Tools for estimating operation and maintenance costs of offshore wind farms:

State of the Art

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TOOLS FOR ESTIMATING OPERATION AND MAINTENANCE COSTS OF OFFSHORE WIND FARMS: State of the Art

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Summary

In 2000, ECN has defined a long term R&D program with the ultimate aim to lower the O&M (Operation and Maintenance) costs of offshore wind farms. Part of this R&D program focuses on the development of models to quantify and optimise the O&M aspects in the planning phase of wind farms. This has resulted in a software tool with which project developers of offshore wind farms are able to estimate the annual average O&M costs. The model takes into account (1) the failure behaviour of turbine components in terms of failure frequencies and associated repair actions; (2) the access vessels and hoisting equipment; and (3) the wind and wave climate at the intended location.

Germanischer Lloyd Industrial Services GmbH, Business Segment Wind Energy (GL Wind) validated the software as a third party. As GL Wind has realised that the financial issues will play a more important role as the project size for wind farm projects increases. Thus validated software will give more security for the developers applying the software tool and for the financers and insurance companies relying on the results of the software tool.

This paper describes ECN's O&M Tool. Second, the paper presents the results and the reasons of the validation, including the description of the limitations and benefits of the software tool. Finally, the paper discusses in a more general way the use of tools to estimate O&M costs during project development and project certification.

1. ECN O&M Tool

ECN has defined a long term R&D program with the ultimate aim to lower the O&M costs of offshore wind farms. In 2004, the R&D program has resulted in a software tool, called "ECN O&M Tool". The tool and user manual [Ref. 1] were updated in 2007 and validated by GL Wind.

The ECN O&M Tool has been developed to estimate the long term annual average costs and downtime of an offshore wind farm, assuming a certain maintenance strategy. By means of "what-if analyses" project developers are able to compare the adequacy of different maintenance strategies with each other. On the one hand, the tool functions very straight forward as it is programmed in MS-Excel and is very user friendly. Each change in the input parameters immediately results in a change of the output parameters. On the other hand, the model requires an extensive list of input parameters and a detailed description of the proposed O&M strategy. By doing so, the tool forces the user to consider all aspects relevant for O&M in large detail. During the process of collecting input data and making assumptions w.r.t. to the O&M strategy, users are often confronted with the fact that only little information on e.g. failure rates, capabilities of vessels, etc. is known in the planning phase. By most users of the model the process of finding agreement within a project team on the input parameters with their uncertainties and on different assumptions w.r.t. the O&M strategy is considered equally important as the model output itself!

The tool is not a simulation tool. Instead it uses long term average data as input (failure rates, wind and wave statistics, costs, etc.) and generates long term average values as output (costs and downtime). The tool is not intended to optimise logistic aspects.

The ECN O&M Tool is programmed in MS-Excel with Visual Basic; the add-in module "@Risk" [Ref. 2, Ref. 3] is needed to carry out uncertainty analyses. The Tool is delivered with a clear and extensive user manual. It contains informative annexes on generic failure rates; sizes, weights, and costs of main components; O&M key figures; information on and capabilities of commonly used access vessels and crane ships; and a template for reporting input, assumptions, and modelling results. The O&M tool has been developed to especially analyse the O&M aspects during the planning phase of a wind farm.

1.1 Types of maintenance

In the CONMOW project [Ref. 6] it is shown that when considering wind turbine technology the following types of maintenance can be distinguished.

1. Calendar based maintenance: the costs and effort are usually determined by one or two visits per year. After 3 or 4 years the calendar based maintenance costs can be somewhat higher due to oil changes in gearboxes or major overhauls.
2. Unplanned corrective maintenance: due to random failures the O&M effort is more difficult to predict than calendar based maintenance.
3. Condition based maintenance: it might be that major overhauls have to be carried out, for instance due to unexpected wear out of components designed for the lifetime (e.g. replacement of gearboxes or pitch drives). This type of maintenance is not foreseen initially, but when it has to be carried out during lifetime it generally can be planned on time to limit unforeseen downtime.

In Figure 1 the contribution of the three different types of maintenance to the total O&M costs are schematically drawn for the lifetime of an offshore wind farm.

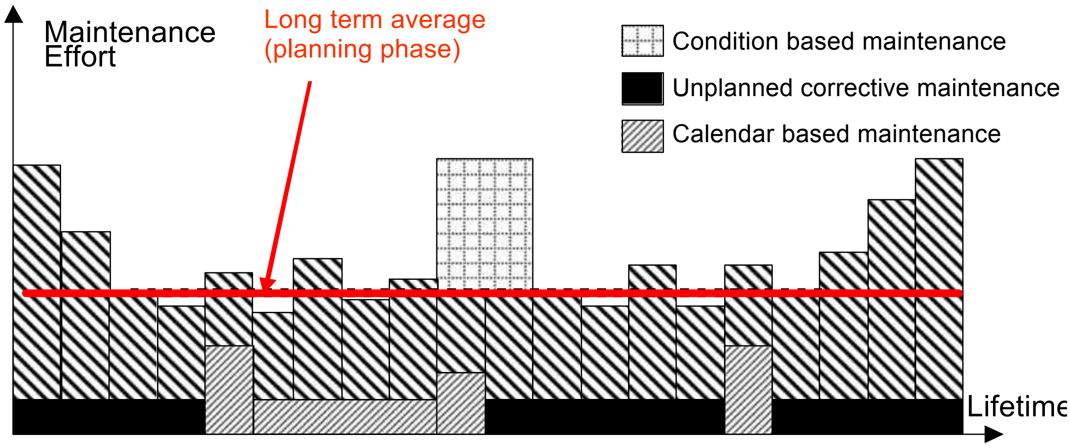

Figure 1: *Schematic overview of the maintenance effort over the lifetime of offshore wind farms*

The calendar and condition based maintenance can be planned in advance and within the ECN O&M Tool, the associated costs and downtimes are be determined straightforwardly with minimum uncertainties. The O&M Tool focuses on determining costs and downtime related to unplanned corrective maintenance because this is much more difficult to predict and covered with large uncertainties. Determining the corrective maintenance costs of an offshore wind farm is similar to the approach for asset management and risk analyses being used in many branches of industry. The risk is defined as: "*Risk = Probability of failure * Consequences".* For offshore wind farms, the risk is expressed in terms of (annual) costs, the probability of failure is represented by the (annual) failure frequency of components, and the consequences are being determined by the repair costs. The repair costs consist among others of: labour costs, material costs, costs for access vessels and or crane ships, and revenue losses. So:

*Annual O&M costs = Annual failure frequency * Repair costs*

The ECN O&M Tool in fact deals with determining the failure frequencies of components and determining the repair costs per failure mode. The tool treats each failure independently.

1.2 Structure of the ECN O&M Tool

The ECN O&M Tool [Ref. 4 and Ref. 5] is intended to be used in the planning phase of an offshore wind farm and should be used to determine the long term annual average costs (indicated by the red line in Figure 1), downtime, and revenue losses. The ECN O&M Tool focuses on determining the costs and downtime resulting from unplanned corrective maintenance. The process of cost modelling is illustrated in Figure 2.

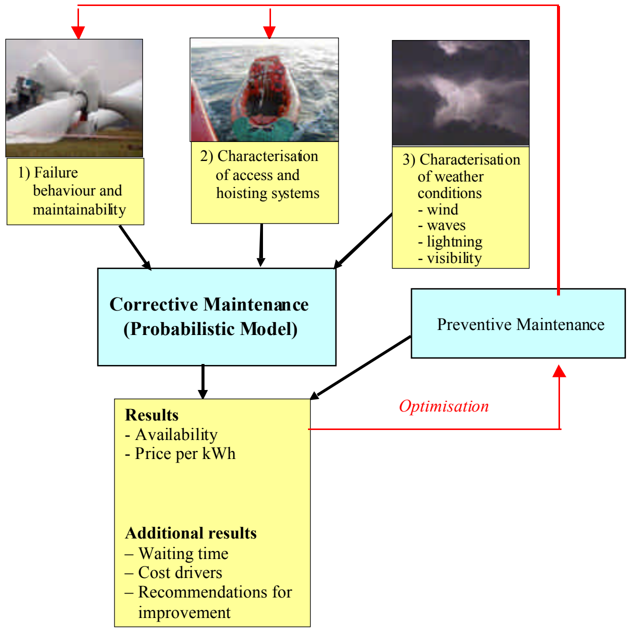

Figure 2: *Schematic representation of the ECN O&M Tool for determining the O&M costs and downtime of an offshore wind farm.*

At first a baseline O&M strategy is determined to maintain the intended wind farm. For the baseline strategy, best guesses are being made by the project team for the different input parameters (failure rates, characteristic values of vessels and equipment, and weather conditions). The model results in costs and downtime and the project team can start analyzing the results. Cost drivers can be identified and based on these possible areas for improvement (e.g. using more reliable components or vessels with improved accessibilities) can be identified. If the project team has selected an optimal maintenance strategy, it is recommended to analyze the uncertainties with the probabilistic part of the model. By doing so, insight is gained in how the different uncertainties in the input parameters contribute to the uncertainties in the outcome of the model.

The model to determine the long term yearly average costs and downtime due to unplanned corrective maintenance is based on the repair process as depicted in Figure 3. In general it can be stated that the central operation office will be informed that an alarm has been triggered. Once the operator has notified the alarm, he has to decide whether the turbine can be restarted remotely or that a visit is necessary to determine whether the wind turbine can be restarted without maintenance or maintenance is required first. If repair is necessary the operator needs to organise the repair action, mobilise the crew, a ship and if necessary spare parts and large hoisting equipment.

The Time To Repair (TTR) can be split up into four time intervals.

1. The interval *T_logistics* denotes the period of time between the wind turbine was shut down and the repair crew is organised and ready to travel to the turbine for repair. In this period, also the time needed to organise equipment and spare parts is considered. So the length of this interval depends on the availability of an inspection team, the availability of materials, and the availability of equipment for travelling and hoisting. The availability of personnel or equipment strongly depends on the company policy. Own personnel or third parties can do the maintenance, equipment can be owned or hired, etc.
2. Once the repair crew and the equipment for travelling are in principle ready for take off it might happen that the weather forecast during the period the mission has to be carried out (*T_mission*) is such that it is not allowed or irresponsible to take off. This interval is denoted as *T_wait*. The length of this interval is dependent on the duration of the mission and the de-

vice planned (see also Figure 3). Due to its dependency on weather conditions (wind speed and or wave height) the duration of this interval shows large scatter and should be treated as a stochastic quantity. As the ECN O&M Tool determines long term yearly average quantities the average value of the waiting time is used in this model.

3. The interval *T_travel* denotes the time needed to travel to the wind turbine that has to be inspected or repaired.
4. The interval *T_repair* is the time needed to carry out the repair.

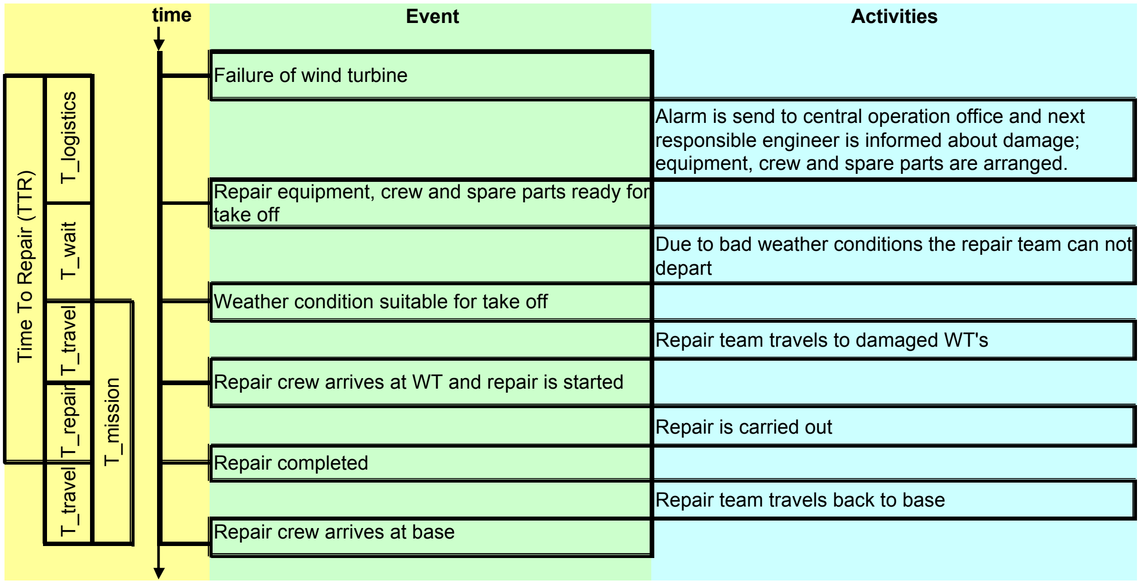

Figure 3: *Repair process*

The ECN O&M Tool has been implemented in two MS-Excel sheets:

<u>WaitingTime.xls</u> to determine the annual (or seasonal) average waiting time (*T_wait*) as a function of the mission time *(T_mission*);

<u>CostCal.xls</u> to determine the annual (or seasonal) average downtime and costs.

1.3 WaitingTime.xls

Offshore equipment can be used or repair actions can be carried out if the wind and wave conditions are below certain values. Based on wind and wave data for a selected location the program WaitingTime.xls determines when the weather conditions are suitable for carrying out certain repair actions and calculates the average time one has to wait before a suitable weather window will occur after a failure. The program uses time series with three hourly wind and wave data as input. The program results in second or third order polynomials for the mean value and the standard deviation of the waiting time as a function of the duration of the maintenance activity. In Figure 4 an example is given of such a polynomial.

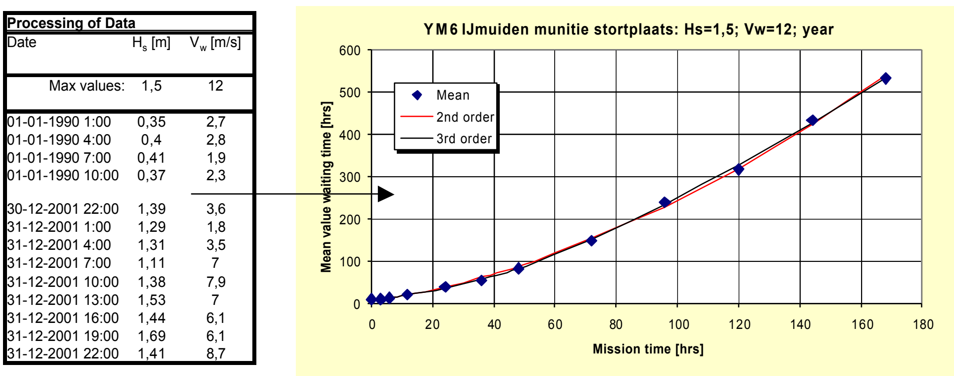

Figure 4: *Example of determining relationship between average waiting time and mission time*

The example represents the annual average waiting time as a function of the mission time at the location "IJmuiden Munitiestortplaats" and is based on 11 years of measured data. The mission can be carried out up to a significant wave height of Hs = 1.5 m and a wind speed of Vw = 12 m/s. Similar polynomials can also be generated per season and for different weather limits Hs and Vw.

1.4 CostCal.xls

The program CostCal.xls is being used to determine the long term annual (or seasonal) costs for O&M and the associated downtime. The program focuses on unplanned corrective maintenance. The program uses among others the following input:

1. weather windows and waiting time polynomials as generated with WaitingTime.xls;
2. wind turbine and wind farm information such as number of wind turbines, capacity factor of the wind farm, investment costs of turbines, costs of technicians, length of working day, etc.;
3. failure behaviour of the turbines and the repair actions which are foreseen;
4. characteristic values of access systems (weather limits, costs, mobilisation time, etc.).

During the modelling process, users spend most time on generating input parameters for item 3. This will be discussed in more detail below.

1.5 Definition of failure behaviour and repair actions

First of all, the ECN O&M Tool requires the occurrence frequencies of failures and associated repair actions as input. Unfortunately, such data are hard to obtain. Often data should be derived from generic databases (e.g. [Ref. 7]), or (more preferred) from similar turbines onshore. If such data can be obtained, mostly only overall annual failure frequencies of the main components are available. Engineering judgement is required to determine the different failure modes of these components. A certain percentage of the component failures comprises failure modes that are small and easy to repair, whereas another percentage comprises failure modes that are more severe and require for instance large crane ships during the repair action.

In order to avoid that the model needs to analyse each individual failure mode and its associated repair actions, all maintenance actions are categorised into a different maintenance categories (MC's). An example of the categorisation of maintenance actions with associated equipment is given in Table 1.

Table 1: *Example of possible subdivision in Maintenance Categories*

MC 1:	Remote reset, no personnel and equipment, no repair time
MC 2:	Small repair inside, only personnel and tools, repair time less than 1 day (e.g. replacement of carbon brushes)
MC 3:	Small repair outside, only personnel and tools, repair time less than 1 day (e.g. cleaning of blades)
MC 4:	Replacement of small parts, small internal crane hoisting outside, repair time around 1 day (e.g. replacement of pitch motor)
MC 5:	Replacement of large parts, large internal crane needed (e.g. replacement of gearbox, generator. etc.); repair time typically 1 to 2 days
MC 6:	Replacement of large parts, large external crane needed (e.g. replacement of, hub, nacelle, yaw system); repair time typically 2 to 3 days

In addition to the categorisation of maintenance classes, it is also necessary to exactly describe how the repair is going to be carried out and how the equipment is going to be used. An example of a detailed description is given in Table 2. This step-by-step description is considered by all users as very relevant; often it is concluded afterwards that repair actions are more complex than originally foreseen.

The information per maintenance class is limited to the use of equipment (vessels and crane ships). Subsequently, each maintenance class is again split up into a limited number of Fault Type Classes (FTC's). A FTC determines the average costs per repair action taking into account: labour costs, costs of spare parts and consumables, costs of equipment, and revenue losses caused by downtime. A FTC also determines the mission time per repair action and thus the associated waiting time due to bad weather conditions (see also Figure 4). The total down-time consists of the four intervals given above: logistic time to organise equipment and spare parts, waiting time due to bad weather, travel time, and repair time (see also Figure 3). The model CostCal.xls is equipped with input sheets to define the above mentioned costs, mission times, and capabilities of vessels and crane ships.

Table 2: *Example of description (MC 4: Replacement of small parts)*

Smaller spare parts like a pitch motor, a yaw motor or parts of a hydraulic system need to be transported to the turbine, put on the platform and hoisted into the nacelle with the help of the internal crane. A typical maintenance action looks as follows:

1. An access vessel with 2 to 4 technicians and the spare part travels to the failed turbine;
2. The technicians are transferred from the access vessel;
3. Technicians inspect failed component and decide whether replacement is needed;
4. In case the failed component needs to be replaced the spare component is hoisted to the platform with the small crane on the lower turbine platform;
5. The failed component is dismantled and lowered outside the tower to the platform using the internal crane;
6. The spare component is hoisted from the platform using the internal crane and mounted;
7. The failed component is hoisted to the access vessel using the small crane on platform; (Depending on the capabilities of the platform and the crane, this step can be done later; the failed part can be stored for some time on the platform.)
8. Personnel return to the access vessel and travels back to the harbour.

The process of “grouping” the different failure modes into a manageable set of FTC's with identical costs and downtime, and the determination of the annual average occurrence frequencies of each FTC is given in Figure 5. The ECN O&M Tool typically deals with 10 to 15 FTC's

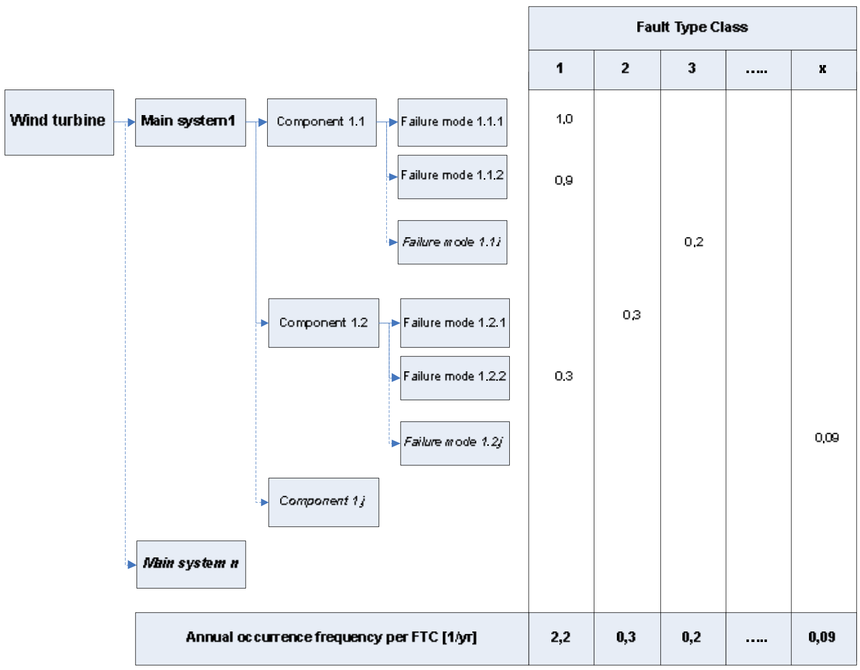

Figure 5: *Process of grouping small and severe failures into manageable set of FTC's*

1.6 Results and Output

If for the baseline O&M scenario all input parameters have been defined, the program immediately shows the output, e.g. in a table as presented in Table 3. The program also generates plots and pie charts to determine e.g. cost drivers or aspects that dominate downtime, see Figure 6. The results may be a reason to optimise the O&M strategy, e.g. by selecting different vessels, changing the turbine design, improving component reliability, or using a hotel boat.

Table 3: *Example of model output (table)*

1 Wind Turbine			Winter	Spring	Summer	Autumn	Total	Year
Downtime per year								
	Logistics	hr	190	141	124	164	618	618
	Waiting	hr	107	28	13	56	204	160
	Travel	hr	2	2	1	2	7	7
	Repair	hr	14	10	9	12	44	44
	TOTAL	hr	313	181	148	233	874	829
Availability		%	86%	92%	93%	89%	90,0%	90,5%
Loss of production per year		kWh	370528	158611	114579	238240	881957	808224
Energy production per year		kWh	2224140	1765284	1586460	2002090	7577974	7727863
Revenue losses per year		Euro	**29642**	**12689**	**9166**	**19059**	**70557**	**64658**
Costs of repair per year								
Material costs		Euro	16236	12038	10644	14018	52936	52936
Labour costs								
	Wages	Euro	1758	1303	1152	1518	5731	5731
	Daily allowance	Euro	0	0	0	0	0	0
	TOTAL	Euro	1758	1303	1152	1518	5731	5731
Costs equipment								
	MOB/DEMOB	Euro	9506	7048	6232	8208	30994	30994
	Waiting	Euro	29281	9367	6413	15550	60612	53055
	Repair	Euro	9522	7060	6242	8221	31046	31046
	TOTAL	Euro	48309	23475	18888	31979	122651	115095
Total costs of repair per WT		**Euro**	**66302**	**36817**	**30684**	**47515**	**181318**	**173762**
Total cost per kWh		**Euro Cent/kWh**	**2,98**	**2,09**	**1,93**	**2,37**	**2,39**	**2,25**

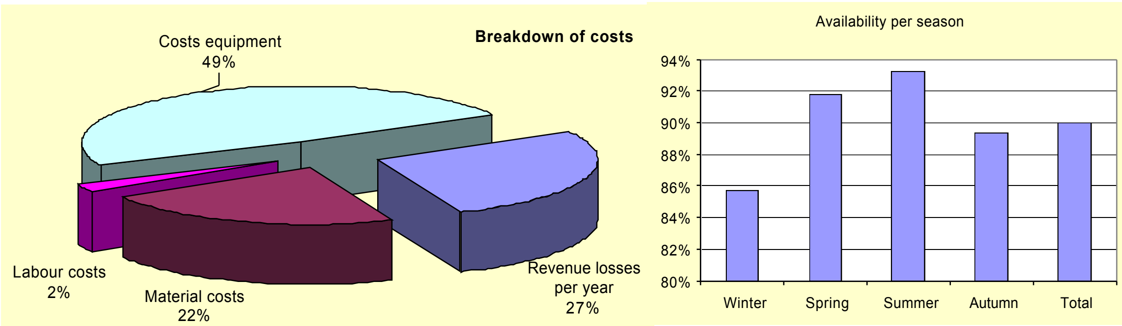

Figure 6: *Example of model output (graphs and pie charts)*

1.7 *Uncertainty analyses*

The ECN O&M Tool model will in most cases be used as a deterministic model in which only mean values or the maximum likelihood are considered. The model can also be used as a probabilistic model to take into account the uncertainties in the parameters, e.g. failure frequencies and costs. To do this, the add-in module @Risk [Ref. 2, Ref. 3] should be used. The model can generate for instance the cumulative density function of the O&M costs per kWh, or determine which uncertain input parameter influences the uncertainty of the results the most by means of a tornado diagram, see Figure 7.

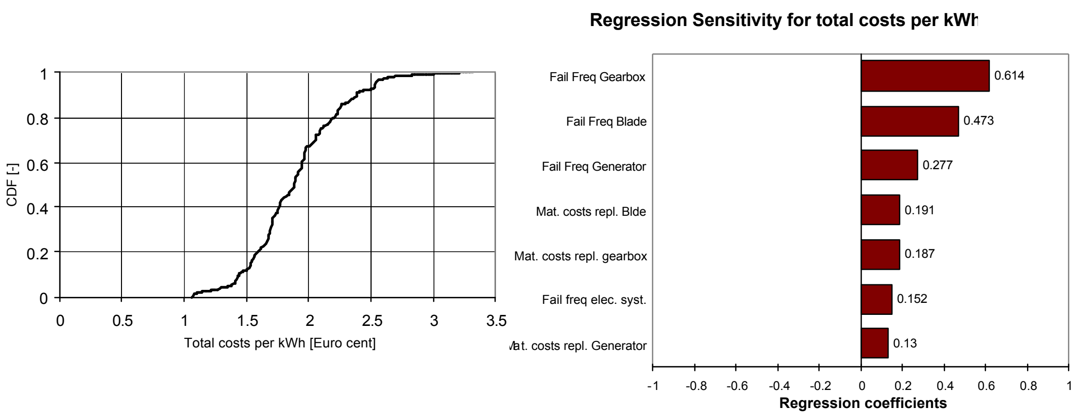

Figure 7: *Example of CDF and tornado diagram*

2. Software Tool Validation by GL Wind

At present the market for knowledge to estimate future O&M costs of offshore wind farms is starting to grow. However, there is no possibility to compare the estimated O&M costs with real data due to the fact that there are no public figures on the experience of O&M strategies. Therefore GL Wind has validated the ECN O&M Tool to increase the security for the users of the model.

GL Wind has validated ECN's software tool by checking plausibility, assessment of the state-of-the-art, the functionality and the correctness of the models used in the software. In the validation GL Wind checked the suitability of the cost modelling and the modelling of the wind farm availability. The correct implementation of the models in the computational code and the calculation procedures were also part of the evaluation

Additionally, the level of detail for the input parameters, such as failure data, wind and wave climate was assessed. The influence of the type and quality of the weather data used for the calculation was investigated in detail be carrying out a parameter study and considering statistical tests. For the users the items of the functionality and the redundancy against fault usage was checked as well as the possibility for customising the software tool.

Most of the findings during the evaluation process have been discussed and solved immediately. Some further suggestions on improvements have been made and will bee included in the next version of the tool.

2.1 Plausibility and the correctness of the models used

The model used was found to be correct and a good representation of the state-of-the-art in O&M cost modelling. The model calculates long term mean values based on statistical data of the failure rates of modern turbines, which is a common approach. During the evaluation work concerning the ECN O&M Tool the methods and procedures were reviewed and confirmed to be correct, no systematic errors were found. In comparison with results of other availability calculations, operational data and literature, the tool delivers reasonable results.

2.2 Implementation in the computational code

As the suggested models seemed correct also the implementation needed to be checked. The models suggested were implemented correctly in the software program and the calculations were approximated correctly if relevant. The deviations found were within the technical tolerances.

2.3 Input of failure data

The software can also be delivered filled with data for demonstration purposes only. The failure data for this "demo-version" are among others derived from the “Wind Energy Report Germany” [Ref. 7], combined with "engineering judgment", and implemented in the structure of the software. The implementation was performed correctly and the statistical data are applicable for the used model. Due to the fact that at present little operational data from offshore wind farms are available and shared within the wind community, validation by comparing the calculations of the software tool with operational data is not possible. Germanischer Lloyd has made an effort to evaluate the data in the demo-version by reviewing the routine, comparing the results with operational data of existing onshore wind farms, with results of questionnaires, literature and other calculation tools. The main conclusion was that the failure data for the demo-version are within acceptable limits and seem realistic as input for an offshore demonstration case. The level of detail to define the failure behaviour is very high. Not only the overall failure rates of components need to be considered but also the occurrence frequencies of failure modes and their associated repair strategy.

2.4 Influence of the wind and wave data

Additionally GL has performed analyses concerning the influence of meteorological data on the results, influence of long-term trends and meteorological data quality. Generally, as mentioned in the ECN user manual, the meteorological data should cover a period as long as possible to decrease the influence on long-term trends on the downtime. Test runs revealed that a period of 5 years or more leads to a situation where the annual variations on the downtime become negligible small.

2.5 User friendliness

In combination with the user manual, the tool demonstrates good functionality, but expert knowledge and reviewing of the results are needed to set up the data and to recognize typographical errors or misunderstandings. On the other hand due to the missing of limits and source code protections, the user can adapt the tool freely and can extent the features of the tool on its own.

Due to the routine of the tool, using averaged waiting times for the downtime calculations, it is difficult to investigate the influence of number of boats or stocks on availability and costs. In the routine, each failure and repair action is treated independently of each other. In exchange, the performance of the tool is very fast and clearly structured.

2.6 Areas for improvement

GL identified several areas for improvement, among others:

- When modeling the use of helicopters analysing the influence of fog on the accessibility is not a standard option in the tool. This option however can easily be implemented by adding an additional time series to the wind and wave time series which are also of influence on the accessibility. It must be noted however that hardly any time series can be found which include visibility (or fog) in addition to wind and wave data.
- Preventive maintenance is considered to a limited extend only and could be considered in more detail.

Most of the findings of GL Wind were recognised and confirmed by ECN and have been incorporated in the release of 2007 version Ref. 1 or will be in the release of 2008.

At present, ECN is developing a new tool with which the O&M aspects can be analysed during the operational phase of a wind farm, making use of data generated by the wind farm (O&M and failure data, condition monitoring data, etc). This tool, called the Operation and Maintenance Cost Estimator (OMCE) [Ref. 8, Ref. 9, Ref. 10] can also be used during the planning phase and will be based on time simulations. By doing so, the capabilities to optimise the logistic aspects will be strongly improved.

3. O&M Cost Estimation and Offshore Project Certification

GL as a certification body for wind turbine types and wind farm projects is interested in the validation of the ECN O&M Tool for the following reasons:

- GL has performed several validations of software models and tools for internal and external usage of their customers.
- Offshore Project Certification is taking place in the same phase of the project development as the phase where O&M cost estimates are being made (which is in the planning phase).
- During the project certification in the Design Basis Certification the same input data as for the O&M cost model is used. These data is mainly described by the environmental conditions.
- The typical GL customers for Offshore Project Certification have demanded the need for an independent investigation of the O&M costs.
- The technical expertise for the validation work and the O&M cost modelling is already available at GL

4. Conclusions and prospects

Since 2000, offshore wind energy is strongly increasing. The cost for investment, operation and maintenance are very high. Moreover, the costs for operation and maintenance are, similar to the energy production, difficult to predict on beforehand during the planning phase. Before erecting an offshore wind farm however, investors and financers would like to have an estimate of the O&M aspects and if possible a quantification of the uncertainties.

ECN has developed a tool for this, called ECN O&M Tool. With this tool the O&M aspects of an offshore wind farm can be analysed in large detail. It quantifies the downtime, revenue losses and O&M costs together with the uncertainties. At present the tool is being used world wide by project developers in the planning and development phase of offshore wind farms.

In order to ensure that the results of the ECN O&M Tool are accepted by e.g. financers and insurance companies, GL has validated the tool. GL came to the conclusion that the tool represents the state-of-the-art. The tool is considered as user friendly and fast. Since the tool treats the O&M aspects in large detail, experts are needed to determine the input parameters. The straight forward modelling approach (using long term average input data and generating long term average values as output) leads to the fact that the tool supports project developers to a limited extent only in optimising logistic aspects like optimising the number of boats or stock control.

The authors would like to make a final comment. All models for optimising O&M aspects or to estimate future O&M costs use failure data of wind turbines as input. It is the author's experience that such data are difficult to obtain and even if they can be obtained, it is time consuming to analyse and structure them and the derived failure rates are covered with large uncertainties. The authors want to encourage the wind community to use better and more structure ways to collect the data, e.g. as described in Ref. 11.

5. References

Ref. 1 H. Braam, LW.M.M. Rademakers, "*Availability and Cost Analysis Model for Offshore Wind Farms; User Guide and Model Description*", ECN-X--07-073, June 2007.

Ref. 2 *"Guide to using @Risk, version 4",* Pallisade Corporation, April 2000

Ref. 3 D. Vose: "*Risk Analysis; A Quantitative Guide*"; second edition, 2000; John Wiley & Sons, Ltd; ISBN 0-471-99765-X

Ref. 4 L.W.M.M. Rademakers, H. Braam, M.B. Zaaijer, G.J.W. van Bussel: "*Assessment and optimisation of operation and maintenance of offshore wind turbines*", Proc. EWEC 2003.

Ref. 5 L.W.M.M. Rademakers, H. Braam, T.S. Obdam, P. Frohboese, N. Kruse: "*Tools for Estimating Operation and Maintenance Costs of Offshore Wind Farms*"; HOW Conference, 6 September 2007, Hamburg.

Ref. 6 E.J. Wiggelinkhuizen et. al.; "*CONMOW Final Report*"; ECN-E-07-044; July 2007.

Ref. 7 M. Durstewitz et.al.; "*Wind Energy Report Germany; Annual Evaluation of WMEP*"; ISET; Germany; 2001-2006.

Ref. 8 P.J. Eecen, H. Braam, L.W.M.M Rademakers, T.S. Obdam; "*Estimating Costs of Operation and Maintenance of Offshore Wind Farms*"; presented at the European Wind Energy Conference 2007.

Ref. 9 T.S. Obdam, L.W.M.M. Rademakers, H. Braam, P. Eecen: "*Estimating Costs of Operation & Maintenance of Offshore Wind Farms*"; EOW Conference, December 2007, Berlin.

Ref. 10 T.S. Obdam, L.W.M.M. Rademakers, H. Braam, P. Eecen: "Estimating Costs of Operation & Maintenance of Offshore Wind Farms"; EWEC 2008, 31/03/2008 - 03/04/200, Brussels.

Ref. 11 H. Braam, L.W.M.M, Rademakers; "The Maintenance Manager; Collecting and Analysing *Maintenance Data of Wind Turbine"s*; ECN-C--01-012.