Copenhagen Offshore Wind 2005

PhD@Sea - A PhD program on large-scale offshore wind energy in the Netherlands

E.H.M. Mast M.B. Zaaijer
Delft University of Technology, DUWIND, Wind energy research group
Kluyverweg 1, 2629 HS Delft, The Netherlands. Contact: e.h.m.mast@lr.tudelft.nl

Keywords: *scenarios, spatial planning, concepts, design, grid, installation, operation and maintenance.*

Abstract

In 2004 the consortium WE@Sea started its research program. It follows an integral approach, creating a viable offshore wind energy industry to meet the ambitious target set by the government; 6000 MW installed offshore wind energy by 2020 in the Dutch Exclusive Economic Zone. Within WE@Sea, a PhD program has been incorporated named PhD@Sea. Nine PhD researchers have started at two partners in WE@Sea, eight at Delft University of Technology and one at the University of Twente.
Eight topics have been defined: Large blades, Concepts, Morphology, Grid stability, Park-grid interaction, Offshore access, RAMS (Reliability, Availability, Maintainability and Serviceability) and Scenarios. The content of the ninth topic is currently under discussion. In this paper the eight topics are described and their aims are presented. Also, an overview of the WE@Sea program is presented and the organisation of PhD@Sea within this framework. Because of its integrating character, the PhD topic Scenarios is presented with some more detail.

Introduction

In the Netherlands some wind parks have ‘wet feet’, such as the Lely wind park in the IJsselmeer. The turbines stand at 800 meter of the coast. None however have been placed in the North Sea, where the conditions are much harsher. Denmark and the UK now have their first projects placed in the North Sea at Horns Rev (2002), Blyth, Scroby Sands and Kentish Flats. The first Dutch offshore wind park under North Sea conditions has started preparations this year and installation will start in 2006 [1].

To aid the development of offshore wind energy in the Netherlands several companies, institutions and interest groups have joined forces in the consortium WE@Sea [2]. The 33 partners of WE@Sea come from all sectors involved in offshore wind energy; offshore technology, wind energy technology, logistics, energy supply, finance, energy consultancy and environmental interest. Following an integral approach several research lines are defined, with the objective to gain knowledge that enables and accelerates the large-scale exploitation of offshore wind energy in the Netherlands. The consortium is set to create a viable offshore wind energy industry to meet the ambitious target set by the government; 6000 MW installed offshore wind energy by 2020 in the Dutch Exclusive Economic Zone. As part of the scientific program of the consortium, a PhD program named PhD@Sea has been formulated, consisting of nine PhD researches. These will be facilitated at Delft University of Technology and the University of Twente. An essential part of the PhD-program is the interaction of activities in the field and the scientific research, bringing together experts and researchers from various disciplines. Experimental facilities will be set up for verification of

theory and models. Subjects are: Large blades, Concepts, Morphology, Grid stability, Park-grid interaction, Offshore access, RAMS and Scenarios.

This paper provides a short description of the research program of WE@Sea and of the position of PhD@Sea therein. Furthermore, the PhD projects and their objectives are described. Because of its integrating character, the project Scenarios is described with some more detail. Fitting into the WE@Sea research line Integration, it combines the different aspects with the objective to find the guidelines for the realisation of the target of 6000 MW offshore wind energy based on the conditions and the opportunities.

WE@Sea and PhD@Sea

The corporation WE@Sea was founded early 2003 with the broad objective of undertaking activities to stimulate the development of offshore wind energy. The first formal activity of the corporation was the submission of the research program *Large-scale wind power generation offshore - towards an innovative and sustainable business* on behalf of a consortium of 33 partners. This research program was granted funding of 13 M€ under the framework of the BSIK-program of the Dutch government. With a budget of 26 M€, an effort of approximately 180 person-years and a duration of over 4 years, the program is organised with secondary tendering of projects of the consortium partners.

The content of the research program is organised in 7 research lines, as illustrated in Figure 1 and explained in the next sections [3].

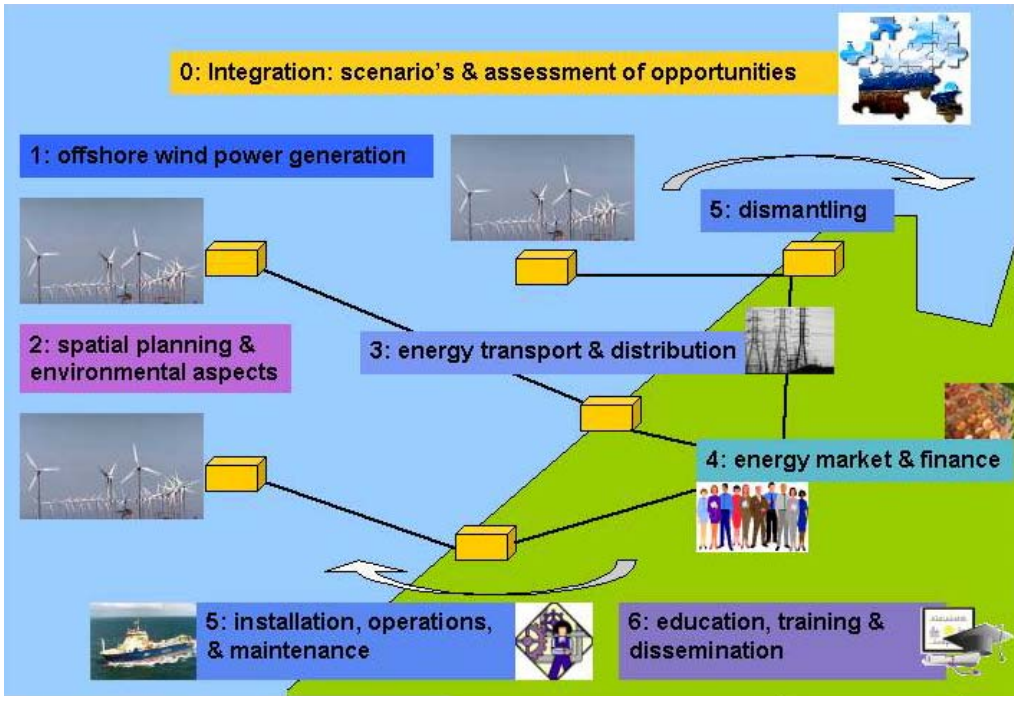

Figure 1: Research lines in the WE@Sea program visually mapped on the offshore wind energy supply chain.

Research line 0: Scenario's & assessment of opportunities

In order to keep an overview scenarios for the development of 6 GW offshore wind energy in the Dutch sector to the North Sea will be generated. The scenarios will set a frame of reference for the other research lines and provide a platform for the exchange of information.

Research line 1: Offshore wind power generation

The objective of this research line is to facilitate and accelerate the design of efficient, reliable and economic offshore wind turbines and wind parks, by improvement of design tools and models.

Research line 2: Spatial planning and environmental aspects

This research line surveys spatial planning requirements to provide investors with information that enables effective site selection and development. This includes an evaluation of safety aspects and of positive and negative effects on the North Sea ecosystem.

Research line 3: Energy transport and distribution

The objective of research line 3 is to develop a full understanding of large scale offshore wind energy integration in the electrical grid with the aim of maintaining electrical system stability and reliability:

Research line 4: Energy market and finance

The objective for this research line is to increase the value of wind power in the electricity market and to obtain insight in insurance and finance risks of offshore wind farms.

Research line 5: Installation, operation & maintenance, dismantling

The target of this research line is to develop optimal installation logistics, establish a decision system for maintenance and inspection visits, develop a vision on dismantling techniques and generate a concept describing the required port capabilities and facilities.

Research line 6: Education, training and knowledge dissemination

This research line aims at educating specialised people, managers, decision makers and other key people in industry and government and transferring new knowledge and skills from the developers to the users.

The PhD@Sea project

The PhD program *PhD@Sea* is one of the projects that have been accepted by WE@Sea in the secondary tendering procedure. The research subjects are divided over the research lines of the overall program. Being embedded in this large program, the PhD researchers have contact with the consortium partners and have good access to their knowledge and information.

PhD topics

The next sections describe seven of the eight PhD topics that are defined in the PhD program [4]. The eighth project, Scenarios, will be described in the following chapter.

Large blades[1]

In the next decades, more than 1,000 turbines will need to be installed in the North Sea. Two of the main requirements formulated by WE@SEA for the 3,000 blades to be constructed are durability and sustainability. The blades should be more fatigue resistant to increase the current lifetime of 20 years and to reduce preventive and corrective maintenance visits, which are currently required 4 to 6 times a year. In the light of producing greener energy, efforts are also put toward the development of economic and environmentally friendly manufacturing processes, in procedures for installation and dismantling, and in the destruction and re-use of materials.

---

[1] Contact: Kjelt van Rijswijk, Design and Production of Composite Structures, Faculty of Aerospace Engineering, TU Delft, Kluyverweg 1, 2629HS Delft, +31 (0)15 27888981, k.vanRijswijk@lr.tudelft.nl

In that respect, design methodologies and manufacturing processes for large thermoplastic composite (TPC) blades are currently being developed at the Delft University of Technology. TPCs potentially offer a higher resistance to fatigue than their thermoset-based counterparts currently used due to the higher toughness of the matrix. In addition, TPCs can be remoulded upon melting, enabling re-use of the blade material. In order to produce blades with lengths in excess of 50 meter, the currently most widely applied manufacturing process for turbine blades, vacuum infusion, is maintained (Figure 1). This process uses a low viscosity resin that is injected in a mould containing pre-placed fibres, followed by a curing step. Since the viscosity of thermoplastic polymer melts is too high, reactive processing is required: a low viscosity monomer melt is injected between the fibres, followed by in situ polymerization of the monomer into a thermoplastic matrix.

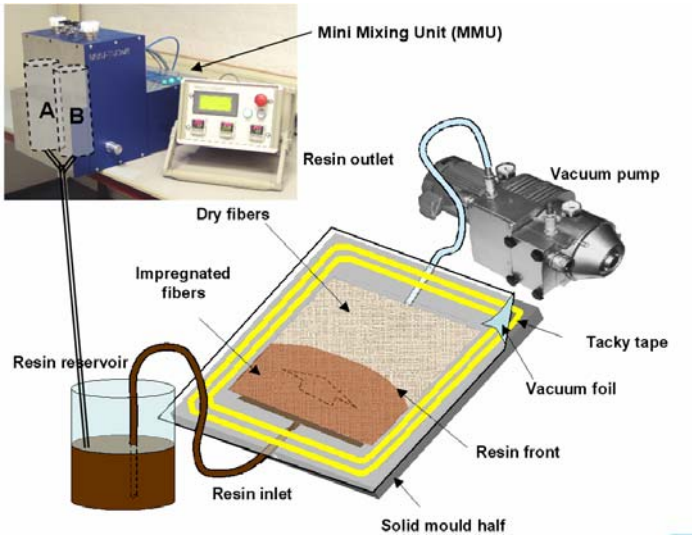

Figure 2: Vacuum infusion process for anionic PA-6 developed at the Delft University of Technology.

Concepts[2]

Over several decades wind turbines have evolved to a now very commonly applied concept: the horizontal axis turbines with three pitchable blades that can rotate at various speeds and a gearbox to increase rotation speed of the generator shaft. The only serious competitive concept in the market is a direct drive, without gearbox and with a large size low speed generator. In an offshore environment, the turbines have a tubular tower mounted on either a gravity base structure or a monopile, which is a cylindrical steel pile foundation. The installation is performed with a jack-up platform or vessel, following more or less the same steps as for an onshore wind turbine. Operation and maintenance is also essentially approached in the same way as for onshore wind turbines. This is complicated, however, by offshore access and low workability. Therefore reliability of offshore turbines does receive extra attention.

Much knowledge and experience of both (onshore) wind energy exploitation and offshore engineering is used in offshore wind farms. This gives existing concepts a tremendous head start for this relatively novel application. However, it is legitimate to ask whether existing concepts are best matched to the exploitation of wind energy in this new environment. In this research various concepts will be generated and their properties compared, to find the answer to that question. Part of the research is dedicated to finding an appropriate approach

[2] Contact: Michiel B. Zaaijer, Wind Energy Research Group, Faculty of Aerospace Engineering, TU Delft, Kluyverweg 1, 2629 HS Delft, tel. +31 (0)15 2786426, m.b.zaaijer@lr.tudelft.nl

to concept design. The results will provide a justification of the current developments or suggest alternative directions with good potential.

Morphology[3]

The North Sea is a very dynamic area, which is reflected in several morphological features, ranging from small ripples to large tidal sand banks. The larger of these patterns interfere with human activities at sea, e.g. sand banks can cause problems for navigation and migrating sand waves are a risk for pipelines and communication cables. Vice versa, new activities like large-scale sand extraction and offshore wind parks may affect the morphological features of the seabed. For a sustainable use of the North Sea, it is important to understand and predict the interactions of the seabed and human activities.

The goal of this project is to build a GIS of the North Sea in which data of the North Sea is gathered. This data can then be compared to the results of morphological models, so these models can be calibrated and validated. By implementing the morphological models, the GIS will be able to predict the integral consequences of human activities in the North Sea area. Therefore, it can be used to propose the most suitable locations for certain activities in the North Sea area.

Grid stability[4]

The anticipated growth of wind power will have increasing impact on power system operation, including the power balance. In power systems, a power balance between generation and load must be maintained at all times. Because large quantities of electric power cannot be stored, generation must equal load at all times: production follows demand at all times in order to maintain the power balance and secure power system stability. In order to do this, the production of power plants is continually adjusted to match the system load. Compared to conventional generation units (fossil fuelled power plants), the production of wind turbines is less controllable due to their uncertain and varying energy source, the wind. Therefore, large-scale wind power complicates power system balancing.

The aim of this PhD-project is to facilitate large-scale integration of wind energy in electrical power systems. This is done by developing solutions for problems in maintaining the power balance. Different strategies are being explored, concerning both generation and load. The capabilities of conventional generation plants to follow wind power variations are investigated: strategies include partial loading of conventional generation (reserves).Also, demand-side management is explored: strategies include load reduction at times of low wind power. Furthermore, the management of wind power production itself is considered, such as wind park production control and improved wind power forecasting. Last, options for large-scale energy storage in power systems are investigated, such as the use of pumped hydro and flow-batteries.

The strategies mentioned are modelled in a continuous mathematical simulation program. Realistic models are made of wind parks, loads and conventional generation units, using literature models and existing models of producers and grid operators. These models are then connected through a basic power system model, taking into account power system balancing control mechanisms, and simulated for minute-hour time-ranges. Furthermore, essential characteristics of the market design are taken into account, such as the organisation of imbalance regulation between the system operator and market parties. The

---

[3] Contact: Henriët van der Veen, Water Engineering and Management, Faculty of Engineering Technology, University of Twente, tel. +31 (0)53 4891013, h.h.vanderveen@utwente.nl

[4] Contact: Bart C. Ummels, Electrical Power Systems Laboratory, Faculty of Electrical Engineering, Mathematics and Computer Science, TU Delft, Mekelweg 4, 2628 CD Delft, +31 (0)15 278 4051, b.c.ummels@ewi.tudelft.nl

overall objective of this PhD-project is the development of optimal solutions for maintaining power system stability with large-scale wind power.

Park-grid interaction[5]

Introduction of large wind parks in the national grid will give a different transient behaviour of the system. The objective of this PhD project is to investigate the integration of wind parks in the grid and the electrical interaction between wind parks and the power grid with respect to normal operation, dynamic behaviour, disturbances and power quality.

To evaluate the transient behaviour of the grid, a model of the Dutch grid and a part of the West European high voltage grid will be developed. First dynamic models of individual wind turbines in wind parks (ITWFM) will be formed. These models will be used to study the interaction between the turbines within a wind park and the interaction at the coupling point to the grid. Based on these ITWFM an aggregated dynamic model of wind parks (AWFM) will be formed as a wind park model for power system studies.

The transient park model of the wind park AWFM will be integrated into the national grid model together with the transient models of the existing power stations. The requirements posed on the spinning reserve of the total system and the primary frequency control of the existing generating units shall form an important item of the study. Disturbances of the system, such as short circuits, loss of main interconnections and loss of production capacity will be studied and evaluated. In case of unacceptable transient behaviour of the total system counter measures will be proposed and the effects of these measures will be evaluated.

Wind speeds exceeding the cut-out wind speed are a reason for sudden loss of production capacity. The probability of these wind speeds as well as the correlation between them at different locations within a wind park and between different parks is examined. With these probabilities and correlations suitable shut-down strategies will be developed.

Ampelmann: offshore access[6]

This PhD research will study the possibility of providing access to offshore wind turbines with the Ampelmann, a system that creates a motionless transfer deck on a ship by using a motion compensating platform, see **Error! Reference source not found.**. The focus of this study will be on the technical and economical feasibility as well as on the safety aspects.

Offshore wind turbines require frequent maintenance and repair. Reaching these turbines offshore is difficult and expensive: unless a deck is mounted on top of a turbine for hoisting personnel from a helicopter, ship-based access is the only option. Such access is however limited by the weather conditions. The main problem is the transfer of personnel and equipment from a moving ship deck to a fixed turbine, and these relative motions become larger in rougher weather conditions. To solve this problem, the Ampelmann was invented. This system consists of a transfer deck on top a Stewart platform mounted on a vessel. By measuring the vessel motions and instantly controlling the actuators in the platform, the transfer deck can be kept motionless.

In this research, the following points shall be addressed: The system requirements are to be determined by deciding on application range and limitations. The basics of design are to be studied and a proof-of-concept shall be delivered in order to further develop the design requirements. The technical feasibility of a prototype shall be examined: problems with

---

[5] Contact: Yi Zhou, Electrical Power Processing, Faculty of Electrical Engineering, Mathematics and Computer Science, TU Delft, Mekelweg 4, 2628 CD Delft, tel. +31 (0)15 2785744, Y.Zhou@ewi.tudelft.nl

[6] Contact: David Cerda Salzmann, Offshore Engineering, Faculty of Civil Engineering and Geosciences, TU Delft, Stevinweg 1, 2628 CN Delft, tel. +31 (0)152785077, Cerda@offshore.tudelft.nl

regard to scale, dynamics, installation and control system shall be addressed. The safety aspects of this system are to be looked upon. An economical feasibility study and a design for a case study shall be made/ performed.

Figure 3: The Ampelmann, an offshore access vessel developed at Delft University of Technology.

RAMS[7]

Achieving high availability is economically vital to offshore wind turbines. This will be guaranteed by improving maintainability and serviceability together with high reliability design. This research will investigate methods and tools for achieving such high availability and reliability by increasing effectiveness and efficiency of maintenance by using better maintenance strategy and planning such as remote maintenance, new monitoring devices, intelligent diagnosis techniques and self-maintenance.

Current practice is mainly focused on preventive and corrective maintenance. This project will investigate the possibilities of modern maintenance concepts, on operational and system level. Systems aim at higher availability during operations by easier or even automated maintenance and service and a quicker recovery after failure. These require technological developments in information and communication technologies and micro-electronics.
Examples of modern maintenance concepts are reliability-centred maintenance, risk-based maintenance and self-maintenance. In the latter monitoring sensors deliver information through communication channels. Once the information is collected, intelligent diagnosis systems decide the appropriate automatic maintenance.

In this project the feasibility of these advanced maintenance concepts are judged. Practical operational data will be gathered from existing wind turbines. New wind turbines to be built in Delft will also be used and here the prototype system can be tested.

Scenarios[8]

Scenarios are internally consistent views of what the future might turn out to be [5]. They are not predictions of the future, but form different possible futures so one can explore the uncertainties of the future. One can look at the influences that a changing environment could

[7] Contact: Erika Echavarria, Intelligent Mechanical Systems, Faculty of Mechanical, Maritime and Materials Engineering, TU Delft, Mekelweg 2, 2628 CD Delft.
[8] Contact: Eeke H.M. Mast, Wind Energy Research Group, Faculty of Aerospace Engineering, TU Delft, Kluyverweg 1, 2629 HS Delft, tel. +31 (0)15 2788092, e.h.m.mast@lr.tudelft.nl

have on a company or events that could occur such as technological developments or an oil crisis. Also the scenarios can make the ramifications of your decisions visible as they play out through time.

Objective

For WE@Sea, scenarios will be formed about the possible developments in offshore wind energy in the Netherlands. They form different paths how the goal of 6000 MW could be achieved and what consequences they would entail for the stakeholders. They should show the critical path giving direction to policy. The opportunities that could speed up the development should be incorporated, as well as the threats that can slow down the development. Different combinations of possible threats and opportunities form different possible futures.
The 6000 MW is not a single park; it is the combined wind power of several wind parks in the North Sea built by different consortia. In WE@Sea, the partners all expressed their support to the target of 6000 MW offshore wind energy, but their interests differ. Conflicts of interests may arise. The scenarios should show where consensus needs to be formed or weaknesses should be tackled. Different scenarios with objective results can be used as a communication tool in the weighing of interests. The aim of the PhD research Scenarios is to find the guidelines for the realisation of the target of 6000 MW offshore wind energy in the Dutch EEZ based on the conditions and the opportunities for the stakeholders. This will be done by generating and assessing possible and realistic scenarios for its implementation.

The approach taken in this project is described in Figure 4. The phases depicted will be clarified in the following paragraph.

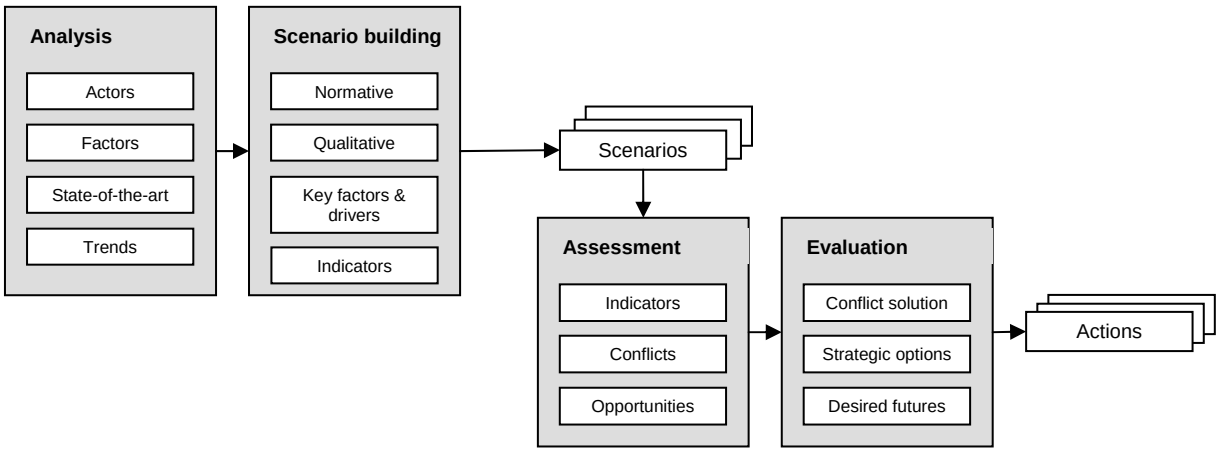

Figure 4: Schematic of methodology.

Analysis

In the analysis phase all critical actors are identified together with the measures they can take that influence the development of offshore wind energy in the Netherlands. Factors are identified that can have influence on or be influenced by the development of offshore wind energy, considering different aspects: social, technological, economical, environmental and political. Together with their causal relations they will form the model of the development of offshore wind parks in the Netherlands, as illustrated in Figure 5. *External factors* form the *environment*; all that can influence the development of offshore wind energy in the Netherlands but cannot be influenced by the WE@Sea partners. *Internal factors* can be influenced by decisions of the partners. The state-of-the-art and expected trends are also analysed for the construction the model and its inputs.

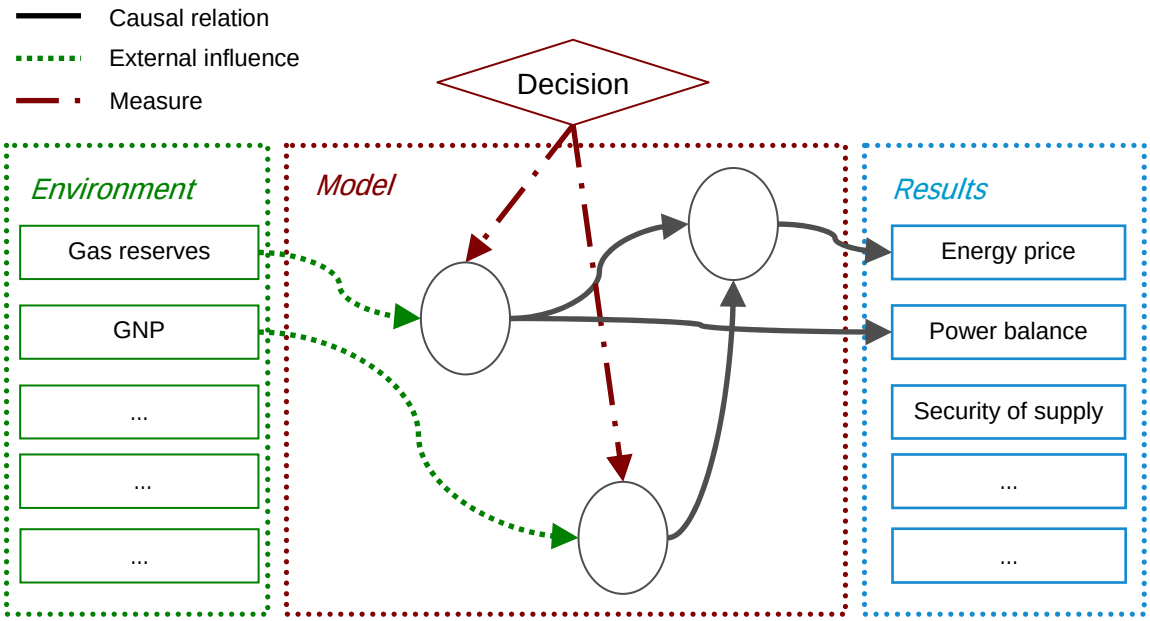

Figure 5: Illustration of the model of offshore wind energy development.

Scenario building

The scenarios to be made are *normative* scenarios; scenarios with a certain desired future. The scenarios will go toward the desired implementation of 6000 MW offshore wind energy in the Dutch EEZ by 2020. The scenarios will also be *strategic* scenarios; they will incorporate the possible and realistic changes of the *environment* as well as the consequences for and of decisions.

Uncertain factors with a great impact form the *key factors* that make the different possible futures of the scenarios [6]. Examples of key factors are the rise of fossil fuel prices and technological developments such as energy storage.

Assessment

To act as guidelines for WE@Sea, the scenarios should show the possibilities and conditions for the development of 6000 MW by 2020. The scenarios can give direction to policy by showing the consequences of decisions. Examples are the start of new technological research or weaknesses that should be tackled.

Since the interests and goals of the actors differ, they have different criteria to measure the desirability of a possible future. Quantification of criteria is therefore subjective. As an objective description of the state described in the scenario, indicators will be given. For example an indicator can be the resulting price of electricity per kWh in each scenario. No judgement is made however what the exact acceptable range for the electricity price is or how the value should be weighed against the other indicators to define the desirability of an individual scenario. The scenarios can be used as a communication tool in the discussion of weighing interests and targets.

Evaluation

With the feedback from the partners of WE@Sea and critical actors such as involved governmental offices the scenarios and the results of the assessment will be evaluated.

Current status

The project, having started January this year, is now in the analysis phase, gathering data on trends and possible key factors. To get a basis for the most important opportunities and threats expected by the partners in the coming 15 years, a Group Decision Room (GDR) meeting was organised. In a GDR meeting computers can be used in the discussion, giving

the possibility of anonymous and parallel participation. The opportunities and threats have been mapped in the GDR session together with their timeframe, impact and uncertainty [7]. The main results show that on the short term (2005 to 2010), inconsistent governmental policy is seen as the most important, certain bottleneck. A key factor is formed by the uncertain possibility that the government will turn to a consistent energy policy. A named threat is the uncertain possibility of great technological failure of offshore wind energy projects. Above opportunity and threat are therefore two of the key factors behind different scenarios.

Acknowledgements

The authors would like to thank the other PhD students for their contributions to the project descriptions. The project PhD@Sea is substantially funded under the BSIK-programme of the Dutch Government and supported by the consortium WE@Sea.

References

1. Noorzeewind, website www.noordzeewind.nl, last visited 15 August 2005.
2. WE@Sea, website www.we-at-sea.org, last visited 15 August 2005.
3. WE@Sea; W&W, *Large-scale wind power generation offshore - Towards an innovative and sustainable business Proposal for a knowledge programme for Bsik* (Confidential), WE@Sea, Petten, 14 February 2003.
4. Delft University of Technology; University of Twente; Energy research Centre of the Netherlands, *PhD@Sea - Proposal for PhD research in the framework of BSIK-programme Large-scale wind power generation offshore*, DUWIND, Delft, 28 June 2004.
5. Gill Ringland, *Scenario planning: Managing for the future,* quoting Michael Porter (1985), Wiley, Chicester, 1997.
6. Peter Schwartz, *The Art of the Long View: Planning for the future in an uncertain world,* Wiley, Chicester, 2002.
7. E.H.M. Mast, *Verslag Group Decision Room bijeenkomst 1 juli 2005,* Wind Energy Research Group, WE-05197 , Delft, July 2005.