environmental Impacts, Berlin.

¹⁹ Smallwood, K.S. & Thelander, C. (2008). *Journal of Wildlife Management* **72**: 215-223.

²⁰ Elliott, M. (2002). *Marine Pollution Bulletin*, **44**, iii-vii.

²¹ *Horns Rev Offshore Wind Farm Environmental Impact Assessment of Sea Bottom and Marine Biology* (2000). At: http://www.hornsrev.dk/Miljoeforhold/miljoerapporter/Baggrundsrapport_19.pdf

²² Summary of IEA RD&D Wind – 51st Topical Expert Meeting on State of the art of Remote Wind Speed Sensing Techniques using Sodar, Lidar, and Satellites, January 2007, Risø, Denmark.

validation dataset useful for detailed modelling of the MBL. The Fino platforms in the southern part of the North Sea and the Horns Rev mast 20 km offshore from the Danish coast currently collect the most suitable datasets²³, but turbulence measurements at more than one elevation are not available from these datasets. These fixed installations consist of observational platforms designed for validation purposes, recording vertical profile measurements of mean airflow, turbulence, temperature, and humidity, along with information about the sea state.

Full-scale field tests of floating offshore wind and wave energy concepts, like the METCentre outside Karmøy and similar test facilities planned along the coast of Norway, will be an important asset for the research activities at the centre. Pilot installations of new concepts, such as the Hywind floating wind turbine concept from StatoilHydro, will be installed for controlled testing and support of further technology development and research. Data collection from such installations are essential for a wide range of the research activities within the NORCOWE consortium:

- Improved understanding of the MBL and validation of CFD-codes (section 2.1.2)
- Assess wind and wave dynamic forces on floating structures (section 2.2.1)
- Validate models for wind energy capture and address issues related to nowcasting (section 2.2.2)
- Explore new technologies and strategies for asset management (section 2.3.1).

High quality measurements require state of the art instrumentation, and NORCOWE will develop dedicated observation packages to be integrated in the relevant full-scale pilot installations. The aim is to measure a broad range of relevant parameters: wave spectra (height, direction, frequency), wind profiles, temperature, humidity, droplet concentration (sea spray), radiation fluxes, slow and fast meteorology, high frequency sampling of momentum, heat and moisture (preferably recorded at two levels: 50 m and 100 m), and condition monitoring. The wind measurements will involve remote sensing techniques and wind profiling with Lidar/Sodar up to about 100 m, combined with point measurements with traditional anemometers. A key point is to link the point measurements to the large-scale wind system by additional measurements and remote sensing by satellite.

The main research tasks under this activity include (scope of work yet to be determined in detail):

- Development of observation methods and strategies to collect wind and wave information, including improved and new instrumentation and measurement concepts/observation packages
- Participation in offshore pilot testing to measure and collect data to support the other research activities in NORCOWE (e.g. sections 2.1.2, 2.2.1, 2.2.2 and 2.3.1).
- Participation in laboratory or model tank experiments (section 2.5.4)

3 Research methods

3.1 Methods to enable industrial innovation

The development of innovative industrial solutions depends just as much on the methods used as on the technology itself. The centre will have the following strengths which will enable innovation: The research teams have a wide and diverse background, ranging from the university partners' academic research and teaching activities, to the scientific, engineering, and commercial skills in the research institutes and industrial companies. The teams are also highly interdisciplinary, covering many fields of research, with both theoretical and experimental approaches. The partners have a large international network, with international collaboration in all the fields covered by the centre. Research will be carried out in such way that these characteristics are exploited in the best possible manner. Within each application area, the industry partners will take active part in the R&D work, and allocate time at the centre, to optimise the synergy between the R&D groups. To stimulate innovation within the research areas, regular open seminars will be organised at the centre to identify industrial needs and gaps in technology and knowledge. Personnel at the centre and its partners will be invited to participate in brainstorming activities to explore relevant challenges and joint projects will be established with the relevant personnel from the centre and its partners to address these challenges and ensure transfer and development of expertise among the partners.

²³ See <http://www.fino-offshore.com/> and www.hornsrev.dk/default.htm

The intention is that the centre shall be a visible and attractive R&D environment for Norwegian companies working internationally, through the active interaction between the R&D groups, and with inherent capabilities for industrial innovation. The track record of the centre partners and the involved industrial partners (cf. e.g. Section 1.4) will ensure that the technologies being developed will be implemented and taken to the market, for the benefit of the manufacturing partners, end users and society. In addition to the resources available within the partner group, guest researchers from around the world will be invited to the centre. Such guest researchers will be appointed to strengthen areas where the centre wishes to expand and in return will be expected to make tangible contributions to specific projects and in the training of PhD students.

3.2 Information / dissemination of results

A strategy for information and public relations will be established for the centre, and information about the centre and its projects will be published through a new Internet site. The work will lead to articles in international scientific and technological journals with high impact factor. It is intended to prioritise international, peer-reviewed journals, but international symposia and industrial conferences will also be used to inform the research and industrial communities of on-going activities, giving high visibility to the centre. Newspapers and non-scientific journals will also be used as information channels for more popular scientific publications. The centre will take an active role in organising national and international conferences and professional meetings.

3.3 Education

The education of PhD, MSc, and BSc students represents an important part of the strategy for education and dissemination in NORCOWE. The centre will also establish new interdisciplinary and application-oriented courses for students, partners, and industry, and organise annual seminars that highlight key topics of relevance for the industrial sector within the centre. There is a serious shortage of qualified science and technology graduates, both in Norway and in the rest of Europe, in particular within the offshore/energy industries. The university partners recognise the problem and will address it, both by establishing interdisciplinary technology oriented study programmes, and through active collaboration with the university colleges in regional networks. The centre will take an active part in the further development of these initiatives, and the state of the art study programmes at PhD level.

The centre will have a unique potential to utilize the complementary academic and engineering expertise at the academic partner institutions and their departments to further build interdisciplinary research programmes. The R&D results will then be exploited through the partners' research-based teaching activities. These relationships will be further developed, and the establishment of the centre will also make it possible for CMR and Unifob staff and industry partners to take part more actively in teaching courses at the academic partner institutions.

PhD students will form a vital part of the R&D of the centre, and will develop valuable links with partners in the centre during their studies. The centre will also consider offering post-experience courses to industry candidates. It is proposed overall that the centre fund and support 20-25 PhD positions and 30-40 MSc student projects, together with a number of BSc student projects linked with these and other projects within the timeframe of the centre. As education is an important integral part of the work, industry will benefit from the education of qualified personnel in this area.

4 Organisation

4.1 Localisation

The main research partners in NORCOWE are from Bergen (CMR, Unifob, and UiB), Stavanger (UiS), Grimstad (UiA), and Aalborg (AAU). The centre administration will be located at CMR, Bergen, but will also have offices and facilities at its disposal at the premises of the academic and industrial partners, and a virtual centre structure will be developed to support efficient collaboration amongst the partners despite its decentralised nature (section 4.2).

4.2 Collaboration and interaction between partners

The decentralised nature of the centre poses certain challenges with respect to management and communication that need to be addressed. The host organisation will dedicate an office landscape to the centre administration, and provide working places to partners in the centre. This will enable research teams within the centre to work together at the host institution in Bergen for shorter or longer periods, and the centre administration will help to organise such research stays. Guest researchers, PhD students, and representatives for the industry partners will also obtain access to this office landscape, and can use it as a common base for shorter or longer periods. The centre will also encourage mobility of personnel between the various research and industry partners.

The centre will provide facilities and equipment for establishing video conferencing or other forms of virtual interaction between the main research partners to promote close and direct communication between the centre partners on a regular basis. Internet and intranet pages for external and internal communication will be developed. This aspect will be given high priority, and is expected to require extra efforts during the establishment of the centre. The aim is to provide a common virtual meeting place where all partners in NORCOWE can access internal project directories for storing and sharing information, take advantage of a common calendar system, utilise bulletin boards for announcements, etc. The centre will also organise regular one-day or two-day seminars between partners, covering pertinent subjects to stimulate networking and knowledge transfer, and hence nourish both the scientific and the collaborative environment.

4.3 Administration and host institution

CMR will be the host organization for NORCOWE, and Eivind Dahl will be the administrative manager. Dahl is Director of CMR Instrumentation, and was instrumental in establishing the Michelsen Centre for Industrial Measurement Science and Technology (described below).

The co-manager and scientific leader of the centre will be Prof. Peter M. Haugan. Prof. Haugan is Appointed Head (director) of the Geophysical Institute at UiB, and affiliated with Bjerknes Centre for Climate Research (BCCR).

Each work package will have its own task manager (section 1.2 introduces the five WPs):

WP1	Idar Barstad (Unifob)
WP2	Asbjørn Strand (CMR)
WP3	Ivar Langen (UiS)
WP4	Trygve Skjold (CMR)
WP5	Joachim Reuder (UiB)

The task managers and the centre leaders constitute the Management Group. The task managers are responsible for the research activities within the respective WPs, and for appointing project managers for each research activity in the respective WPs. The project managers report to the task manager.

The centre will be managed through its executive board and the management group. The board consists of representatives from the research partners and industry, with the latter in majority. The chair of the board will be selected from the staff of partner members. The centre administrative manager acts as the secretary for the board.

The industry stakeholders will be able to influence the activities directly via membership in the executive board. A scientific committee consisting of representatives from all active partners will also be established, chaired by the Scientific Leader, Prof. Haugan. An advisory board open to all industry partners and including international experts may also be established.

CMR as the host institution is a well-established R&D environment with roots back to the 1930's, and the research has contributed significantly to international industrial developments. This activity has resulted in and contributed to the establishment of a number of companies such as Nera, Aanderaa Data Instruments, Fluentia (now part of Roxar), Inside Reality (now part of Schlumberger Ltd), and Clamp-On. The CMR group has thus demonstrated its capability to deliver innovative industrial solutions, and high-tech manufacturing industry have been built on these developments,

and a significant quantity of new jobs created. These developments have positioned Norway as a leading provider of advanced technologies within economically important fields covered by the CMR group, representing important technologies for Norway to build on in the future.

In 2006, the Michelsen Centre for Industrial Measurement Science and Technology was appointed status as a Centre for Research Based Innovation by the Research Council of Norway (www.michelsencentre.com). The Michelsen centre is a joint initiative between CMR and the University of Bergen together with the Bergen University College and a number of industrial partners, where CMR is the host institution for the centre. Through the build-up of this centre, already delivering substantial results, CMR has demonstrated our capabilities being a host also for the proposed centre for wind energy. This experience will also support a rapid establishment of the new centre and there will be potentials for exploitation of synergies and close cooperation between the centres.

5 International cooperation

In addition to Aalborg University (university partner in NORCOWE), the centre will cooperate with several foreign research institutions. The main partners and their role in the centre are:

- *National Centre for Atmospheric Research (NCAR), Boulder, USA*, Dr. Piotr Smolarkiewicz: Hosting visiting scientists from the centre; Numerical modelling of physical problems.
- *University of Strathclyde UK*, Prof. D. Vassalos, Dept. Naval Arch. & Marine Eng.: Scientific cooperation and exchange of students; Motion dynamics and control of marine operations.
- *National Tech. Univ. of Athens GR*, Prof. A.D. Papanikolaou, Naval Arch. & Marine Eng.: Research cooperation and student exchange; Hydrodynamic analysis and conceptual design.
- *ETHZ, Zurich, CH*, Prof. M.H. Faber: Scientific cooperation; Risk and reliability.
- *Universität Stuttgart D*, Prof. M. Kühn: Scientific cooperation and exchange of students; Offshore wind energy support structures.
- *Delft University of Technology NL*, Prof. Dr. C.W. Oosterlee Delft Inst. Appl. Math. (DIAM): Hosting visiting scientists from the centre; Modelling and wind-farm optimisation.
- *University of Glasgow UK*, Prof. Robert Furness, Dept. Ecology and Evolutionary Biology: Co-supervisor PhD Environmental studies; Ornithology.
- *Klaipeda University LT*, Prof. S. Olenin, Coastal Research and Planning Inst.: Visiting professor at the centre (1 year); Environmental studies, Marine biology and coastal ecology.
- *National Science Foundation Centre for Intelligent maintenance systems, USA*, Prof. J. Lee, Director/IMS Centre: Scientific cooperation; Intelligent maintenance systems
- *VTT Industrial Systems, FIN*, H. Kortelainen, Project Manager/VTT: Scientific cooperation; Risk evaluation.
- *Corporate Research Centre for Engineering Asset Management AUS*: Prof. J. Mathew, Chief Executive Officer/CIEAM. Scientific cooperation; Integrated Engineering Asset Management.
- *Technical University of Lisbon P*, Profs. R. Fernandes & L. Alves, Inst. of Mech. Eng.: Scientific cooperation on BOREAS technology for offshore high altitude wind power systems.

NORCOWE intends to utilise the extensive international network of the partners to establish further research projects related to offshore wind power or other sourced of environmental-friendly energy.

6 Work schedule and milestones

All major research activities will run simultaneously within the centre to best exploit the synergies. The centre will be established on April 1, 2009 (provisional date), and is planned to continue for 5+3 years. It is however our hope and intention that the centre will have built a strong position and sufficient income over these eight years so it will be possible to maintain the centre after the NFR project finishes. In general, the centre will have an annual milestone towards the end of each year to update strategies, agree on budgets and priorities and make more detailed plans for the coming year. Annual strategy conferences will be important to define work schedules and set short term and long-term milestones. The following major milestones are defined (on a preliminary basis):

- M1 Establishment of the centre (Q2-Q4 2009)
- M2 Start-up of the first PhD and Post Doc research fellowships (Q1 2010)
- M3 Annual research and innovation seminars (Q1 and Q3 each year)
- M4 Annual strategy conferences / meetings for next year planning (Q4 each year)
- M5 Decision on continuation or closure of the centre (Q1 2017)

7 Budget

Budget issues will be subject to short (one year) and long term (2 – 3 year) planning by the centre administration in close cooperation with the Executive Board of the centre.

Table 7-1 Budget (MNOK) as of December 3, 2008.

Activities\Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Wind and ocean conditions	3.6	5.4	5.4	5.8	5.8	6.1	6.2	6.5	2.0	46.8
Offshore wind technology and innovative concepts	5.7	8.4	8.4	8.4	8.4	8.6	8.6	8.8	2.0	67.3
Offshore deployment and operation	5.6	10.1	10.1	10.1	10.1	10.6	10.6	10.6	2.6	84.5
Wind farm optimisation	3.9	5.8	5.8	5.9	5.9	6.1	6.1	6.3	1.6	47.4
Common themes	3.5	4.8	4.8	4.8	4.8	4.8	4.8	4.3	1.0	37.6
Equipment	6.0	3.0	3.0	2.5	2.5	1.3	1.2	1.0	0.0	20.5
Management and operating costs	1.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.8	20.0
SUM	30.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	10.0	320.0

8 Cost distribution among partners

Detailed budgets and cost distributions among the main partners will be worked out as part of a process to establish the centre, and cooperation partners will work through the main partners.

Table 8-1 Cost distribution among partners (MNOK), as of December 3, 2008.

Partner \Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Unifob	5.2	7.6	7.6	7.6	7.6	7.9	7.9	8.0	2.1	61.5
University of Bergen	2.6	3.7	3.7	3.7	3.7	3.8	3.8	4.0	1.0	30.0
CMR (host institution)	13.4	13.8	13.9	13.3	13.4	12.4	12.3	12.3	3.2	108*
University of Agder	2.0	3.0	3.0	3.0	2.9	3.1	3.1	3.1	0.8	24.0
University of Stavanger	1.9	2.8	2.7	2.8	2.8	2.9	2.9	2.9	0.7	22.5
University of Aalborg	2.9	4.3	4.3	4.3	4.3	4.4	4.4	4.5	1.2	34.5
Industrial partners	2.0	4.8	4.8	5.3	5.3	5.5	5.6	5.2	1.0	39.5
SUM	30.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	10.0	320.0

(*) This item includes centre management, operating costs, and equipment, for a total amount of 44.5 MNOK (cf. Table 7-1). The centre administration and Executive Board determine the final distribution of the equipment costs.

9 Funding plan

Table 9-1 should be viewed as a preliminary model for funding. Changes in the distribution among partners and other details will be subject to discussion as part of a process with all partners to establish the centre. The proposal is discussed with several companies who have expressed interest in participation. Please c.f. the attached letters of intent (LoI) from industry partners.

Table 9-1 Funding plan (MNOK) as of December 3, 2008.

Institution \ Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Unifob	0.69	0.91	0.91	0.91	0.92	0.91	0.92	0.91	0.22	7.30
University of Bergen	0.36	0.47	0.47	0.47	0.48	0.47	0.48	0.47	0.13	3.80
CMR (host institution)	0.72	0.96	0.97	0.96	0.97	0.96	0.96	0.96	0.24	7.70
University of Agder	0.28	0.38	0.37	0.38	0.37	0.38	0.37	0.38	0.09	3.00
University of Stavanger	0.26	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.09	2.80
University of Aalborg	1.49	1.99	1.99	1.99	1.98	1.99	1.99	1.99	0.49	15.90
Research Council	15.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	5.00	160.00
Industry funding*	11.20	14.94	14.94	14.94	14.93	14.94	14.93	14.94	3.74	119.50
SUM	30.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	10.00	320.00

(*) Industry funding includes an estimated 80 MNOK in cash and 39.5 MNOK in kind.

10 Industrial relevance

Both the motivation for the centre (section 1.3) and the attached letters of intent from the industrial partners testify to the high industrial relevance of the programme. The industrial partners in the centre are all world leaders within their respective fields, and their participation demonstrates the industrial relevance and innovative potential of the centre. In addition to the results from the research activities, there are several specific deliverables from an industrial point of view:

- An operational CFD tool with built in models for wind park optimisation (FLACS-Wind²⁴)
- Advanced models for the structural response of complex floating structures subjected to both hydrodynamic and aerodynamic loads.

Norwegian industry will also benefit from the highly qualified personnel that will be educated through the NORCOWE project.

11 Environmental impact

The primary long-term environmental impact from the prospective research activities within NORCOWE is increased supply of environmentally friendly and sustainable wind energy, and this will be an important contribution to the ongoing efforts on reducing global climate change. However, large-scale deployment of offshore wind parks may also influence the marine ecosystem in hitherto unforeseen ways, and the centre includes research to address this issue as well.

12 Gender aspects – recruitment of female scientists

All partners in NORCOWE promote gender equality, and are committed to the principle of equal opportunity in employment between men and women. NORCOWE aims at recruiting 50 % female researcher for the 20-30 PhD scholarships in the centre. Furthermore, the partners will actively seek to address the unacceptably low number of female scientists within the natural sciences through dedicated and long-term initiatives for motivating pupils in secondary school, high school, and in early years of higher education to choose science courses. UiB and CMR participate in the funding of the Bergen Science Centre that promotes the interest in natural sciences. A committee at the Faculty of Mathematics and Natural Sciences at UiB addresses ways of recruiting more women to scientific positions. NORCOWE intends to become an effective tool for CMR, Unifob, UiB, UiS, UiA, and AAU in recruiting female researchers into permanent positions.

²⁴ CMR GexCon owns the full intellectual property rights to the CFD codes FLACS and FLACS-Wind.