

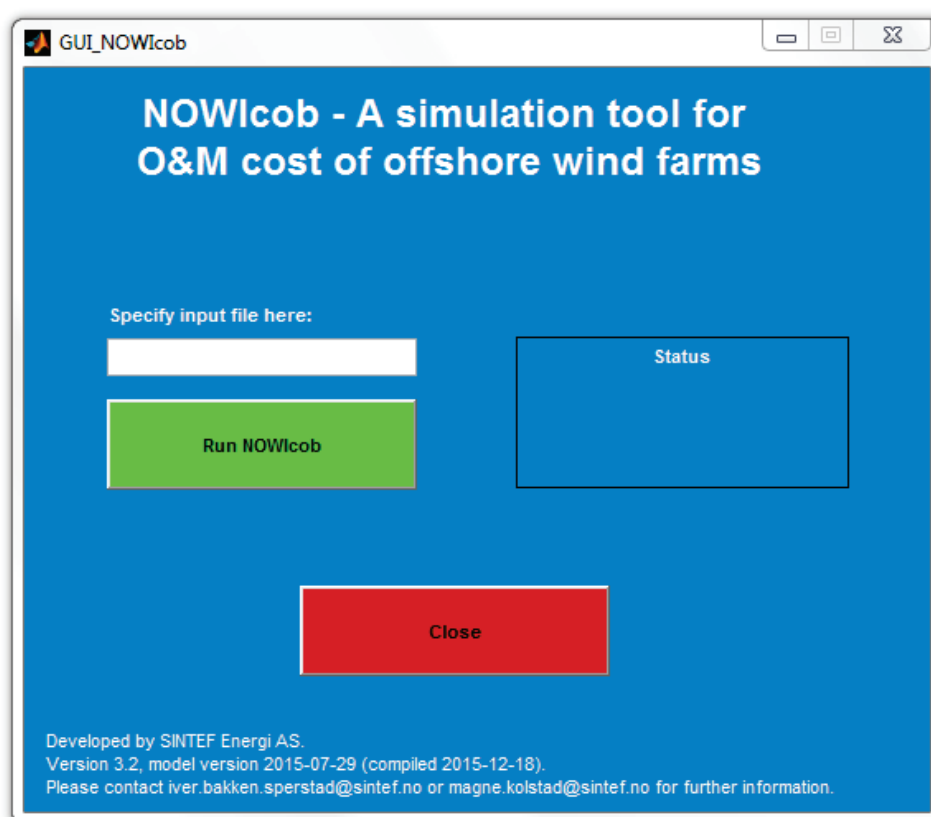
Report

User guide for the NOWIcob tool (DB.1-2)

NOWIcob version 3.2

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Report

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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 a 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
 - o Run *MCRInstaller.exe* in the folder *Help*
 - o 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

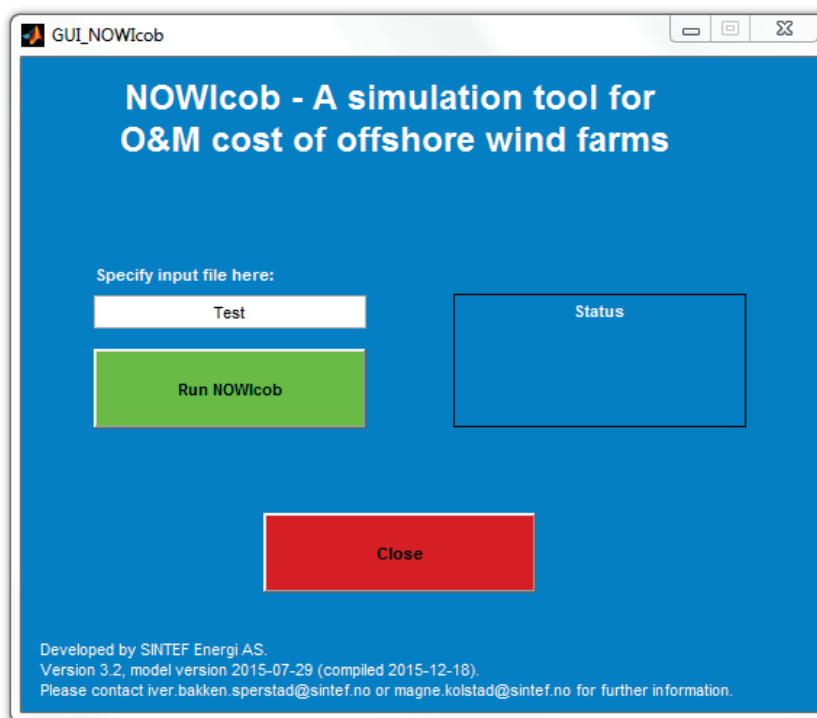
2 Quick start

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. 4.3.5 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. 0 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 *Results_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

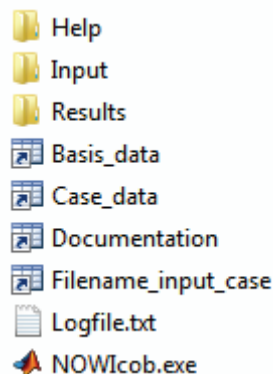
1. Change case data
 - a. Open a case file in folder *Input*, for example *Test.xlsx*, and change the input values.
 - b. Save it.
2. Run model
 - a. Run *NOWIcob.exe*.
 - b. Write the file name in the input text box (without the ".xlsx" extension).
 - c. Press Run NOWIcob.
3. Results
 - a. Results are 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 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:

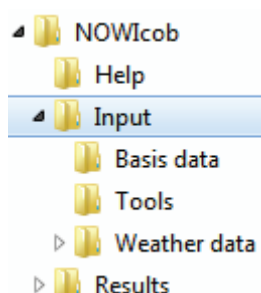
- *Help*: contains this user guide and the installation file for MATLAB Compiler Runtime
- *Input*: contains files and subfolders where the user specifies and stores all input data.
- *Results*: contains the result files that are automatically saved by the program in case specific subfolders.
- *NOWIcob.exe*: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

The user can also include the relative path of the input case file when specifying the input file before running the model (cf. Ch. 2) if the input case file is not located in the "Input" subfolder. In that case, the results will be stored in a "Results" subfolder of the folder containing the input case file.

For practical guidelines on handling and maintaining the folder structure, see the list of "dos and don'ts" in Ch. 7.

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.

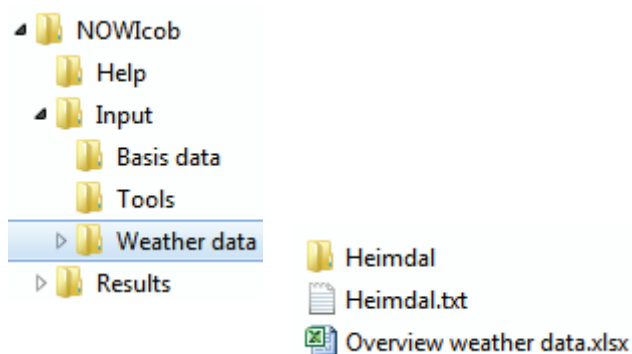


The basis data contain all information that can be reused in several case-specific set ups. Examples for basis data are electricity price scenarios and different types of vessels. Since the case-specific data refer directly to the basis data, a typical approach for preparing the data for the model is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

For general guidelines and warnings on using the input spreadsheets, see the list of "dos and don'ts" in Ch. 7.

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]

Wind speed data for a single height above sea level is used in the model, and if input time series for several heights are available, the user is free to choose which time series to use. However, typically wind speed data measured at hub height should be used to more accurately estimate electric power production, since the power curve will typically be specified for wind speeds at hub height. No particular measure of the wave height is assumed for the wave height time series, but the measure should be consistent with that used for the wave height limits specified for vessels. The mean significant wave height is the wave height measure that is most typically used. Similarly, no particular measure of the wave period is assumed.

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, but all 11 columns need to be present. The decimal operator that is assumed is period ("."). In this example the Heimdal data contain only wind speed and wave height data with a resolution of 20 minutes. If the first calendar year of the weather time series is incomplete, only data from the first full calendar year onwards will be used as input.

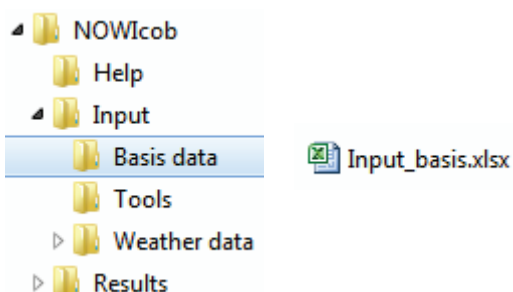
Heimdal.txt										
1	2004	6	21	7	40	0	3.2	0	1.7	0
2	2004	6	21	8	0	0	3	0	1.8	0
3	2004	6	21	8	20	0	3.3	0	1.4	0
4	2004	6	21	8	40	0	3.1	0	1.3	0
5	2004	6	21	9	0	0	3.1	0	1.4	0
6	2004	6	21	9	20	0	3.1	0	1.7	0
7	2004	6	21	9	40	0	3.2	0	1.5	0
8	2004	6	21	10	0	0	3.6	0	1.4	0
9	2004	6	21	10	20	0	3.1	0	1.5	0
10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

Currencies

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.

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

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.

<i>Power curve</i>	Name of power curve, is also used as identifier
<i>Description</i>	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 %
Siemens SWT- 2.3 82	6	13,80 %

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. When calculation of the power production, wind speeds are rounded to the nearest integer value, and only specified or interpolated power curve data points with integer wind speeds are used. In the model, power production is set to zero at and below the cut-in wind speed and above the cut-out wind speed specified in the Table *Main components*. If the highest wind speed entered in the table is below the cut-out wind speed, the power production is assumed to be constant between the highest wind speed in the table and the cut-out wind speed.

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 at hub height

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]	Technician space	Offshore wave height limit [m]	Offshore wind speed limit [m/s]	Approach time for access [hours]	Transfer time for access [hours/person]	Access ability [No, Yes]
CTV 1	Crew transfer vessel with wave height limit 1.2 m	20	50	15	12	2,5	30	0,083	0,05	Yes
CTV 2	Crew transfer vessel with access system and therefore wave height limit 1.8 m	20	50	15	12	2,5	30	0,250	0,05	Yes
Surface effect ship	SES - fast crew transfer vessel	35	50	15	12	4	30	0,083	0,05	Yes
Small Accomodation Vessel	SAV - Vessel can stay offshore for several weeks	20	100	100	12	4	30	0,083	0,05	Yes
Mini mother vessel	Capacity for 2 daughter vessels	14	200	200	12	5	30	0,167	0,03	Yes
Mother vessel	Capacity for 4 daughter vessels	14	300	300	24	5	30	0,167	0,03	Yes
Daughter vessel	Daughter vessel	16	50	15	6	2	20	0,083	0,05	Yes
Offshore Service vessel	OSV - Medium sized vessel with lifting capacity (also referred to e.g. as a SOV)	14			40	5	30	0,167	0,03	No
Jack-up vessel	Heavy-lift vessel	5			40	5	30	0,15	0,03	No
CTV O&M group	CTV used in O&M Modelling group (used in Dinwoodie et al. 2015)	20	100	50	12	4	30	0	0	Yes
Field support vessel	FSV/OSV/SOV used in O&M Modelling group (used in Dinwoodie et al. 2015)	12	1200	270	60	4	30	0	0	No
Heavy Lift	Jack-up vessel used in O&M Modelling group (used in Dinwoodie et al. 2015)	11			100	4	30	0	0	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.

<i>Vessel name</i>	Name of the vessel, is used as identifier in the case specific data
<i>Vessel description</i>	Description of the vessel
<i>Travel speed [knots]</i>	Average travel speed of the vessel in transit
<i>Fuel consumption travelling [l/hour]</i>	Fuel consumption when travelling
<i>Fuel consumption stationary [l/hour]</i>	Fuel consumption when stationary
<i>Technician space</i>	Maximum space for maintenance technicians on the vessel
<i>Offshore wave height limit [m]</i>	Wave height limit above which the vessel has to return to a safe harbour
<i>Offshore wind speed limit [m/s]</i>	Wind speed limit above which the vessel has to return to a safe harbour
<i>Approach time for access [hours]</i>	Time from the access vessel is in the vicinity of the wind turbine to it is ready for technician transfer
<i>Transfer time for access [hours/person]</i>	Time needed to transfer one technician to the wind turbine after the vessel is connected to the wind turbine and ready for technician transfer
<i>Access ability [Yes,No]</i>	Specifies if the vessel has the ability to let technicians access offshore structures. For e.g. jack-up vessels transferring technicians via a gangway, it is recommended to set this to "No" and also set "Access needed" to "No" for the maintenance action(s), i.e. not model technician transfer explicitly.

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]	Ability 2 wind speed limit [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).

It is recommended to state wind speed and wave height limits using the same resolution as specified for the weather model (cf. Sec 4.3.1) to reduce possible rounding errors. No particular measure of the wave height is assumed for the wave height limits, but the measure should be consistent with that used for the weather time series. The mean significant wave height is the wave height measure that is most typically used. When setting the wind speed limits the user needs to recall that the wind speed time series at a single height above sea level is used throughout the model. This means that if the hub height wind speed is given as input data, this must be taken into account when setting limits for the wind speed closer to sea level (such as access limits for a vessel), and vice versa.

<i>Access wave height limit [m]</i>	Wave height limit for accessing offshore structure
<i>Access wind speed limit [m/s]</i>	Wind speed limit for accessing offshore structure
<i>Access weather limits input file name</i>	File name of text file with alternative description of weather limits (see below).
<i>Ability 1</i>	Name of the ability as specified in table <i>Abilities</i>
<i>Ability 1 wave height limit [m]</i>	Wave height limit for using that ability
<i>Ability 1 wind speed limit [m/s]</i>	Wind speed limit for using that ability
<i>Ability 1 weather limits input file name</i>	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. 0 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 (unit: m) 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									
1	7	7							
2	0	30	60	90	120	150	180		
3	3	5	7	9	11	13	15		
4	0.75	0.55	0.55	0.65	0.75	0.85	0.95		
5	0.85	0.65	0.65	0.75	0.85	0.95	1.05		
6	0.95	0.75	0.75	0.85	0.95	1.05	1.15		
7	1.05	0.85	0.85	0.95	1.05	1.15	1.25		
8	0.95	0.75	0.75	0.85	0.95	1.05	1.15		
9	0.85	0.65	0.65	0.75	0.85	0.95	1.05		
10	0.75	0.55	0.55	0.65	0.75	0.85	0.95		

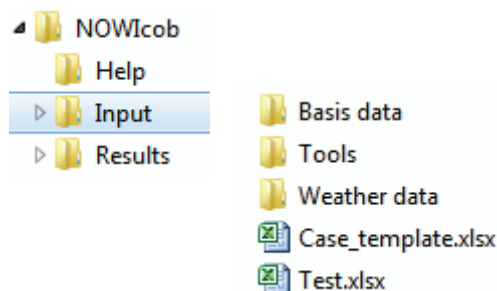
Accessibility time series:

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, technicians 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	
1	0
2	0
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	1
11	1
12	1
13	1
14	1
15	1
16	1
17	1
18	1
19	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 maintenance bases, 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.

Guide to colour codes for input fields:	
	Input fields (mandatory)
	Input fields (optional)
	Not applicable / not relevant
	Information field (no input field)

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 period [years]	3
Number of Monte Carlo iterations	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]	0,10
Wave period resolution [s]	n/a
Wave direction resolution [degrees]	n/a
Internal wind farm average distance - unplanned [km]	1,5
Internal wind farm average distance - planned [km]	1,0
Prioritisation of maintenance tasks	Prioritise maintenance tasks that stop the turbine
Working hours per shift [hours]	12
Daily shifts [number]	1
Shift starts [hour, 0...23]	6
Minimum working time [hours]	1
Fixed cost technicians [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:

	Input fields (mandatory)
	Input fields (optional)
	Not applicable / not relevant
	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

<i>Description</i>	Short description of the case
<i>Start year [yyyy]</i>	Start-up year of the operational phase of the wind farm. This information is only needed for the electricity price scenario
<i>Simulation period [years]</i>	Defines the length of the simulation in years; does not have to be equal to the life time of the wind farm
<i>Number of Monte Carlo iterations (simulation runs)</i>	Defines the number of Monte Carlo iterations (simulation runs). Results from the model are averaged over all Monte Carlo iterations, and the statistical uncertainty in these averages decrease as one over the square root of the number of iterations. In choosing the number of iterations, the user needs to make a trade-off between increasing the statistical precision in the results and increasing the computation time.
<i>Output economic sensitivities?</i>	Create additional output file with which one may more easily calculate economic sensitivities.
<i>Weather data</i>	Name of the text file with the historic time series weather data; if weather data are documented in <i>Overview weather data.xlsx</i> , the file can be chosen from a drop-down list. The file should be located in the folder <i>Input/Weather data</i> .
<i>Use only historic weather data?</i>	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.
<i>Weather limits for vessels</i>	<p>Three options are available for the format of the vessel weather limits</p> <p><u>Simple wave height limits:</u> Uses only limiting values of wave height and wind speed as specified in the basis data.</p> <p><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.</p> <p><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 <i>Use only historic weather data?</i> above).</p>
<i>Boat landing direction [degrees]</i>	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.
<i>Wind speed resolution [m/s]</i>	The smallest difference in wind speed between weather states

<i>Wind direction resolution [degrees]</i>	<p>regarded as distinct in the weather model.</p> <p>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.</p>
<i>Wave height resolution [m]</i>	<p>The smallest difference in wave height between weather states regarded as distinct in the weather model.</p>
<i>Wave period resolution [s]</i>	<p>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.</p>
<i>Wave direction resolution [degrees]</i>	<p>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.</p>
<i>Internal wind farm average distance – unplanned [km]</i>	<p>Average distance for vessels when travelling between main components in the wind farm to an unplanned maintenance task</p>
<i>Internal wind farm average distance – planned [km]</i>	<p>Average distance for vessels when travelling between main components in the wind farm to a planned maintenance task</p>
<i>Prioritisation of maintenance tasks</i>	<p>Three options (a,b,c) are available for choosing which maintenance tasks to give priority in cases where several maintenance tasks are scheduled for one shift.</p> <p><u>a: Prioritise failures/alarms that stop the turbine.</u> Within this option, maintenance tasks are prioritised by: 1) Whether the turbine is stopped at failure/alarm 2) maintenance type, in the following order: i) corrective, ii) condition based, iii) time based; 3) whether the maintenance task is already started; 4) whether a vessel has been chartered (ordered) for the task. (This is the default option.)</p> <p><u>b: Always prioritise corrective maintenance.</u> Within this option, maintenance tasks are prioritised by: 1) Maintenance type, in the following order: i) corrective, ii) condition based, iii) predetermined preventive maintenance; 2) whether the maintenance task is already started; 3) whether a vessel has been chartered (ordered) for the task.</p> <p><u>c: Prioritise maintenance tasks that have started.</u> Within this option, 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) predetermined preventive maintenance. (This was the option used in version 3 of the model.)</p>
<i>Working hours per shift [hours]</i>	<p>Length of the shift for all maintenance teams and other resources, all days are considered as working days</p>

<i>Daily shifts [number]</i>	Number of daily shifts, working hours per shift times daily shifts has to be equal or lower than 24 hours
<i>Shifts starts [hour, 0...23]</i>	Time of the day the first shift starts (Example: 6 means 6 am)
<i>Minimum working time [hours]</i>	Lower time limit for a weather window to start or continue a maintenance task
<i>Fixed cost technicians [Currency per year]</i>	Fixed cost per maintenance person / technician per year. This number should include all costs associated with having the specified average number of technicians available at the bases / vessels each shift (taking into account shift rotations, weekends, holidays, leaves, etc.)
<i>Wake loss [%]</i>	Factor for loss due to wake effects in the wind farm, the electricity production is reduced by this factor
<i>Electrical loss [%]</i>	Factor for the electrical losses in the wind farm and from export to shore, the electricity production is reduced by this factor
<i>Lost production due to downtime electrical infrastructure [%]</i>	Factor for lost production due to downtime in electrical infrastructure, the electricity production is reduced by this factor
<i>Currency</i>	Choose the currency for all the economic parameters; drop-down list can be extended in basis data
<i>Discount rate [%]</i>	Discount rate for the net present value calculations
<i>Fuel price vessels [Currency/l]</i>	Fuel price for the vessels
<i>Constant electricity price [Currency/kWh]</i>	A constant value for the electricity price over the whole simulation period. Is overruled if an electricity price scenario is specified.
<i>Electricity price scenario</i>	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.

<i>Main component</i>	Name of the main component, has to be chosen from the available main components as specified in the basis data
<i>Number</i>	Number of main components of that type in the wind farm
<i>Investment cost total [currency]</i>	Investment cost for that main component per unit until its commissioning

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

Each main component can contain several subcomponents.

<i>Main component</i>	Name of the main component; has to be chosen from the main components that have been specified for that case
<i>Subcomponent</i>	Name of the subcomponent
<i>Number</i>	Number of components of that type in the main component
<i>Function loss of main component [%]</i>	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	Active maintenance time [hours]	Access needed [Yes,No]	Logistics time [hours]	Technicians 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.

<i>Maintenance action</i>	Name for the specified maintenance action; the name needs to be unique.
<i>Active maintenance time [hours]</i>	Time needed to execute the maintenance task, exclusive travel time, access time, waiting time for the next working shift and other logistic delays. The number of hours needed is independent of the number of technicians, i.e. it is <i>not</i> the total number of man-hours needed.
<i>Access needed [No,Yes]</i>	Specifies if access to an offshore structure is needed. For e.g. jack-up vessels transferring technicians via a gangway, it is recommended to set this to "No", i.e. not model technician transfer

<i>Logistics time [hours]</i>	explicitly. 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.
<i>Technicians needed on structure</i>	Number of technicians needed to be transferred from the access vessel to the offshore structure for the maintenance action
<i>Ability needed [No, Yes]</i>	Is additional vessel ability (other than technician transfer) needed for the maintenance task?
<i>Pre-inspection needed [No, Yes]</i>	Is a separate inspection of the component and the failure needed prior to the actual repair (before ordering spare parts, additional vessels, etc.)?

[illegible]

The Jack-up vessel maintenance actions table specifies the type of operations that have to be performed for a maintenance action requiring a jack-up vessel. Each jack-up vessel maintenance action can be divided into up to three operation phases (not including pre-inspection). The lifting (repair/replacement) phase is considered the main phase and has to be specified.

<i>Maintenance action</i>	Name for the specified jack-up vessel maintenance action; the name needs to be unique.
<i>Ability 1</i>	Identifier of the ability that is needed for the positioning/jack-up phase, has to be chosen from the available abilities specified in basis data
<i>Active maintenance time 1 [hours]</i>	Time needed to perform the positioning/jack-up phase of the maintenance action, exclusive weather delay, travel time and access time. However, one can also consider including the positioning time for the vessel in this phase.
<i>Ability 2</i>	Identifier of the ability that is needed for the lifting (repair/replacement) phase of the maintenance action, has to be chosen from the available abilities specified in basis data
<i>Active maintenance time2 [hours]</i>	Time needed to perform the lifting (repair/replacement) phase of the maintenance action, exclusive weather delays, travel time and access time.
<i>Access needed [No,Yes]</i>	Specifies if access to an offshore structure is needed for the lifting (repair/replacement) phase of the maintenance action. This typically is the case only if a separate access vessel is needed for the required technicians to access the turbine.

Logistics time [hours]

If a separate access vessel is needed: The time needed for logistics associated with transferring e.g. lifting equipment on the wind turbine or other logistics (associated with the maintenance action as such and not the access vessel and the transfer of technicians) before work can start and the access vessel can move on.

Technicians needed on structure

If a separate access vessel is needed: Number of technicians needed to be transferred from the access vessel for the for the lifting (repair/replacement) phase of the maintenance action

Ability 3

Identifier of the ability that is needed for the jack-down phase of the maintenance action, has to be chosen from the available abilities specified in basis data

Active maintenance time 3 [hours]

Time needed to perform the jack-down phase of the maintenance action, exclusive travel time and access time.

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 [Yes,No]	Logistics time [hours]	Technicians 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.

Technicians needed on structure for inspection

Number of technicians needed for the inspection

For maintenance actions where abilities are needed				
Maintenance action	Ability 1 needed	Technicians needed on vessel for ability	Ability 2 needed	Technicians 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

Technicians needed on vessel for ability

The number of extra technicians 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.)

Predetermined preventive maintenance							
Main component / component	Maintenance name	Maintenance interval [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 active maintenance

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

Maintenance interval [years]

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

Start date [dd.mm.]

Number planned serviced per shift

Costs spare part [Currency]

Lead time [days]

Maintenance action

Stop during maintenance

maintenance tasks to be scheduled once per year each.

Day of the year when the scheduled maintenance should start

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.

Cost for the spare part/consumables used

Lead time to provide the spare parts

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.

Does the component have to be stopped during maintenance? If set to *Only during active maintenance* 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	Condition 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

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]

The inverse of the mean time to failure for the component. Specifies how often the component is expected to fail on average per year per component. The failure rate corresponds to the rate of occurrence of failures (the inverse of the mean time between failures) only if the time to repair is zero (and the mean time to repair MTTR = 0). If the recorded number of faults per year are used as input, these should therefore be corrected with the down time due to the failures.

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

Comment

4.3.3 Sheet 3

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

Locations											
Location name	Distance to offshore wind farm [km]	Technicians available per shift	Seasonal dependence? [Yes,No]	Season starts [dd.mm.]	Season stops [dd.mm.]	Technicians available per shift off season	Yearly fixed cost [GBP/year]	Vessel for resupplying	Ability for resupplying	Days between resupplying	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.

<i>Location name</i>	Name of the location
<i>Distance to the offshore wind farm [km]</i>	Distance from the location to the offshore wind farm borders
<i>Technicians available per shift</i>	Number of technicians that are available at the location for each shift
<i>Seasonal dependence? [Yes,No]</i>	If there should be seasonal dependence of the technicians available at the location, typically so that there are more technicians available in the campaign period (summer season) than off season
<i>Season starts [dd.mm.]</i>	Date of the year when campaign period starts. Do not include year.
<i>Season stops [dd.mm.]</i>	Date of the year when campaign period stops. Do not include year.
<i>Technicians available per shift off season</i>	Number of technicians available at location per shift off season
<i>Yearly fixed cost [Currency/year]</i>	Fixed cost per year incl. cost per year associated with transporting supply or technicians to a location (meant especially for locations such as offshore platforms)
<i>Vessel for resupplying</i>	The vessel that is used for resupplying the location with technicians (if, e.g., the location is an offshore platform). If no vessel is specified, it is assumed that no technician resupplying is needed.
<i>Ability for resupplying</i>	The vessel ability that is used to specify the weather limits for the technician resupplying operation. Only relevant if a vessel is specified for resupplying, but this vessel needs to have the ability that is specified for resupplying. If no ability is specified, the access ability of the vessel is assumed.

Days between resupplying

The time interval in days between each time technician resupply should be scheduled for the location. For several daily shifts, there is one set of technicians for each shift, and each set of technicians needs to be replaced. In this case, the number of *days between resupplying* is the time interval between the times there is a set of technicians that is replaced; it is *not* the time interval each set of technicians is staying offshore before being replaced.

Vessel properties					
Vessel	Number	Home port (safe haven)	Daughter vessel	Number daughter vessels	Day rate daughter vessel [GBP/day]
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 vessels 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 vessels

Day rate per 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 (Ability no. 1 etc.) and what abilities are needed for the maintenance activities (Abilities needed). To check if there are vessels chosen for each ability needed, one can compare the ability entries in the columns to the left with those in the columns to the right.

Availability and cost of vessel										
Vessel	Ordered? [Yes, No]	Mobilisation time [days]	Charter duration [days]	Mobilisation cost [GBP]	Seasonal dependence? [Yes, No]	Season starts [dd.mm.]	Season stops [dd.mm.]	Available at another base off season? [Yes, No]	Home port off season	Day rate [GBP/day]
CTV 1	No									
Jack-up	Yes	60	14		No					

Vessels can be (if the value of "Ordered?" is "No") available immediately since they are on long-term charter or are purchased by the wind farm owner/operator. Alternatively (if the value of "Ordered?" is "Yes"), they have to be chartered (ordered) with a given mobilisation time when the demand for them is identified. 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. To model vessels that are available during a number of pre-determined maintenance campaigns during the year, one can specify one vessel for each campaign period, each being available only during that one campaign period. 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 for short-term on-demand charters ("Fix on Failure" charter strategy)?

Mobilisation time [days]

Time to wait from the need for the vessel is identified to the ordered vessel is available at the "home port" specified for the wind farm. This lead time includes both waiting for a vessel to become available on the market, waiting for it to travel to the "home port" of the wind farm, waiting for it to be re-equipped, etc.

Charter duration [days]

Duration of charter, i.e. how long the vessel will remain available at the location

Mobilisation cost [currency]

Mobilisation cost for chartering a vessel (covering travel, re-equipping, etc.; 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

Three options are available for specifying which shift the vessel can work:

The vessel is working only one shift per day irrespective of the number of daily shifts. If there are multiple daily shifts, the vessel will only work the first shift of each day.

The vessel is working all shifts, but not working outside of ordinary working shifts.

The vessel is working around the clock, 24 hours a day, irrespective of the number and length of working shifts.

[illegible]

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 Monte Carlo iterations 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:

- Technicians
 - Technicians available per shift per location
 - Technicians available per shift off season per location
 - Technicians available per shift per vessel
- Maintenance
 - Failure rate
 - Maintenance intervals for preventive 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 technicians per location.

Technicians 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.

Technicians:

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

Maintenance:

The maintenance interval for the preventive maintenance is rounded to the next full year, since only full years are allowed.

Vessels:

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

4.3.5 Stochastic variables

The Stochastic sheet can be used to specify which parameters that are to be treated as stochastic variables by the model. The use of the Stochastic sheet is optional. The following variables can be set to be treated as stochastic variables:

- Mobilisation time of chartered vessel
- The lead time of spare parts
- The active maintenance time of maintenance tasks
- The pre-warning time for condition-based maintenance tasks.

All tables are following the same format and will be explained with the example of Mobilisation time of chartered vessel.

Vessel Mobilisation Time					
Treat stochastic?	Yes				
Distribution	Normal Distribution				
Vessel	Normal Distribution		Triangular Distribution		
	Mean value	Std	Min	Mode	Max
CTV 1					
Jack-up	60	10			

Treat stochastic?

Whether or not this variable should be treated as a stochastic variable in the model.

Distribution

Sets the probability distribution. Two options for probability distribution are available: normal distribution or triangular distribution.

Mean value

Mean value (expectation) for the normal distribution (only relevant if normal distribution is chosen)

Std

Standard deviation for the normal distribution (only relevant if normal distribution is chosen)

Min

Lower limit for the triangular distribution (only relevant if triangular distribution is chosen)

Mode

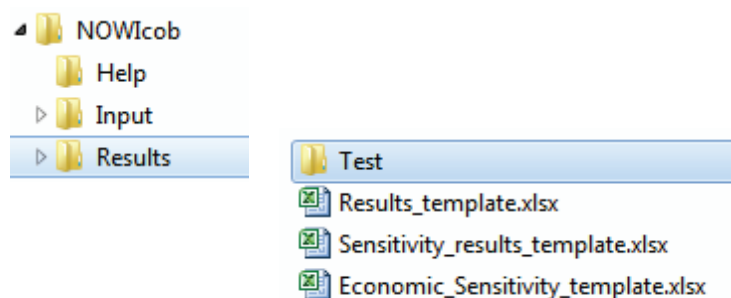
Mode of the triangular distribution (only relevant if triangular distribution is chosen)

Max

Upper limit of the triangular distribution (only relevant if triangular distribution is chosen)

5 Result files

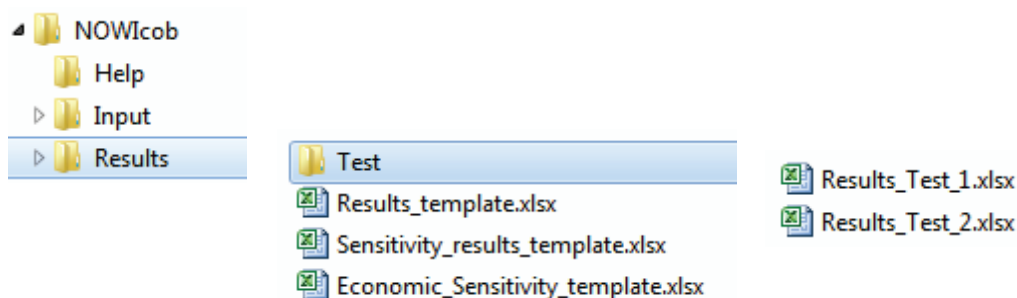
Results are saved automatically in an Excel files after the simulation is finished. The result files are stored in a subfolder in the Result folder. The subfolder has the same name as the name of the case specific data input file. In our example the case specific data input file is *Test.xlsx*, therefore 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 Monte Carlo iteration
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 technician 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
- *Energy-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
 - Technician cost
 - Location cost (for example rental of harbour)

Results - details

This sheet contains all data for each Monte Carlo iteration 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 maintenance tasks. 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. The time-based availability results are calculated separately from these downtime results and are *not* calculated by summing up downtime contributions. For instance, only entire shifts are registered in the downtime contribution, with the exception of shifts where maintenance a maintenance task is finalised. Also, if the function loss associated with a component is less than 100%, the downtime assigned to maintenance of this component is reduced accordingly. For these reasons, there may be discrepancies between these availability results and the down-time results.)

The downtime is split in these categories:

- *Lead time*: Average over all Monte Carlo iterations. 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 Monte Carlo iterations. Down time due to waiting time due to overbooking of technicians / vessels until the next shift starts (only corrective tasks). Downtime due to vessels with seasonal availability is also assigned to this category.
- *Travel/working*: Average over all Monte Carlo iterations. 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 and energy-based availability of the wind farm for each month of the year and for each operation year. The standard error of the 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 technicians 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 technicians 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 technicians per shift*: Average number of technicians used per shift when working. Only shifts when at least one technician was working are considered.
- *Utilized technicians per year*: Average of the total number of technician-shifts per year, i.e. the average utilized technicians per shift summed over all shifts. Can also be interpreted as total yearly number of offshore-days for technicians (if one shift per day). To find the number of technicians shifts for the entire wind farm, one has to sum over all maintenance bases (locations) and all accommodation vessels (vessels having their own pool of technicians).
- *Utilization in %*: Percentage of the utilized technicians to the available persons at a maintenance base or at a vessel. Only shifts when at least one technician was working are considered. This number is 100% for vessels that go in and out in same shift since they take only that many technicians they need.
- *Utilization space*: Percentage of the utilized technicians to the available space. Only shifts when at least one technician 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 technicians.
- *Overtime days per year*: The average number of days per year that resupplying of technicians to this location or vessel has been delayed, leading to overtime for technicians. Overtime is counted as a whole day even if the delay is only for a single shift (if multiple working shifts per day).
- *Overtime technician-days per year*: The average number of technician-days per year that resupplying of technicians to this location or vessel has been delayed, leading to overtime for technicians. For each day of delay, an overtime technician day is counted for each technician whose replacement is delayed.

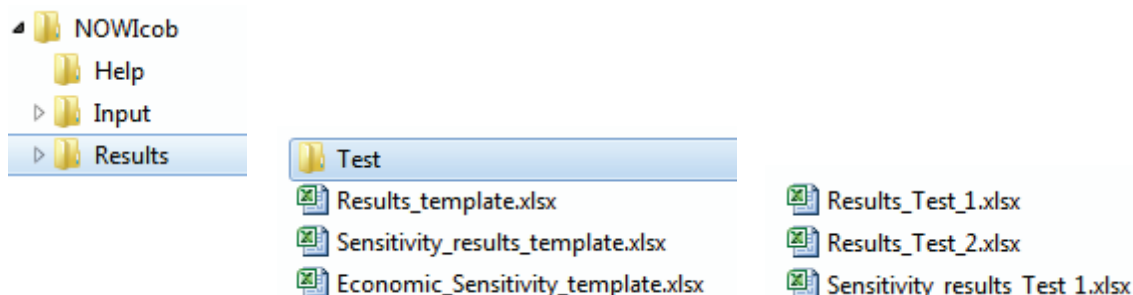
5.1.2 Input data documentation sheets

Copies of the following input spreadsheets are included in the results file so that the user should be easily able to document and then later trace what input data were used for each case that has been simulated.

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.

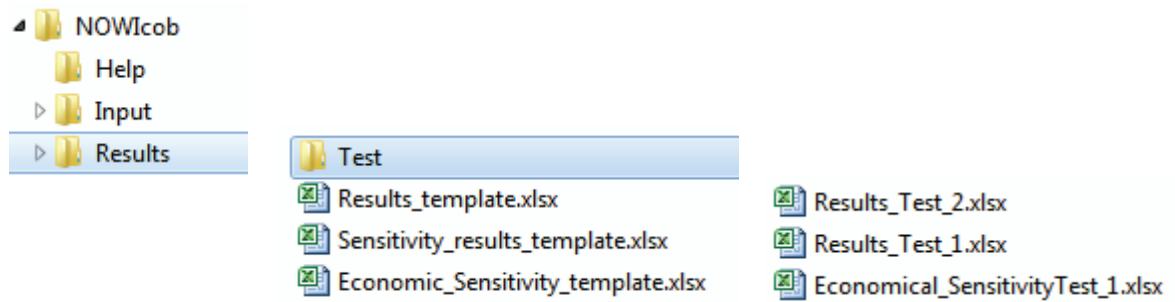


Each sensitivity result file contains three sheets with result data, documentation of the sensitivity cases and a graphical presentation of the results. In the following the three sheets are explained in detail.

Sheet name	Description
Sensitivity cases	Copy of sheet Sensitivity in case specific data input file
Details	<p>Results of all sensitivity cases. The following results are available:</p> <ul style="list-style-type: none"> • Time-based availability • Energy-based availability • O&M cost as net present value • Lost income due to downtime as net present value • Profit as net present value <p>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.</p>
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

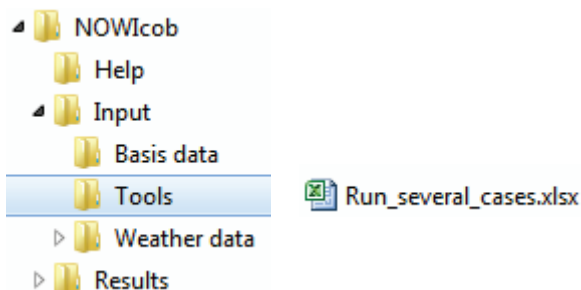
Selected simulation results, for each year in the simulation, are written to an Excel workbook designed for studying sensitivities regarding economical parameters. In this way sensitivity to economical parameters can be studied without having to run the simulations several times. The economic sensitivity 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.

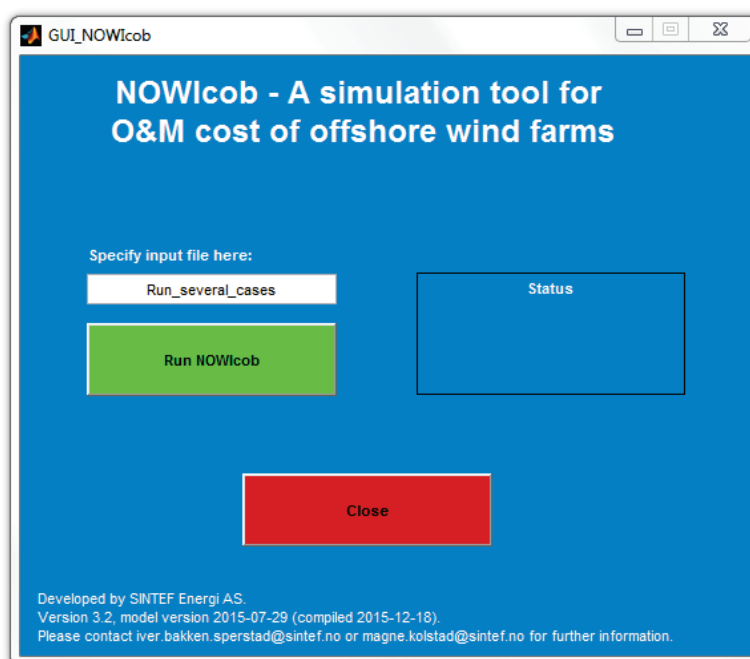


The file contains a table where several case input files can be specified and a comment to each file can be written. When the model is run, it will call all the input files automatically and save the results in the correct folders in the same way as if the user had chosen a new file in the graphical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



7 Do's and don'ts

This chapter is meant to give some practical guidelines on how to use the NOWIcob model, or rather, to give warnings on what you should be careful not to be doing ("dos and don'ts").

Do's and don'ts related to the Excel input spreadsheets:

- When parsing the input spreadsheet, the model expects that no further input rows are given in a table below an empty row. That means that the first empty row indicates the end of input in a table. For instance, if one in the "Vessel properties" table enters "CTV" in the first row, "SOV" in the second row, leaves the third row empty, and then enters "SOV" in the fourth row, the model will never see the "SOV" entry when reading the spreadsheet.
- Do not cut and paste cells within the input spreadsheets to move or reorder input data. Instead, it is advised to rather copy and paste cells and then afterwards delete the contents of the cells you copied from. (Some functionality in the spreadsheets rely on references to other cells, and moving or cutting-and-pasting cells makes Excel tries to update the references, which may cause problems with the intended functionality.)
 - When moving case input files, you may have to maintain the Excel links to the basis data file and the weather overview file yourself. These links are easily broken when one starts to move things around, especially if the files linking to other files are open in Excel while you are doing the moving.
- When an update to the model changes the structure of the input spreadsheets by changing the row/column numbers, adding new input fields, etc., input files in the old format needs to be converted to the new format before they can be read. This is done automatically when simulating the old case with the model. However, since the input file is overwritten, you cannot have the input file open in Excel while running the model in these cases. (A backup of the old version of the input file is made with file name on the format "<case name>_old_format_<format date>.xlsx".) The conversion tool currently does not copy contents of the comments columns or the sensitivity spreadsheet.)

Do's and don'ts related to the folder structure:

- One may want to create new copy of the folder with the NOWIcob model to be able to run separate analyses in parallel or for some other reason. Then, one needs to make sure the folders contain all files that come with a clean installation of NOWIcob.
- In particular, also make sure that
 - you have the version of "Input_basis.xlsx" that you want,
 - that all the weather data (both the .txt file and the folder with pregenerated time series) are included in the "Weather data" folder
 - the "Case_template.xlsx" file is included in the "Input" folder,
 - the "Results_template.xlsx" file is included in the "Results" folder.
- If updating NOWIcob to a new revision, one may need to replace the executable "NOWIcob.exe", some Excel template files, or all the files; which files need to be replaced should be clear from the contents of the revision (the .zip file or otherwise). The user has to maintain the relevant files for all separate folders with separate installations of the NOWIcob model.
- When running simulations, the model will at some intervals need to read from or write to the disk. Therefore, make sure that the computer that is running the simulation will have uninterrupted access to the disk for the expected duration of the simulation.



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