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Report

User guide for the NOWIcob tool (D5.1-75)

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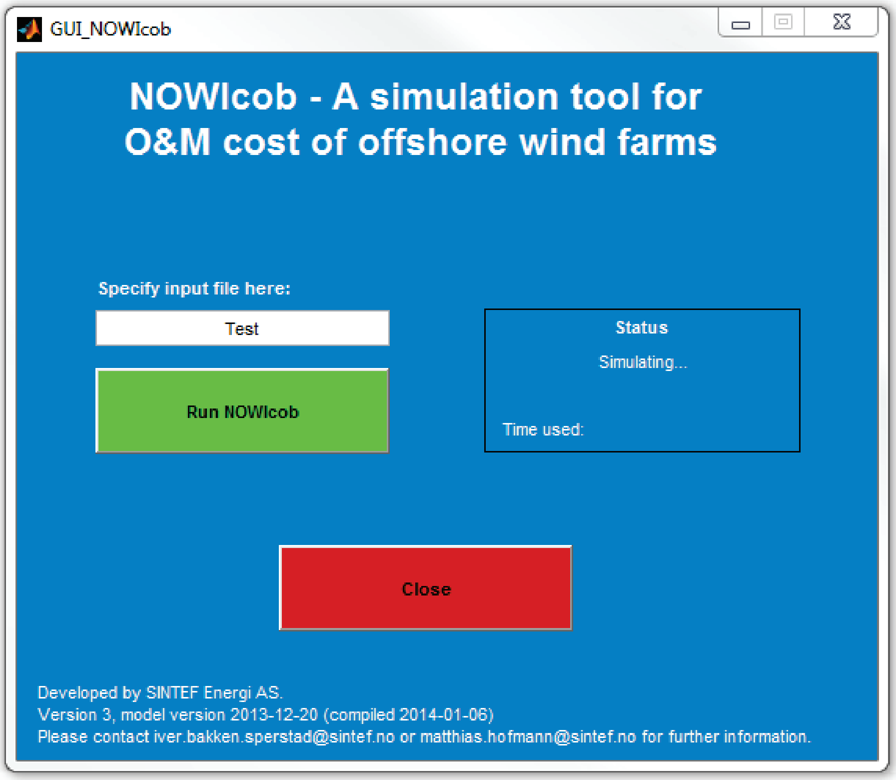

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ABSTRACT

This user guide describes the installation procedure of the NOWIcob model and how analyses can be performed with NOWIcob. The model can be used for analysing and providing decision support on maintenance and logistics strategies for offshore wind farms. It simulates maintenance operations in an offshore wind farm over the complete life time. This document and NOWITECH deliverable is based on the previous version of the user guide for NOWIcob, which was a report prepared as a deliverable of the FAROFF project.

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1 Installation

Please follow the following installation procedure:

- Extract zip file NOWIcob.zip
- Install MATLAB Compiler Runtime with one of the following methods
    - Run *MCRInstaller.exe* in the folder *Help*
    - Or download program from http://www.mathworks.se/products/compiler/mcr/
      (Choose version R2012a (7.17) for the operating system of your computer)

The model is implemented in MATLAB, user inputs are specified in Excel files and results are exported to Excel files too. Therefore the following system requirements have to be fulfilled:

- Windows PC with installed MS Excel version Excel 2007 or higher
  (files with the .xlsx extension have to be supported)
- Installed MATLAB Compiler Runtime

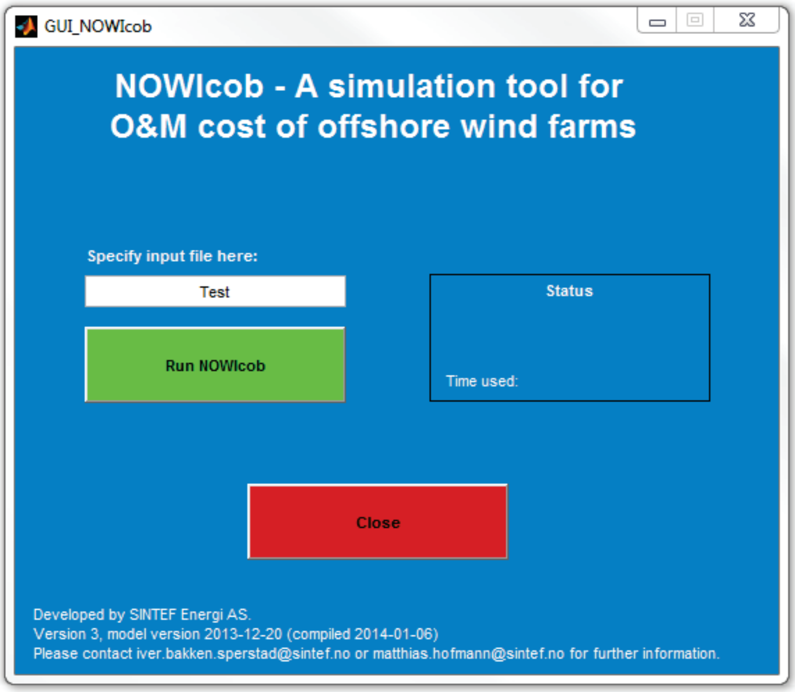
2 Quick start

2.1 Run the program

The program comes with a test case with specified basis data and weather data so that a new user can try the model without the need of specifying input data.

1. Run model
    a. Run *NOWIcob.exe* (it can take several seconds before the program starts).
    b. Write *Test* in the input box.
    c. Press Run NOWIcob.
2. Results
    a. Results are saved automatically and can be found in *Results/Test* in *Results_Test_1.xlsx*. (See Ch. 5 for more details.)

The program may stop due to wrong data inputs or other errors. If so, the user may find the reason for it in the logfile Logfile.txt.



2.2 Specify case

Different procedures can be used to set up a new case. In the following, all steps that are needed for each procedure are described shortly for three typical alternatives.

Set up a completely new case

1. Prepare weather data
    a. Optional step. Only needed if no weather data have already been prepared or a new set of weather data is to be used. (See Ch. 4.1 for more details)
    b. Save weather data as text file in *Input/Weather_data*.
    c. Describe weather data in *Input/Weather_data /Overview weather data.xlsx.*
2. Specify basis data
    a. Optional step. Only needed if no basis data are already specified or data are missing.
    b. Specify basis data in *Input/Basis_data/Input_basis.xlsx.* (See Ch. 4.2 for more details)
3. Set up case data
    a. Copy *Input/Case_template.xlsx* and give the file a new case name, for example *New_case.xlsx*.
    b. Set up the case by specifying values in this case input file. (See Ch. 4.3 for more details)
4. Run model
    a. Run *NOWIcob.exe.*
    b. Write the file name in the input text box (without the ".xlsx" extension).
    c. Press Run NOWIcob.
5. Results
    a. Results are saved automatically as an Excel file (for example R*esults_New_case_1.xlsx*) in the *Result* folder in subfolder that has the same name as the input file, for example *Results/New_case*.

Change an existing case

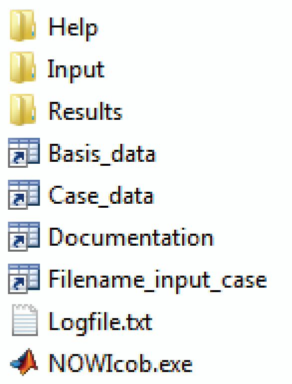
1. Change case data
    a. Open a case file in folder *Input*, for example *Test.xlsx*, and change the input values.
    b. Save it.
2. Run model
    a. Run *NOWIcob.exe.*
    b. Write the file name in the input text box (without the ".xlsx" extension).
    c. Press Run NOWIcob.
3. Results
    a. Results are saved automatically in the same result folder as the previous case but with a higher number (for example *Results_Test_2.xlsx*).

Set up new case based on an existing case

1. Change case data
    a. Change input values in the case file in folder *Input*, for example *Test.xlsx*.
    b. Save it with a new name, for example *Test_new.xlsx*.
2. Run model
    a. Run *NOWIcob.exe.*
    b. Write the file name in the input text box (without the ".xlsx" extension).
    c. Press Run NOWIcob.
3. Results
    a. Results are saved automatically as an Excel file (for example *Results_Test_new_1.xlsx*) in a new result subfolder with the same name as the new input file (for example *Results/Test_new*).

3 Description folder structure

The user will see the following folder structure when the program is installed:

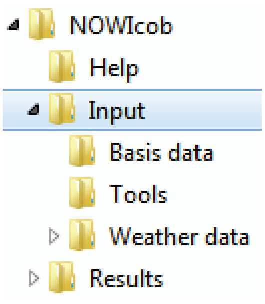


The different folders and files are used for the following purposes:

- *Help*: contains this user guide and the installation file for MATLAB Compiler Runtime
- *Input*: contains files and subfolders where the user specifies and stores all input data.
- *Results*: contains the result files that are automatically saved by the program in case specific subfolders.
- *NOWIcob.exe*: the program
- *Logfile.txt:* if the program stops, the user may find the reason in the logfile

4 Setting up a case

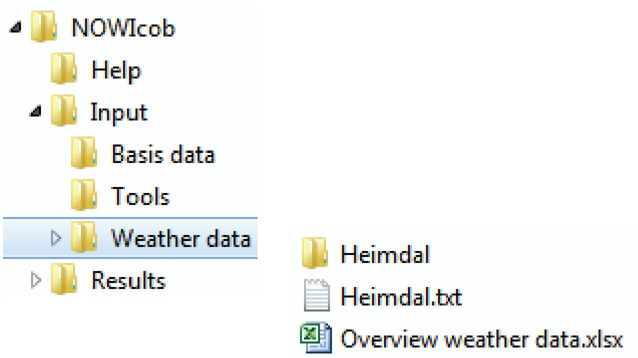
Data input to the NOWIcob model is organized in the *Input* folder through two Excel workbooks, where one contains basis data and the other case-specific data. In addition, a text file with historical weather time series is needed.



The basis data contain all information that can be reused in several case-specific set ups. Examples for basis data are electricity price scenarios and different types of vessels. Since the case-specific data refer directly to the basis data, a typical approach for preparing the data for the model is first to specify the basis data and thereafter the case specific data. One also has to choose which weather data is to be used in the model.

4.1 Weather data

Weather data are stored in a text file in *Input/Weather data*. Synthetic weather time series are created with the Markov chain weather model and stored in a subfolder with the same name, when weather data are used for the first time in a simulation. If a new simulation uses the same weather, the saved synthetic weather time series can be used. All main parameters for the weather data should be documented by the user in the file *Overview weather data.xlsx.*



The NOWIcob tool already includes weather data from the Heimdal platform in the North Sea (*Heimdal.txt*) as a test data set. If new weather data should be used, the data have to be stored in a new text file with the following parameters in columns separated by tabulators:

1. Year
2. Month
3. Day
4. Hour
5. Minute
6. Second
7. Wind speed [m/s]
8. Wind direction [0-360]
9. Wave height [m]
10. Wave period [s]
11. Wave direction [0-360]

The structure of the weather data can be seen in the example of the Heimdal data. Columns with no information can be set to zero. In this example the Heimdal data contain only wind speed and wave height data with a resolution of 20 minutes.

Heimdal.txt

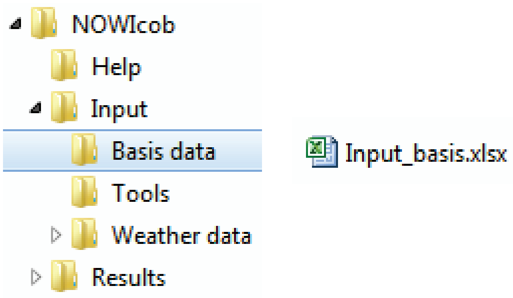
1	2004	6	21	7	40	0	3.2	0	1.7	0	0
2	2004	6	21	8	0	0	3	0	1.8	0	0
3	2004	6	21	8	20	0	3.3	0	1.4	0	0
4	2004	6	21	8	40	0	3.1	0	1.3	0	0
5	2004	6	21	9	0	0	3.1	0	1.4	0	0
6	2004	6	21	9	20	0	3.1	0	1.7	0	0
7	2004	6	21	9	40	0	3.2	0	1.5	0	0
8	2004	6	21	10	0	0	3.6	0	1.4	0	0
9	2004	6	21	10	20	0	3.1	0	1.5	0	0
10	2004	6	21	10	40	0	2.7	0	1.2	0	0
11	2004	6	21	11	0	0	3	0	1.6	0	0
12	2004	6	21	11	20	0	2.8	0	1.3	0	0
13	2004	6	21	11	40	0	3.9	0	1.6	0	0
14	2004	6	21	12	0	0	4.1	0	1.6	0	0
15	2004	6	21	12	20	0	4.2	0	1.3	0	0
16	2004	6	21	12	40	0	3.8	0	1.3	0	0
17	2004	6	21	13	0	0	4	0	1.5	0	0
18	2004	6	21	13	20	0	3.7	0	1.2	0	0
19	2004	6	21	13	40	0	3.4	0	1.2	0	0
20	2004	6	21	14	0	0	3.3	0	1.4	0	0

Metadata for the weather have to be stored by the user in *Overview weather data.xlsx.*

	Parameters included									
File/folder name	Wind speed	Wind direction	Wave height	Wave period	Wave direction	Time	Time resolution	Location	Source	Comment
Heimdal	yes		yes			June 2004 - June 2009	20 min	Heimdal platform in North Sea	eKlima	

4.2 Basis data

Basis data contain all information that can be used in several set ups for different cases. All data are stored in the *Input_basis.xlsx* in the folder *Input/Basis data*.



The basis data are specified in the following sheets:

- Currencies
- Electricity price scenarios
- Electricity prices
- Failure rate adjustments
- Failure rate adjustment data
- Main components
- Power curves
- Power curve data
- Abilities
- Vessels

<u>Currencies</u>

Name	Description
NOK	Norway Krone
SEK	Sweden Krona
DKK	Denmark Krone
EUR	Euro Member Countries
GBP	United Kingdom Pound
USD	United States Dollar
JPY	Japan Yen

This table can be used to define different currencies for use in the model.

Name	Name of the currency, is also used as identifier
Description	Description of the currency

Electricity price scenarios

Electricity price scenario	Description	Currency
Test price scenario	For test purposes. All prices are constant. Time horizon: 2010 -2035	GBP

This table is used for defining names for different electricity price scenarios. Each scenario has to be specified in one currency. If the same price scenario shall be used in different currencies, several scenarios have to be defined.

Electricity price scenario	Name of the electricity price scenario, is also used as identifier
Description	Description of the scenario
Currency	Currency of the electricity price, identifier from *Currencies*

Electricity prices

Electricity price scenario	Year	Month	Electricity price [Currency/kWh]
Test price scenario	2010	1	0,12
Test price scenario	2010	2	0,12
Test price scenario	2010	3	0,12
Test price scenario	2010	4	0,12
Test price scenario	2010	5	0,12
Test price scenario	2010	6	0,12
Test price scenario	2010	7	0,12
Test price scenario	2010	8	0,12
Test price scenario	2010	9	0,12
Test price scenario	2010	10	0,12
Test price scenario	2010	11	0,12
Test price scenario	2010	12	0,12
Test price scenario	2011	1	0,12
Test price scenario	2011	2	0,12
Test price scenario	2011	3	0,12

This table contains the price data for each price scenario specified per year and month. All prices for the simulation time beginning from the start-up year of the simulation have to be specified; otherwise the model will not work.

Electricity price scenario	Identifier for the electricity price scenario as defined in the *Electricity price scenarios* table
Year	Year for which the price is valid
Month	Month of the year
Electricity price [Currency/kWh]	Average electricity price for year and month specified in the chosen currency

Failure rate adjustments

Adjustment name	Adjustment description
Bathtub curve	Higher failure rate for years 1 - 3 and 17 - 20. Failure rate is 1.4 times higher the first and last year.

This table defines and describes different failure rate adjustments. It is possible to adjust the failure rates given for corrective maintenance with a factor for each year.

Failure rate adjustment	Name of failure rate adjustment, is also used as identifier
Description	Description of the failure rate adjustment

Failure rate adjustment data

Failure rate adjustment ID	Year	Adjustment factor
Bathtub curve	1	1,4
Bathtub curve	4	1
Bathtub curve	17	1
Bathtub curve	20	1,4

This table contains the data for the failure rate adjustments factors specified per year. Missing data for years between two specified adjustments are linearly interpolated in the model. A constant adjustment is assumed for years without data where the simulation starts earlier or ends later than the data specified.

Failure rate adjustment ID	Identifier for the failure rate adjustment, several entries can be made for each adjustment specified in table *Failure rate adjustments*
Year	Relative year of operation counted from the start-up of the wind farm
Adjustment factor	The failure rate is adjusted by this factor for the specified year. Failure rate equals the unadjusted failure rate times the failure rate adjustment factor

Main components

Main component name	Main component description	Producing unit [Yes, No]	Rated power [MW]	Cut-in [m/s]	Cut-out [m/s]	Power curve
6 MW turbine	Default turbine in FAROFF project	Yes	6	4	25	Vestas V90
10 MW turbine		Yes	10	4	25	Vestas V90
5 MW turbine		Yes	5	3	25	Vestas V90
3 MW turbine		Yes	3	3	25	Vestas V90
3.6 MW turbine		Yes	3,6	3,5	25	Siemens SWT- 3.6 107

Main components are for example different types of wind turbine or substations that are often used in different cases. Main components can produce electricity or not.

Main component	Name of the main component, is also used as identifier for the case specific input data
Main component description	Description of the main component
Producing unit [Yes,No]	Defines whether the component produces electricity
Rated power [MW]	Rated power of the wind turbine
Cut-in [m/s]	Cut-in wind speed of the wind turbine
Cut-out [m/s]	Cut-out wind speed of the wind turbine
Power curve	Identifier for the power curve referring to table *Power curves*

Power curves

Power curve name	Power curve description
Vestas V90	For 3 MW turbine (used as generic power curve for several turbines)
Siemens SWT- 2.3 82	
Siemens SWT- 2.3 93	
Siemens SWT- 3.6 107	
Vestas V34	
Vestas V80	
Vestas V112	
Vestas V164	
Repower MM82	
Repower MM92	

This table defines the name for different power curves and is used as identifier for the *Power curve data* table.

Power curve	Name of power curve, is also used as identifier
Description	Description of the power curve

Power curve data

Power curve ID	Wind speed [m/s]	Power production [% of rated]
Vestas V90	0	0,00 %
Vestas V90	3	0,00 %
Vestas V90	4	2,50 %
Vestas V90	5	6,23 %
Vestas V90	6	11,60 %
Vestas V90	7	19,13 %
Vestas V90	8	29,17 %
Vestas V90	9	41,90 %
Vestas V90	10	56,27 %
Vestas V90	11	70,60 %
Vestas V90	12	83,80 %
Vestas V90	13	93,90 %
Vestas V90	14	98,60 %
Vestas V90	15	99,80 %
Vestas V90	16	99,97 %
Vestas V90	17	100,00 %
Siemens SWT- 2.3 82	0	0,00 %
Siemens SWT- 2.3 82	1	0,00 %
Siemens SWT- 2.3 82	2	0,00 %
Siemens SWT- 2.3 82	3	0,00 %
Siemens SWT- 2.3 82	4	1,83 %
Siemens SWT- 2.3 82	5	5,91 %
[illegible]	6	[illegible]

This table contains the data for the power curves by relating the electricity production (specified relative to the rated power) to several wind speed data points. The power curve as used in the model is interpolated linearly between the specified data points of wind speed and power production and the defined cut-in and cut-out wind speeds. It is assumed that the power production is zero below cut-in and above cut-out.

Power curve ID	Identifier for the power curve as specified in table *Power curves*, several entries can be included for each power curve to specify wind speed and related electricity production
Wind speed [m/s]	Wind speed
Power production [% of rated]	Electricity production in % of rated power for the specified wind speed

Abilities

Ability name	Ability description
Lifting	Use of heavy-lift vessels (jack-up)
OSV	Use of vessel with external crane (as on a typical offshore supply vessels)

Abilities describe operations that vessels can execute in addition to give access to structures. Examples can be lifting equipment, subsea inspections and others.

Ability name	Name of the ability, is also used as identifier in the case specific input data
Ability description	Description of the ability

Vessels

Vessel name	Vessel description	Travel speed [knots]	Fuel consumption travelling [l/hour]	Fuel consumption stationary [l/hour]	Personnel space	Offshore wave height limit [m]	Offshore wind speed limit [m/s]	Mobilisation time for access [hours]	Transfer time for access [hours/person]	Access ability [No, Yes]
CTV 1	FAROFF	20	50	15	12	2,5	30	0,083	0,05	Yes
CTV 2	FAROFF	20	50	15	12	2,5	30	0,250	0,05	Yes
SES boat	FAROFF	35	50	15	12	4	30	0,083	0,05	Yes
Small accomodation vessel	FAROFF	20	100	100	12	4	30	0,083	0,05	Yes
Mini mother vessel	FAROFF	14	200	200	12	5	30	0,167	0,03	Yes
Mother vessel	FAROFF	14	300	300	24	5	30	0,167	0,03	Yes
Daughter craft	FAROFF	16	50	15	6	2	20	0,083	0,05	Yes
Offshore Service vessel	FAROFF	14			40	5	30	0,167	0,03	No
Jack-up	FAROFF	5			40	5	30	0,15	0,03	No

Vessels can be seen as resources with given abilities that are needed to perform a maintenance action. Therefore, a helicopter can be defined as a vessel.

Vessel name	Name of the vessel, is used as identifier in the case specific data
Vessel description	Description of the vessel
Travel speed [knots]	Average travel speed of the vessel in transit
Fuel consumption travelling [l/hour]	Fuel consumption when travelling
Fuel consumption stationary [l/hour]	Fuel consumption when stationary
Personnel space	Maximum space for maintenance personnel on the vessel
Offshore wave height limit [m]	Wave height limit above which the vessel has to return to a safe harbour
Offshore wind speed limit [m/s]	Wind speed limit above which the vessel has to return to a safe harbour
Mobilisation time for access [hours]	Time from the access vessel is in the vicinity of the wind turbine to it is ready for personnel transfer
Transfer time for access [hours/person]	Time needed to transfer one technician to the wind turbine after the vessel is connected to the wind turbine and ready for personnel transfer
Access ability [Yes,No]	Specifies if the vessel has the ability to let personnel access offshore structures

Vessel name	Access wave height limit [m]	Access wind speed limit [m/s]	Access weather limits input file name	Ability 1	Ability 1 wave height limit [m]	Ability 1 wind speed limit [m/s]	Ability 1 weather limits input file name	Ability 2	Ability 2 wave height limit [m]	Abilit wind speed [m/s]
CTV 1	1,20	16								
CTV 2	1,8	16								
SES boat	2	16								
Small accomodation vessel	2	16								
Mini mother vessel	2,5	16								
Mother vessel	2,5	16								
Daughter craft	1,2	16								
Offshore Service vessel				OSV	2,5	16				
Jack-up				Lifting	2,5	10				

This is the continuation of the vessel table with the specification of the weather limits for each vessel. Weather limits can be defined as constant limits for wave height and wind speed both for accessing the wind turbine or other abilities (maximum 3 other abilities per vessel).

Access wave height limit [m]	Wave height limit for accessing offshore structure
Access wind speed limit [m/s]	Wind speed limit for accessing offshore structure
Access weather limits input file name	File name of text file with alternative description of weather limits (see below).
Ability 1	Name of the ability as specified in table *Abilities*
Ability 1 wave height limit [m]	Wave height limit for using that ability
Ability 1 wind speed limit [m/s]	Wind speed limit for using that ability
Ability 1 weather limits input file name	File name of text file with alternative description of weather limits (see below) for that ability.

The fields for ability 2 and ability 3 are entirely analogous to the fields for ability 1.

In the *weather limits input file name* fields, one can specify the name of a text file that contains an alternative description of the weather limits. The file needs to have the file extension .txt, but it is not necessary to include the extension in the input field. Which weather limits are used is dependent on what choice is made in the input field *Weather limits for vessels* in sheet 1 of the case data file:

- If the choice "Matrix of limiting wave heights" is chosen, the model will look for the text file in the *Input\Basis data* folder.
- If one chooses "Accessibility time series", the model will look for the text file in the subfolder within *Input\Weather data* for the specific set of weather data used for a given case (for example *Heimdal*). This is because weather limits in this format only apply to that specific set of historic weather data.
- If one chooses "Simple wave height limits", the name of the text file will be disregarded and the specified single-valued wave limit will be used instead.

The format of "Accessibility time series" for the weather limits text files is described below. See also the explanation for the field *Weather limits for vessels* in Ch. 4.3.1 for more details on the fields for weather limits input files.

Matrix of limiting wave heights:

This format for the weather limits specifies the limiting wave height, above which a vessel ability (including access) cannot be performed, as a function of wave period and wave heading. The file must be located in the *Input\Basis data* folder. The format of the text file is illustrated below. The first row gives first the number of wave headings and the number of wave periods, respectively, being considered in the input matrix contained in the text file. The second row gives the values of the wave headings for which a limiting wave height will be given. The third row gives the values of wave periods for which a limiting wave height will be given. The remaining rows are a matrix of limiting wave heights in which different rows correspond to different wave headings and different columns correspond to different wave periods. If only wave headings up to 180 degrees are given, the wave limits are assumed to be symmetric around 180 degrees. If specifying a dependence on wave period, it is recommended to specify wave height limits for odd wave periods 3 s, 5 s, 7 s, etc. Correspondingly, it is recommended to use a resolution of 2 s for the wave period in the weather model, cf. Section 4.3.1. It is also recommended to use values for the wave heading that correspond to the resolution of the wave heading in the weather model. Below the lowest specified wave period, the wave height limit for a given wave heading is assumed to remain at a constant value equal that for the lowest specified wave period. Above the highest specified wave period, the wave height limit for a given wave heading is assumed to remain at a constant value equal that for the highest specified wave period.

Weather_limits_demo.txt

```
7	7
0	30	60	90	120	150	180
3	5	7	9	11	13	15
0.75	0.55	0.55	0.65	0.75	0.85	0.95
0.85	0.65	0.65	0.75	0.85	0.95	1.05
0.95	0.75	0.75	0.85	0.95	1.05	1.15
1.05	0.85	0.85	0.95	1.05	1.15	1.25
0.95	0.75	0.75	0.85	0.95	1.05	1.15
0.85	0.65	0.65	0.75	0.85	0.95	1.05
0.75	0.55	0.55	0.65	0.75	0.85	0.95
```

<u>Accessibility time series:</u>

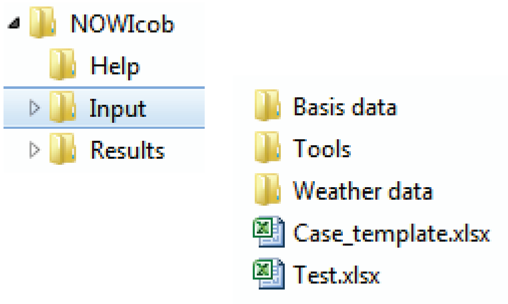
This format for the weather limits specifies for each time step (hour) of the historic weather data, if a given vessel can access a wind turbine. If a line contains the value 1, personnel can access the wind turbine from the vessel for the time step corresponding to this line number, and if the value is 0, they cannot. The format of the text file is illustrated below. These input data are expected to be provided as output from a technical analysis of a given vessel concept for the given weather data. The first line must correspond to the first time step of the historic weather data. This format can in principle also be used for other abilities than access, and the text file will in that case be interpreted as a time series of operability or feasibility of that ability for the given vessel. The file must be located in the subfolder for the weather data used within the *Input\Weather data* folder. Such a text file has also to be saved in each weather sub folder of the historic weather data, one wants to use the simulations. The file name can be chosen freely as long as the file extension is .txt and the same file name is used in each weather sub folder for the same vessel.

Weather_limits_demo.txt

```
0
0
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
```

4.3 Case data

Case data contain all data that are specific for a case and have to be specified in an Excel file in the *Input* folder. They include typical decisions that in sum represent a strategy for the operation and maintenance phase inclusive logistics.



New cases can be set up in three ways:

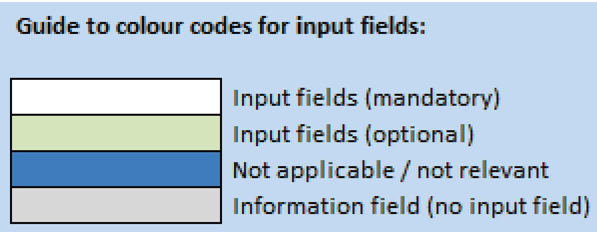
1. Start with empty template case file
   a. Copy *Input/Case_template.xlsx*
   b. Give the file a new case name, for example *New_case.xlsx.*
   c. Set up the case by specifying values in this case input file.
2. Change an existing case file
   a. Change input values in an existing case file in the *Input* folder, for example *Test.xlsx*.
   b. Save it.
3. Set up new case file based on existing case file
   a. Change input values in the case file in the *Input* folder, for example *Test.xlsx*.
   b. Save it with a new name, for example *Test_new.xlsx*.

The only difference between alternative 2 and 3 is how the results are saved. The results in alternative 2 are saved in the same folder, so all results for one case with variations in some input parameters can be collected in one folder. The results in alternative 3 are saved in a new folder and it has to be understood as a completely new case. Alternative 2 should be used when doing a sensitivity analysis, whereas alternative 3 can be used when a new case should be set up that has a lot of data in common with an existing case. For all three alternatives, the input data used for that particular simulation are stored together with the results, removing any ambiguity as to what parameter values were actually used.

The input parameters are specified in three sheets (1-3) and the best way to set up a case is to follow the order of the sheets since sheets with higher number are dependent on information specified in sheets with a lower number. The different sheets contain the following input parameters

- *Sheet 1*: General input parameter about the wind farm as weather, number of wind turbines, etc., parameters about operation of the wind farm as shift schedule, etc. and economic data as electricity prices, etc.
- *Sheet 2*: Specification of what kind of resources is needed for a maintenance action and how often a maintenance need occurs that triggers these actions.
- *Sheet 3*: Logistical set up for the wind farm with harbours, vessels and how the vessels are operated.
- *Sensitivity*: Optional set-up of a sensitivity analysis for different parameters

Not all input parameters are mandatory. It was tried to use the following colour code in the input sheets to help the user to understand which input cells the user has to focus on. All numbers presented in the following pictures are only for illustrative purposes and should not be understood as a real case.



Below follows an explanation of each input field for each of the three input sheets and the sensitivity sheet. Explanations of the fields can also be found in comments associated with the relevant cells in Excel. These comments are made available to the user by hovering the mouse pointer above a cell with a red triangle in the upper right corner.

4.3.1 Sheet 1

Sheet 1 is used for general input parameter about the wind farm (weather, number of wind turbines, etc.), parameters about operation of the wind farm (shift schedule, etc.) and economic data (electricity prices, discount rate, etc.).

General data	
Case name	
Wind farm	
Description	
Start year [yyyy]	2010
Simulation horizon [years]	3
Number of simulations	100
Output economic sensitivities?	No
Weather data	Heimdal
Use only historic weather data?	No
Weather limits for vessels	Simple wave height limits
Boat landing direction [degrees]	n/a
Wind speed resolution [m/s]	1,0
Wind direction resolution [degrees]	n/a
Wave height resolution [m]	0.1
Wave period resolution [s]	n/a
Wave direction resolution [degrees]	n/a
Inner wind farm average distance - unplanned [km]	1,5
Inner wind farm average distance - planned [km]	1,0
Prioritisation of maintenance tasks	Always prioritise corrective maintenance tasks
Working hours per shift [hours]	12
Daily shifts [number]	1
Shift starts [hour, 0...23]	6
Minimum working time [hours]	1
Fixed cost personnel [GBP per year]	100 000
Wake loss [%]	0,0 %
Electrical losses [%]	0,0 %
Lost production due to downtime electrical infrastructure [%]	0,0 %
Currency	GBP
Discount rate [%]	10 %
Fuel price vessels [GBP/l]	0,60
Constant electricity price [GBP/kWh]	0,12
Electricity price scenario	
Currency price senario	
Description	

Guide to colour codes for input fields:

White	Input fields (mandatory)
Light green	Input fields (optional)
Blue	Not applicable / not relevant
Grey	Information field (no input field)

General data specifies parameter for the whole wind farm.

Case name	Name of case that is simulated
Wind farm	Name of the wind farm
Description	Short description of the case
Start year [yyyy]	Start-up year of the operational phase of the wind farm. This information is only needed for the electricity price scenario

Simulation horizon [years]	Defines the length of the simulation in years; does not have to be equal to the life time of the wind farm
Number of simulations	Defines the number of simulation runs (Monte Carlo iterations)
Output economic sensitivities?	Create additional output file with which one may more easily calculate economic sensitivities.
Weather data	Name of the text file with the historic time series weather data; if weather data are documented in *Overview weather data.xlsx*, the file can be chosen from a drop-down list. The file should be located in the folder *Input/Weather data.*
Use only historic weather data?	Yes if weather time series used in the simulation should be the actual historic weather time series from the specified weather data file; no if synthetic weather time series should be used for each simulation using the Markov chain weather model.
Weather limits for vessels	Three options are available for the format of the vessel weather limits <u>Simple wave height limits:</u> Uses only limiting values of wave height and wind speed as specified in the basis data. <u>Matrix of limiting wave heights:</u> Uses reference to a file specified in the basis data with a matrix of limiting wave heights (as a function of wave direction and wave period). See the table for vessels in Ch. 4.2 for more details on the file format. For the vessels and vessel abilities for which there is no reference to such a file in the basis data, simple wave height limits will be used. The specified limiting value of wind speeds is used in both cases. <u>Accessibility time series:</u> Uses reference to a file specified in the basis data with an array of accessibilities or operabilities (yes or no) for each time step of the historical time series. See the table for vessels in Ch. 4.2 for more details on the file format. For the vessels and vessel abilities for which there is no reference to such a file in the basis data, simple wave height and wind speed limits will be used. This option only works in conjunction with historic weather data (see *Use only historic weather data?* above).
Boat landing direction [degrees]	Position of the boat landing on the wind turbines in degrees relative to the coordinate system of the weather data (i.e., relative to the direction corresponding to wave headings of 0 in the weather time series). The direction is given as a positive number below 360.
Wind speed resolution [m/s]	The smallest difference in wind speed between weather states regarded as distinct in the weather model.
Wind direction resolution [degrees]	The smallest difference in wind direction between weather states regarded as distinct in the weather model. The wind direction resolution must be a positive number smaller than 360 and must be a divisor of 360. If this field is set to "n/a", wind direction will not be taken into account in the weather model.
Wave height resolution [m]	The smallest difference in wave height between weather states regarded as distinct in the weather model.
Wave period resolution [s]	The smallest difference in wave period between weather states

	regarded as distinct in the weather model. If this field is set to "n/a", wave period will not be taken into account in the weather model.
Wave direction resolution [degrees]	The smallest difference in wave direction (wave heading) between weather states regarded as distinct in the weather model. The wave direction resolution must be a positive number smaller than 360 and must be a divisor of 360. If this field is set to "n/a", wave direction will not be taken into account in the weather model.
Inner wind farm average distance – unplanned [km]	Average distance for vessels when travelling between main components in the wind farm to an unplanned maintenance task
Inner wind farm average distance – planned [km]	Average distance for vessels when travelling between main components in the wind farm to a planned maintenance task
Prioritisation of maintenance tasks	Two options are available for choosing which maintenance tasks to give priority in cases where several maintenance tasks are scheduled for one shift. Always prioritise corrective maintenance. Maintenance tasks are prioritised by: 1) Maintenance type, in the following order: i) corrective, ii) condition based, iii) time based; 2) whether the maintenance task is already started; 3) whether a vessel has been chartered (ordered) for the task. (This is the default option.) Prioritise maintenance tasks that have started. Maintenance tasks are prioritised by: 1) Whether the maintenance task is already started, 2) whether a vessel has been chartered (ordered) for the task, 3) maintenance type, in the following order: i) corrective, ii) condition based, iii) time based. (This was the option used in the previous version of the model, version 3.)
Working hours per shift [hours]	Length of the shift for all maintenance teams and other resources, all days are considered as working days
Daily shifts [number]	Number of daily shifts, working hours per shift times daily shifts has to be equal or lower than 24 hours
Shifts starts [hour, 0...23]	Time of the day the first shift starts (Example: 6 means 6 am)
Minimum working time [hours]	Lower time limit for a weather window to start or continue a maintenance task
Fixed cost personnel [Currency per year]	Fixed cost per maintenance person / technician per year. This number should include all costs associated with having the specified average number of personnel available at the bases / vessels each shift (taking into account shift rotations, weekends, holidays, leaves, etc.)
Wake loss [%]	Factor for loss due to wake effects in the wind farm, the electricity production is reduced by this factor
Electrical loss [%]	Factor for the electrical losses in the wind farm and from export to shore, the electricity production is reduced by this factor
Lost production due to downtime electrical infrastructure [%]	Factor for lost production due to downtime in electrical infrastructure, the electricity production is reduced by this factor
Currency	Choose the currency for all the economic parameters; drop-down list can be extended in basis data
Discount rate [%]	Discount rate for the net present value calculations
Fuel price vessels [Currency/l]	Fuel price for the vessels
Constant electricity price	A constant value for the electricity price over the whole simulation

[Currency/kWh] horizon. Is overruled if an electricity price scenario is specified.

Electricity price scenario Which electricity price scenario is to be used for case, referring to lists of monthly electricity price scenarios as defined in basis data. If no electricity price scenario is specified, the electricity will be constant in time with value as given by the constant electricity price.

Wind farm main components		
Main component	Number	Investment cost total [GBP]
3 MW turbine	20	

It is possible to specify as many main components and components as needed. Components are always part of a main component. The main components are chosen from a list that has been specified by the user in the basis data.

Main component Name of the main component, has to be chosen from the available main components as specified in the basis data

Number Number of main components of that type in the wind farm

Investment cost total [currency] Investment cost for that main component per unit until its commissioning

Subcomponents				
Main component	Subcomponent	Number	Function loss of main compo-nent [%]	Description

Each main component can contain several subcomponents.

Main component Name of the main component; has to be chosen from the main components that have been specified for that case

Subcomponent Name of the subcomponent

Number Number of components of that type in the main component

Function loss of main component [%] Describes how much of its function the main component loses when this component fails

4.3.2 Sheet 2

Sheet 2 is used to specify what kinds of resources are needed for a maintenance action and how often a maintenance need occurs that triggers these actions.

Maintenance actions						
Maintenance action	Working duration [hours]	Access needed [Yes,No]	Logistics time [hours]	Personnel needed on structure	Ability needed [Yes,No]	Pre-inspection needed [Yes,No]
Annual service	60	Yes	0,00	3	No	No
Fault repair	8	Yes	0,00	2	No	No
Breakdown repair	50	Yes	0,00	5	Yes	Yes

Maintenance actions specify the type of operations that have to be performed for a maintenance task.

Maintenance action	Name for the specified maintenance action,
Working duration [hours]	Time needed to execute the maintenance task, exclusive travel time and access time
Access needed [No, Yes]	Specifies if access to an offshore structure is needed
Logistics time [hours]	The time needed for e.g. lifting equipment on the wind turbine or other logistics (associated with the maintenance action as such and not the vessel/access solution and the transfer of technicians) before work can start and the access vessel can move on.
Personnel needed on structure	Number of maintenance personnel needed for the maintenance action
Ability needed [No, Yes]	Is additional vessel ability (other than technician transfer) needed for the maintenance task?
Pre-inspection needed [No, Yes]	Is a separate inspection of the component and the failure needed prior to the actual repair (before ordering spare parts, additional vessels, etc.)?

For maintenance actions where pre-inspection is needed				
Maintenance action	Time needed for inspection [hours]	Access needed for inspection [No,Yes]	Logistics time [hours]	Personnel needed on structure for inspection
Annual service				
Fault repair				
Breakdown repair	8	Yes	0	2

If a pre-inspection is needed further information has to be specified for that.

Time needed for inspection	Time needed to perform inspection at the location of the maintenance task. Exclusive travel time and time to access the wind turbine.
Access needed for inspection [No,Yes]	Specifies if access to an offshore structure is needed
Logistics time [hours]	The time needed for e.g. lifting equipment on the wind turbine or other logistics (associated with the maintenance action as such and not the vessel/access solution and the transfer of technicians) before work can start and the access vessel can move on.
Personnel needed on structure for inspection	Number of maintenance personnel needed for the inspection

For maintenance actions where abilities are needed				
Maintenance action	Ability 1 needed	Personnel needed on vessel for ability	Ability 2 needed	Personnel needed on vessel for ability
Annual service				
Fault repair				
Breakdown repair	Lifting	0		

Each operation step can have demand for up to 2 other abilities besides the access to structure.

Ability 1 needed — Identifier of the ability that is needed, has to be chosen from the available abilities specified in basis data

Personnel needed on vessel for ability — The number of extra personnel needed on the vessel for using that ability. (For the need of specialist personnel on chartered vessels, e.g., for the lifting ability of a jack-up vessel, this is most easily modelled by setting the value to 0 and assume that these specialists comes with the vessel and does not need to be transported from the maintenance base.)

Time-based maintenance							
Main component / component	Maintenance name	Recurrence [Each ... year]	Start date [dd.mm.]	Number planned serviced per shift	Costs spare part [GBP]	Maintenance action	Stop during maintenance?
3 MW turbine	Annual service	1	01.05.	1	10000	Annual service	Only during work

Here, maintenance tasks are specified that occur based on a time schedule as for example yearly inspections.

Main component/component — has to be chosen from the available components in the wind farm (the available components are all subcomponents defined for main components as well as the main components themselves)

Maintenance name — Name of the maintenance

Recurrence [Each ... year] — Specifies how often the maintenance has to be performed. Example: If the value is 5, maintenance will be planned for the first time the 5th year of operation of the wind farm. The value has to be 1 or higher; if the value is 0, no maintenance will be planned. To schedule multiple maintenance tasks per year for the same component, one needs to specify these as separate time-based maintenance tasks to be scheduled once per year each.

Start date [dd.mm.] — Day of the year when the scheduled maintenance should start

Number planned serviced per shift — How many components one plans to service each shift. Is used to distribute the maintenance over different shifts. (Note that actual number serviced per day may be lower when the resources are insufficient or the weather is unfavourable.) Example: If the start date is May 1st and one plans to service one of in total 100 turbines per shift with one shift per day, the service of the 100th turbine will at the earliest start August 8th.

Costs spare part [Currency] — Cost for the spare part/consumables used

Lead time [hours] — Lead time to provide the spare parts

Maintenance action — Identifier of the maintenance action that has to be performed, has to be chosen from the available maintenance actions specified in the *Maintenance actions* table.

Stop during maintenance — Does the component have to be stopped during maintenance? If set to *Only during work* the component is stopped while work is performed but runs as normal between shifts if the maintenance task runs over several shifts.

Corrective maintenance										
Main component / component	Maintenance name	Failure rate [1/year]	Failure rate adjustment curve	Description	Costs spare part [GBP]	Lead time [hours]	Maintenance action corrective	Condi-tion based [Yes, No]	Stop at failure?	Stop during repair?
3 MW turbine	Fault repair	2,00	Bathtub curve		10000	0	Fault repair	No	No	Yes
3 MW turbine	Breakdown repair	0,10	Bathtub curve		10000	0	Breakdown repair	No	Yes	Yes

Here, maintenance tasks are specified that occur randomly. In addition, it can be specified if condition monitoring can be used to detect a prospective failure.

Main component/component	Identifier of the component that needs maintenance, has to be chosen from the available components in the wind farm (the available components are all subcomponents defined for main components as well as the main components themselves)
Maintenance name	Name of the maintenance
Failure rate [1/year]	Specifies how often the component fails on average per year
Failure rate adjustment curve	Name of the failure rate adjustment, has to be chosen from the available failure rate adjustment curves as specified in the basis data, specifies how the failure rate is adjusted by a factor each year; if no adjustment is specified, the factor is 1 for all years
Costs spare part [Currency]	Cost for the spare part/consumables used
Lead time [hours]	Lead time to provide the spare parts
Maintenance action corrective	Identifier of the maintenance action that has to be performed; has to be chosen from the available maintenance actions specified in the *Maintenance actions* table.
Condition based [Yes,No]	Specifies if condition-based maintenance is available for this failure
Stop at failure?	Is the component stopped at the instant the fault occurs?
Stop during repair?	Consequence for the function during the execution of the maintenance work, i.e. does the component have to be stopped?

Condition-based maintenance										
Main component / component	Maintenance name	Detect-ability [%]	Efficiency [days]	Maintenance action condition based	Costs spare part [GBP]	Lead time [hours]	False alarms [1/year]	Maintenance action false alarms	Stop at alarm?	Stop during repair?
3 MW turbine	Fault repair									
3 MW turbine	Breakdown repair									

Each corrective maintenance can also be specified as a condition-based maintenance task by choosing yes in the corrective maintenance table. As a result, if an incipient fault is discovered at a sufficiently early stage, a condition-based maintenance task will be planned and executed before the potential corrective maintenance task. In this table, the user can specify parameters for the condition based maintenance activities.

Detectability [%]	Probability to discover a failure before it occurs
Efficiency [days]	Number of days the failure was detected in advance before it will have consequences

Maintenance action condition based	Identifier of the maintenance action that has to be performed for the condition-based maintenance; has to be chosen from the available maintenance actions specified in the *Maintenance actions* table.
Costs spare part [Currency]	Cost for the spare part/consumables used for the condition-based maintenance
Lead time [hours]	Lead time to provide the spare parts for the condition based maintenance
False alarms [1/year]	Number of false alarms from the condition monitoring system for that component per year [number/year]
Maintenance action false alarms	Identifier of the maintenance action that has to be performed in case of false alarm; has to be chosen from the available maintenance actions specified in the *Maintenance actions* table.
Stop at alarm?	Is the component stopped at the instant of an alarm?
Stop during repair?	Consequence for the function during the execution of the maintenance work, i.e., does the component have to be stopped?

It is also possible to add comments to each row by using the table to the far right.

Comment

4.3.3 Sheet 3

Sheet 3 is used for the specification of the logistical set up for the wind farm with harbours, vessels and how the vessels are operated.

Locations								
Location name	Distance to offshore wind farm [km]	Personnel available per shift	Seasonal dependence? [No,Yes]	Season starts [dd.mm.]	Season stops [dd.mm.]	Personnel available per shift off season	Yearly fixed cost [GBP/year]	Description
Harbour 1	17,0	24	No					
Harbour 2	63,3	24	No					

The locations table contains all the locations where vessels are stationed, for example a harbour or offshore platform.

Location name	Name of the location
Distance to the offshore wind farm [km]	Distance from the location to the offshore wind farm borders

Personnel available per shift	Number of personnel that are available at the location for each shift
Seasonal dependence? [Yes,No]	If there should be seasonal dependence of the personnel available at the location, typically so that there are more technicians available in the campaign period (summer season) than off season
Season starts [dd.mm.]	Date of the year when campaign period starts. Do not include year.
Season stops [dd.mm.]	Date of the year when campaign period stops. Do not include year.
Personnel available per shift off season	Number of personnel available at location per shift off season
Yearly fixed cost [Currency/year]	Fixed cost per year incl. cost per year associated with transporting supply or personnel to a location (meant especially for locations such as offshore platforms)

Vessel properties					
Vessel	Number	Home port (safe haven)	Daughter vessel	Number daughter vessels	Fixed cost per daughter vessel [GBP/year]
CTV 1	2	Harbour 2			
Jack-up	1	Harbour 1			

Vessels comprise all kind of resources that can be used for maintenance actions. A helicopter can be defined as a vessel. The vessels have to be chosen from a list that is specified in the basis data.

Vessel	Identifier of the vessel, has to be chosen from the available vessels types in the basis data
Number	Number of vessels of this type that are available
Home port (safe haven)	Identifier of the location the vessel is associated with. For mother ships etc., the vessel only comes back to this base for resupplying etc. or during extreme weather. The same thing applies for chartered vessel, which uses this location as home port / safe haven during charter period.
Daughter vessel	Specifies if the vessel has daughter vessels and, if so, which vessels that are; has to be chosen from the available vessels in the basis data. The field is left blank if the vessel has no daughter vessels
Number daughter vessels	Number of daughter vessels that are available at each of the mother ships
Fixed cost per daughter vessel [Currency/year]	Fixed cost per year per daughter vessel incl. cost for maintenance etc.

Description	Access	Ability no. 1	Ability no. 2	Ability no. 3		Abilities needed	Abilities needed
FAROFF	Yes						
FAROFF	No	Lifting					
						Lifting	

The grey-marked cells contain information about the abilities the different vessels have and what abilities are needed for the maintenance activities (Abilities needed). This information can be used to check if there are vessels chosen for each ability needed.

Availability and cost of vessel										
Vessel	Ordered? [No, Yes]	Order lead time [days]	Charter duration [days]	Charter cost incl. mobilisation cost [GBP]	Seasonal dependence? [No, Yes]	Season starts [dd.mm.]	Season stops [dd.mm.]	Available at another base off season? [No,Yes]	Home port off season	Fixed cost per vessel [GBP/year]
CTV 1	No				No					
Jack-up	Yes	60	14		No					

Vessels can be available immediately since they are on long-term rental / purchased or they have to be chartered with a given lead time. In addition, vessels may be specified to only be available in the summer season or to operate from different maintenance bases in summer or winter. All these aspects and the related cost can be defined in this table.

Ordered? [Yes,No]	Does the vessel have to be ordered/chartered from external enterprise?
Order lead time [days]	Time that has to be waited until the ordered vessel is available
Charter duration [days]	Duration of charter, i.e. how long the vessel will remain available at the location
Charter cost incl. mobilisation cost [currency]	Cost for chartering a vessel for the specified charter duration incl. mobilisation cost (fuel cost are considered separately)
Seasonal dependence? [Yes,No]	Is the vessel only available during a season?
Season starts [dd.mm.]	Date from which the vessel is available at location
Season stops [dd.mm.]	Date until which the vessel is available at the location
Available at another base off season? [Yes,No]	Is the vessel also available off season from another base?
Home port off season	Location the vessel is associated with off season. (Only vessels that go out and in in the same shift can be stationed at another harbour off season.)
Fixed cost per vessel [Currency/year]	Cost per year for that vessel (inclusive daughter vessels, if available)

Operation of vessels							
Vessel	Operation mode [One shift, Several shifts, Always offshore]	Days offshore - over-night [days]	Days onshore - over-night [days]	Personnel available per shift per vessel	Offshore logistic costs [GBP/year]		Personnel space available
CTV 1	One shift						12
Jack-up	Always offshore			40			40

Vessels can be operated in different operation modes. Small access vessels will start and return typically from and to harbour each shift. Larger vessels can maybe stay offshore to do their maintenance work for one week, whereas mother vessels will essentially always stay offshore. These different operation modes can be specified here.

Operation mode [One shift, Several shifts, Always offshore]	Type of operational schedule the vessel is used with, One shift (in and out each shift), Several shifts (stays offshore overnight a limited period), Always offshore (typical a mother ship)
Days offshore - over night [days]	Number of days the vessel can stay offshore, only applicable to vessels that stay offshore several shifts
Days onshore - over night [days]	Number of days the vessel has to stay onshore after each time it has been offshore, only applicable to vessels that stay offshore several shifts
Personnel available per shift per vessel	Personnel available per shift, only applicable for vessels that stay offshore for more than a shift, it is assumed that they have their own maintenance crew
Offshore logistic costs [Currency/year]	Yearly cost for transporting people and supply to e.g. a mother ship

Fixed vessel for maintenance	
Maintenance action	Access vessel
Annual service	
Fault repair	
Breakdown repair	

This table can be used to fix an access vessel or helicopter to use for a given maintenance tasks. If nothing is specified, the model chooses the cheapest vessel available for each occurring maintenance task during the simulation.

4.3.4 Sensitivity

The Sensitivity sheet can be used to define changes for several parameters based on the values specified in Sheet 1-3. It helps to perform several simulation runs with changes in input parameters without the need of setting up new Case data sheets each time.

The use of the Sensitivity sheet is optional. If one wants to use it, it has to be activated by choosing "Yes" for the option "Execute sensitivity analysis". In addition, it can be chosen if the base case as specified in Sheet 1-3 should be run first or if one wants to start right away with simulating the new cases.

Execute sensitivity analysis?	Yes
Run base case?	No

The following parameters can be changed with the Sensitivity sheet:

- Personnel
  - Personnel available per shift per location
  - Personnel available per shift off season per location
  - Personnel available per shift per vessel
- Maintenance
  - Failure rate
  - Recurrence of time-based maintenance
- Vessels
  - Number of vessels
  - Access wave height limit
  - Access wind speed limit
  - Travel speed

All tables are following the same format and will be explained with the example of personnel per location.

Personnel available per shift

Include table in sensitivity analysis?	Yes

Location name	Base value	Value 1	Value 2	Value 3	Value 4
All locations	*100 %*	*50 %*	*200 %*		
Harbour 1	24	20	30		
Harbour 2	24	18	26		

First of all, it has to be marked if a parameter should be considered in the sensitivity analysis by marking "Yes" to "Include table in sensitivity analysis?". Each green cell with a specified value represents a sensitivity case. In this example, 6 sensitivity cases are specified. The order of running the cases is from left to right and from up to down (here 50 %, 200 %, 20, 30, 18, 26). Values in the first row (here *All locations*) are always relative values and effective for all objects (here *Harbour 1 and Harbour 2*) in the table. In the example the first sensitivity case is specified as 50 %. This means that both harbours would have 12 persons (50% of 24) and in the second sensitivity case 48 (200 % of 24). All following rows (here *Harbour 1* and *Harbour 2*) specify only a change in one object, here a location, and are specified in absolute values. The third sensitivity case would therefore be run with 20 persons at *Harbour 1* and whereas the number of persons at *Harbour 2* would be unchanged, and still 24 persons.

In the following, important assumptions for the different parameters are summarised.

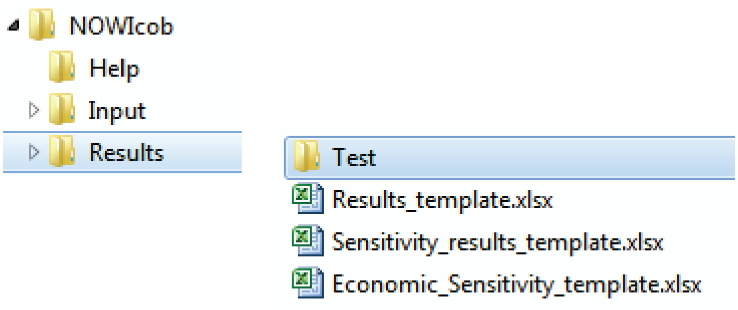
Personnel:
The number of personnel is rounded to the next integer, when relative values are used. Only vessels that are offshore overnight have their own personnel and therefore the personnel can be only changed for these vessels.

Maintenance:
The recurrence of the time-based maintenance is rounded to the next full year, since only full years are allowed.

Vessels:
The tables are divided into normal vessels and daughter ships. However, values specified in the first row have effect on all vessels.

5 Result files

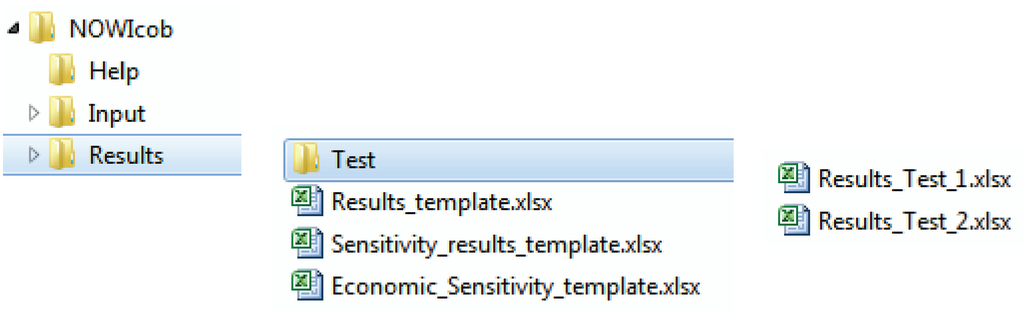
Results are saved automatically in an Excel files after the simulation is finished. The result files are stored in a subfolder in the Result folder. The subfolder has the same name as the name of the case specific data input file. In our example the case specific data input file is *Test.xlsx*, therefore the results will be saved in *Results/Test*.



The files *Results_template.xlsx*, *Sensitivity_results_template.xlsx* and *Economic_Sensitivity_template.xlsx* contain the template for all result files and should not be changed since it can cause failures in the program. However, text and descriptions can be changed.

5.1 Results for a simulation case

The result file is named the same as the case-specific input file with an additional starting and a counting number (*Results_..._1.xlsx*). In our example, the file would be named *Results_Test_1.xlsx*. The number at the end of the file increases if a case is run several times with changes in the input parameters. Subsequent result files would therefore be named *Results_Test_2.xlsx, Results_Test_3.xlsx* and so on.



Each result file contains several sheets with result data and in addition sheets that document the case-specific input data that lead to these results. As for the input sheets, some cells in the results sheets include comments with more detailed explanations that can be read by hovering the mouse pointer over the cell.

5.1.1 Result sheets

Sheet name	Description
Results – summary	Main results
Results – details	Results per simulation run
Results – down-time	More detailed results for downtime per component and maintenance
Results – availability	More detailed for availability of the wind farm
Results – vessel utilization	More detailed results for vessel utilization
Results – personnel utilization	More detailed results for personnel utilization

Results – summary

All economic values are calculated as net present values. If one wants to have absolute values, the discount rate has to be set to 0 in the input file and the simulation has to be rerun. The following results are presented in the sheet:

- *Theoretical income*: Potential income if availability of the wind farm is 100%, but considering losses due to wake and losses in the electrical infrastructure
- *Lost income due to downtime*: Lost income due to downtime of the wind turbines as well as possible downtime of the electrical infrastructure (if that factor was defined upfront in the input sheet)
- *Real income*: Income from the produced electricity (Theoretical income – Lost income)
- *Investment cost*: Sum of the investment cost if specified in the input sheet
- *O&M cost*: Sum of spare parts cost, vessel cost, personnel cost and location cost
- *Profit*: Theoretical income – Lost income – Investment cost – O&M cost
- *Cost of energy*: Levelized cost of energy, i.e. the constant energy price that would cause the project to break even when energy income and costs are discounted to year 0
- *Time-based availability*: Availability of the wind farm incl. availability of electrical infrastructure measured in time
- *Electricity-based availability*: Availability of the wind farm incl. availability of electrical infrastructure measured in produced electricity. (Note that when evaluating an O&M strategy using the model, in addition to looking at the availabilities it is also recommended to check the results sheet "Results – down-time" (below) to see whether all time-based maintenance has been completed.)
- *Energy produced*: considers availability, wake losses and electrical losses
- *Capacity factor*: Electricity produced for 100% availability / Theoretical production with full load all time
- O&M cost split
  - Spare parts cost
  - Fixed vessel cost
  - Fuel cost for vessels
  - Vessel charter cost
  - Personnel cost
  - Location cost (for example rental of harbour)

Results - details

This sheet contains all data for each simulation run for the main results. It can be used to create customized histograms or statistical analyses for output parameters of interest.

Results – down-time

This sheet contains results for the downtime organized after the different components and maintenances. The results in this sheet can be used to understand what contributes most to the downtime. (Note that this split of down-time is indicative of the reasons behind the unavailability result, but the model cannot exactly and ambiguously assign each period of downtime to a specific reason. Also, if the function loss associated with a component is less than 100%, the downtime assigned to maintenance of this component is reduced accordingly.) The downtime is split in these categories:

- *Lead time*: Average over all simulation runs. Down time due to lead time spare parts / ordered vessels, waiting time until next shift (only corrective tasks)
- *Weather*: Down time due to waiting time for weather until the next shift with good weather starts (only corrective tasks)
- *Resources*: Average over all simulation runs. Down time due to waiting time due to overbooking of personnel / vessels until the next shift starts (only corrective tasks)
- *Travel/working*: Average over all simulation runs. Down time due to working time and accessing wind turbine (on/off) and travel to the wind turbine and/or the rest of the hours of the shift if the task (only for corrective tasks) is not yet completed and is being split over several shifts

Results – availability

This sheet contains the average time-based availability of the wind farm for each month of the year and for each operation year. The standard error of the time-based availability is also presented to illustrate the uncertainties of the numbers.

Results – vessel utilization

This sheet contains results organized after the different vessels. It can be used to understand what accessibility can be reached with the vessels and how the utilization of the vessels has been. The following main results are presented:

- *Accessibility* to the wind farm in % based on
  - *Hours:* Percentage of hours when a vessel has good weather and could work (the least limiting limits), excluding onshore hours and hours outside of shift
  - *Shifts:* Percentage of shifts when a vessel has good weather and could work at least 1 hour (the least limiting limits), excluding time onshore
- *Utilized hours and shifts*
  - *Hours:* All hours a vessel is working and travelling (waiting for personnel that are on turbines offshore is not considered as working)
  - *Shifts:* All shifts a vessel is working and travelling, launching of daughter vessels is not considered working
- *Utilization* in % based on
  - *Hours:* Utilized hours / available working hours (all hours excluding time outside shifts and onshore time)
  - *Shifts:* Utilized shifts / available working shifts (all shifts excluding onshore shifts)
- *Utilization* in good weather in % based on
  - *Hours:* Utilized hours / real available hours (all hours excluding time outside shifts, onshore time and hours with bad weather)
  - *Shifts:* Utilized shifts / real available shifts (all shifts excluding onshore shifts and shifts with bad weather so that the vessel could not even work 1 hour)

Results – personnel utilization
This sheet contains results about the utilization of the personnel at the different locations (for example harbours) and vessels (each vessel that stays offshore overnight has its own team). The following results are presented:

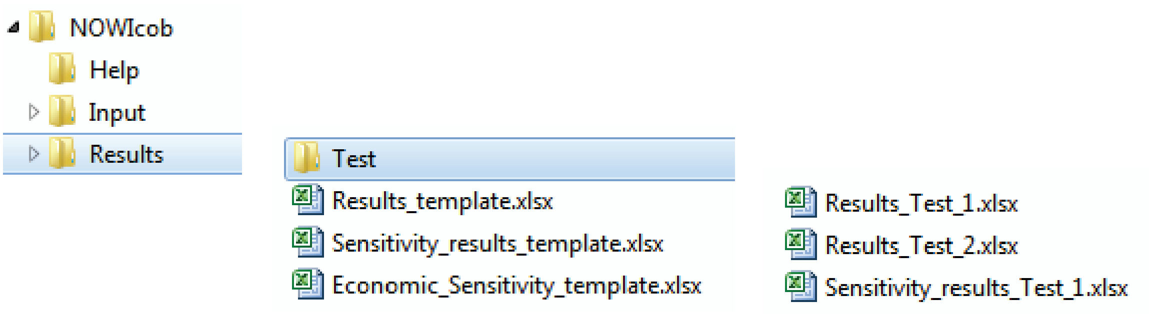
- *Utilized personnel per shift*: Average number of personnel used per shift when working. Only shifts when at least one person was working are considered.
- *Utilization in %*: Percentage of the utilized personnel to the available persons at a maintenance base or at a vessel. Only shifts when at least one person was working are considered. This number is 100% for vessels that go in and out in same shift since they take only that many persons they need.
- *Utilization space*: Percentage of the utilized personnel to the available space. . Only shifts when at least one person was working are considered. Gives new information only for vessels that go in and out in same shift since other vessels have their fixed number of personnel.

5.1.2 Input data documentation sheets

Sheet name	Description
Input – 1	Copy of sheet 2 in case specific data input file
Input – 2	Copy of sheet 2 in case specific data input file
Input – 3	Copy of sheet 2 in case specific data input file
Input data – Main components	Copy of some basis data that were used in the simulation
Input data – Power curve	Copy of some basis data that were used in the simulation
Input data – Vessels	Copy of some basis data that were used in the simulation
Input data – Electricity price	Copy of some basis data that were used in the simulation
Input data – Failure rate adj	Copy of some basis data that were used in the simulation
Random number generator	Information and details on the random number generator used for generating the sequence of (pseudo)random times for occurrence of failures

5.2 Sensitivity results

Some major results are saved for all sensitivity analyses in an extra Excel file. The result file is named the same as the case-specific input file with an additional starting and a counting number (*Sensitivity_results_…_1.xlsx*). In our example, the file would be named *Sensitivity_results_Test_1.xlsx*. The number at the end of the file increases if several sensitivity analyses are performed. Subsequent result files would therefore be named *Sensitivity_results_Test_2.xlsx, Sensitivity_results_Test_3.xlsx* and so on.

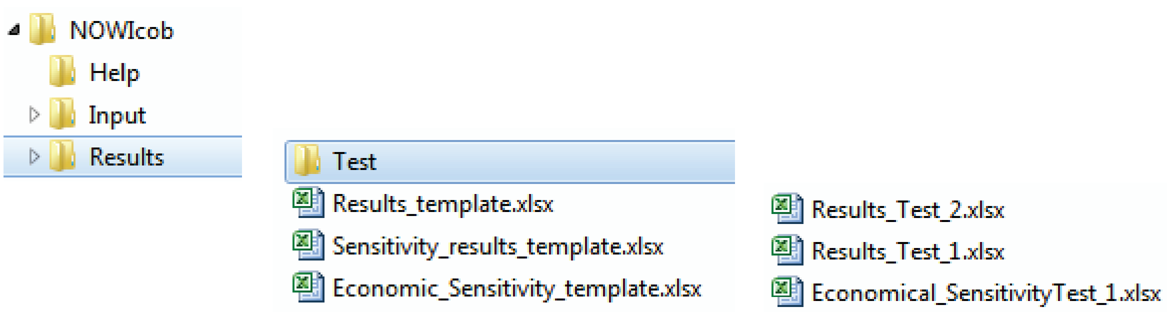


Each sensitivity result file contains three sheets with result data, documentation of the sensitivity cases and a graphical presentation of the results. In the following the three sheets are explained in detail.

Sheet name	Description
Sensitivity cases	Copy of sheet Sensitivity in case specific data input file
Details	Results of all sensitivity cases. The following results are available: • Time-based availability • Electricity-based availability • O&M cost as net present value • Lost income due to downtime as net present value • Profit as net present value In addition, the name of the Excel file with the detailed results is saved in the table. Therefore, it is possible to find more results as presented here for each case.
Graph	Sensitivity graphs can be produced for all result parameters available from sheet Details and for all sensitivity cases that have been run

5.3 Economic sensitivity results

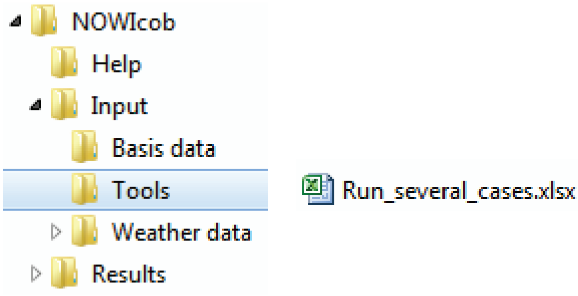
Selected simulation results, for each year in the simulation, are written to an Excel workbook designed for studying sensitivities regarding economical parameters. In this way sensitivity to economical parameters can be studied without having to run the simulations several times. The economic sensitivity file is named the same as the case-specific input file with an additional starting and a counting number (*Economic_Sensitivity_..._1.xlsx*). In our example, the file would be named *Economic_Sensitivity _Test_1.xlsx*. The number at the end of the file is the same as for corresponding results file.



Each economic sensitivity file contains of one sheet with the results of the sensitivity study and a documentation sheet describing how to use the workbook.

6 Run several cases

The user can find the file *Run_several_cases.xlsx* in the folder *Input/Tools.* This file can be used to automatize the running of several simulations.

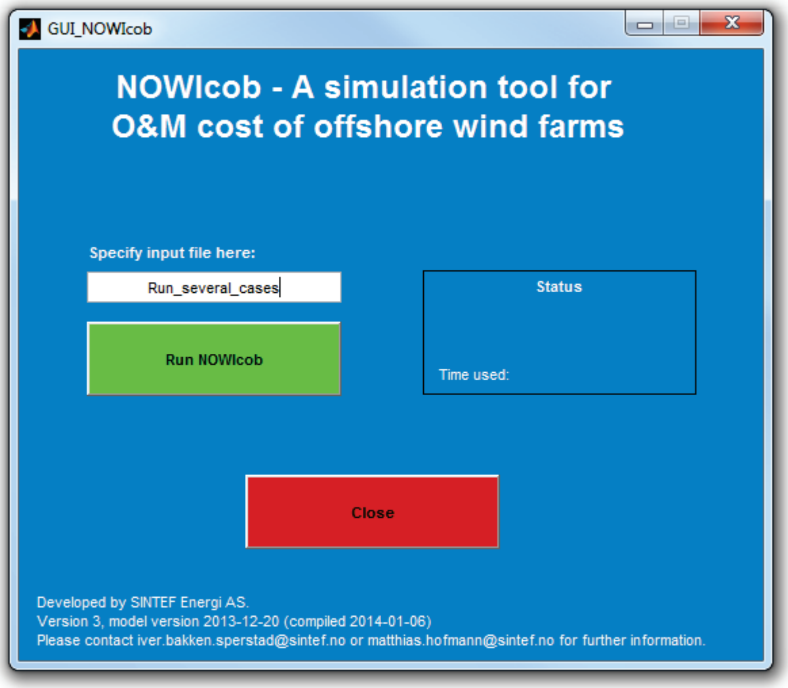


The file contains a table where several case input files can be specified and a comment to each file can be written. When the model is run, it will call all the input files automatically and save the results in the correct folders in the same way as if the user had chosen a new file in the graphical user interface after each finished simulation.

Specify cases

File name	Comment

This tool can be used by writing Run_several_cases in the input cell of the graphical user interface and pressing the Run NOWIcob button.



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