Opti-OWECS Final Report Vol. 5:

User Guide OWECS Cost Model

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FINAL REPORT

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Preface

Overview of the JOULE III project Opti-OWECS

The project described in this report, 'Structural and Economic Optimisation of Bottom-Mounted Offshore Wind Energy Converters' (Opti-OWECS), was supported by the European Commission under grant JOR3-CT95-0087 within the scope of the Non-Nuclear Energy Programme JOULE III (Research and Technical Development).

Objectives of the Opti-OWECS project

It was the mission of the Opti-OWECS project to extend the state-of-the-art in Offshore Wind Energy, by deriving methods and demonstrating practical solutions which will significantly reduce the electricity cost. Such work will facilitate the further exploitation of offshore wind energy within a medium term time scale of 5 to 10 years from now.

The specific objectives included:

- Calculation of a cost estimate for and comparison of offshore wind energy converters of different sizes and different design concepts.
- Estimation of the cost per kWh of offshore wind energy produced electricity at sites in different regions of the EU.
- Development of methods for the simultaneous structural and economic optimisation of offshore wind energy converters with due consideration of the site characteristics.
- Production of at least one design solution for a bottom-mounted offshore wind energy conversion system.

Partnership and responsibilities

The project was undertaken by an international co-operation of engineers and researchers from the wind energy field, offshore technology, power distribution and universities.

The participants included:

- Institute for Wind Energy (IvW), Delft University of Technology
 A Dutch research group active for more than 20 years in various fields of wind energy application, including major offshore wind energy research since 1992.
- Kvaerner Oil & Gas, Ltd. (KOGL)
 A major engineering and construction company, based in the United Kingdom, with an established track record for implementing innovative concepts for offshore oil and gas developments.

- Kvaerner Turbin AB (KT)
 A Swedish wind turbine manufacturer with expertise in the design of multimegawatt machines (since the 1970s) and participant in another large study on offshore wind energy (1991).
- Renewable Energy Centre, University of Sunderland (US)
 A British research group involved in techno-economic studies of renewable energy sources since 1978 including two major projects on wind energy costs.
- Workgroup Offshore Technology (WOT), Delft University of Technology A Dutch research group with particular expertise in the fluid loading of offshore structures and probabilistic methods. WOT maintains good relations with Shell Research Rijswijk.
- Energie Noord West (ENW)
 A Dutch utility supplying 600,000 households in North-Holland and operating wind farms for more than 12 years amongst which is the first Dutch offshore plant (Lely, 1994).

Kvaerner Oil & Gas, Ltd. and Kvaerner Turbin AB both form part of the international Kvaerner group which is organised in seven core business streams - KOGL being part of the Oil & Gas stream and KT being part of the Energy business. The role of the partners is summarised in Table 0-1.

Partner	Role	Major scientific tasks
IvW	coordinator	
1000	coordinator	- general expertise on (offshore) wind energy,
		- overall dynamics of OWEC,
		- wind turbine reliability, operation & maintenance,
		 design of grid connection and farm layout,
		 assistance in the cost analysis of OWECS,
		- aerodynamic rotor design,
KOGL	contractor	- general expertise on offshore technology,
		- design of support structure and installation procedure,
		- assistance in the cost analysis of OWECS
КТ	contractor	- general expertise on wind turbine technology,
		- adaptation of wind turbine to offshore conditions
US	contractor	- concept and economic analysis of OWECS
		- development of cost models for OWECS,
		- estimate of costs of offshore wind energy at European
		sites
WOT	contractor	- general expertise on offshore technology,
		- structural reliability consideration,
		- assistance in the cost analysis of OWECS
ENW	sub-	- general expertise as utility and as operator of (offshore)
	contractor (of	wind farms,
	IvW)	
	1000	- design of grid connection

Table 0-1: Distribution of responsibilities among the partners.

Relation of this report to other work within Opti-OWECS

The project continued with earlier work from CEC Joule project JOUR 0072 and made use of recent developments in wind engineering and offshore technology. The study examined what was considered to be the most promising and feasible OWECS concepts for the near future specifically horizontal axis wind turbines rated approximately between 1MW and 3MW, erected on bottom-mounted support structures in the Baltic or the North Sea.

The project comprised three consecutive major tasks:

- Task 1 Identification of main cost drivers The main cost drivers of offshore wind energy were identified and the base case concepts and the reference sites were selected.
- Task 2 Development

The economic and structural optimisation and improved design methods were developed in three parallel tasks. A cost model for manufacturing, installation and operation and maintenance of offshore wind farms was compiled. Design concepts for all main sub-systems, the wind turbine, the support structure, the grid connection and operation and maintenance, were investigated and the best combination for certain sites was selected. Also, particular design methods for OWECS including structural reliability considerations and overall dynamics of OWEC were further developed.

• Task 3 Integration

In the final phase the work of the preceding tasks was integrated and the relationships between them were fully considered. The progress achieved was demonstrated in a typical design solution for OWECS. Moreover, energy costs at different European sites or regions were estimated.

The project was divided into three phases lasting from January 1996 to December 1997. Figure 0-1 presents an overview of the work packages (shaded boxes) and tasks (dashed boxes).

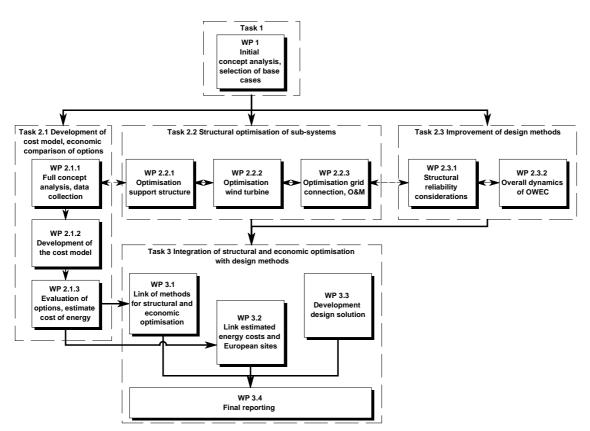


Figure 0-1: Opti-OWECS project organisation of tasks and work packages.

The final reporting is organised in a more coherent way with a view to the subjects considered rather than in the sequence the work was carried out. Therefore the report available to the public is subdivided into six volumes:-

• Vol. 0	Executive Summary	[0-1]
• Vol. 1	Integrated Design Methodology for OWECS	[0-2]
• Vol. 2	Methods Assisting the Design of OWECS	[0-3]
• Vol. 3	Comparison of Cost of Offshore Wind Energy	
	at European Sites	[0-4]
• Vol. 4	Design Solution for OWECS	[0-5]
		[0, 0]

Vol. 5 User Guide OWECS Cost Model [0-6]

As illustrated by figure 0-2 the reports cover all of the work packages. It has been the intention of the authors that it should be possible to read each volume independently of the others and, as a result, some issues are tackled in more than one report. The individual documents, however, tackle such 'common' issues from differing points of view. By way of an example, development of a cost model is described in volume 2, its use for economic evaluations is discussed in volumes 3 and 4, and a guide to its use may be found in volume 5.

This volume of the final report acts as a user guide to the OWECS cost model. It is entirely a procedural manual, describing only the steps necessary to 'drive' the model. For a description of the calculations underlying the model, reference should be made to volume 2 of this report.

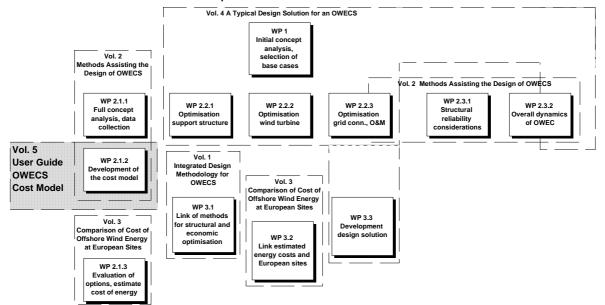


Figure 0-2: Interrelation between Opti-OWECS work packages and final report

Terminology used in this volume

Use is made of a terminology for OWECS which has been developed and successfully applied during the project (see appendix A of Vol.1 [0-2], [0-7]). In order to avoid misunderstandings there are two essential conventions that should be appreciated. Firstly, the acronym "OWECS" (standing for Offshore Wind Energy Conversion System) or its synonym "offshore wind farm" describes the entire system, that is the wind turbines, the support structures, the grid connection up to the public grid and any infrastructure for operation and maintenance. Secondly, "OWEC" (Offshore Wind Energy Converter) is used to refer to a single unit of an offshore wind farm comprising support structure (i.e. tower and foundation) and the wind turbine (i.e. aero-mechanical-electrical conversion unit on top of the tower).

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1. Introduction

1.1 General

This document provides a guide to straightforward and moderately sophisticated uses of the Opti-OWECS cost model. It is predominantly a procedural manual, making little attempt to justify or describe the way in which the model performs its calculations. For such details, reference should be made to volume 2 of this report [1-1]. A good knowledge of the use of Microsoft Excel is a pre-requisite for using the cost model.

The model has been developed using Microsoft Excel 5.0 running under Microsoft Windows 3.1, and is designed to run in that environment. It is understood that the code should run under more recent versions of Excel (7.0, 95), but, as it has not tested on such platforms, no guarantees can be made.

1.2 Disclaimer

This cost model is provided 'as is'. No warranty whatsoever, either implied or explicit, is made of its fitness for any purpose or of the accuracy of any of its calculations. The owners of the model and its constituent components will accept no liability whatsoever for any direct or indirect loss or damage caused by use, or attempted use or failure to function of any or all parts of the model, or by any reliance placed on any of the calculations contained in or results produced by the model.

Warning: Use of this cost model is made entirely at the users own risk.

1.3 Copyright notice

This cost model is the joint property of the contractors within the 'Opti-OWECS' project. Distribution of the cost model as a whole is co-ordinated by the University of Sunderland. No copying, transmission, decompilation, modification or use of this model is permitted without the explicit, written permission of the University of Sunderland. The University of Sunderland reserves the right to charge a fee before granting such permission.

Certain parts of the cost model are owned jointly by the University of Sunderland and by other partners in the 'Opti-OWECS' project. These individual parts of the cost model may be distributed, used or modified at the discretion of either the University of Sunderland or of the Opti-OWECS partner or partners with property rights applying to that part of the model.

Any results produced by the model must be accompanied with a statement acknowledging the model was used with either the permission of the University of Sunderland or another Opti-OWECS contractor as appropriate.

2. Structure of the model

The model consists of four interlinked workbooks, written for Excel 5.0. All the workbooks are required to make use of the model.

The workbooks are:

- perfmod1.xls: This is the main part of the model, containing the vast majority of the input and output facilities, and most of the calculation routines except for the structural design and the grid connection.
- struc1.xls: contains the structural design routines and some detailed input/output sheets relating to details of the support structure.
- grid1.xls: performs the design and optimisation of the grid connection. It was written by a number of students at IvW and modified slightly at US. The workbook includes an input/output facility, but it is not envisioned that direct user interaction will be necessary with the workbook, aside from some highly specialised uses.
- tools1.xla: This workbook contains a small library of utility routines that are called by many parts of the model. No provision is made for direct user interaction with this workbook. The workbook is provided as an "add-in" which means both that its contents are not accessible to the user and also that it does not appear on the Excel desktop once loaded.

Within each workbook, the calculations are broken down into a number of separate sheets, each responsible for a distinct area. In general, efforts have been made to give the sheets 'descriptive' names.

3. Preliminaries

Before attempting to use the model, it is necessary to launch one copy of Excel and load the four workbooks. It is not strictly necessary to load more than the main sheet, perfmod1.xls, as the others should load 'on-demand'. This has been found to be unreliable however and better performance is obtained if the four sections are loaded manually.

Once loaded, grid1.xls can be minimised as there is essentially no need to interact with it directly. As noted in chapter 3, tools1.xla will not appear on the desktop once loaded, and henceforth can be forgotten about. For the moment, struct.xls can also be minimised, although as we will see, it can be advantageous to keep it visible for access to certain sophisticated options, and for 'real-time' information while the calculations are taking place.

Unless explicitly noted otherwise, all cost values input to and output from the model should be assumed to be in ECU.

4. Basic use

Warning: Read the whole of this section and the 'More advanced use' section before trying to use the model.

4.1 General

The 'MasterSheet' of perfmod1.xls is the main area for controlling and interacting with the model.

The main area of this sheet consists of various parameters, listed down the left hand side of the sheet in the yellow area (see figure 4.1-1), with 'runs' numbered across the sheet on the grey area. The general idea is that each column represents a particular OWECS configuration that the user wishes to evaluate. Thus, a single calculation (or 'run') is set up by filling in appropriate values down a column. Parameters studies may be undertaken by filling in several columns with suitably differing values. The section labelled 'results' is intended for output only and should not be filled in by the user (any values there will be overwritten when the code is run).

Most of the values are reasonably self explanatory, and only a few will be explained in great detail. It should be noted though that the values for availability and O&M under the Economic Parameters section can act as input or output variables, depending on their setting.

Once the values in the main table have been finalised, the user should go to the top left of the MasterSheet, and find the area labelled 'control', where there are two important variables.

The value of the area 'No. to calculate' influences the number of runs that the code will perform. Thus, if it is set to 1, the model will just evaluate the first column of values and then stop. If it is set to 10, the model will evaluate all 10 columns before halting. Note that there is no limit in principle to the number of separate configurations that the model can evaluate at once, although the input and output sheets are only formatted to deal with ten columns.

The other area labelled 'Recalculate support' has an important influence on the way in which the support structure is dealt with. If set to 1, the support structure is redesigned from scratch for each run on the basis of the values in the appropriate columns. If set to 0, the support structure designer is disabled for all runs except the first one, with subsequent runs using the design produced for the first run, irrespective of the values in their column. This is useful to speed up the code when investigating the effect of parameters that have no or very limited influence on the support structure design (e.g. the finer points of the grid connection), as the support structure calculation can take a significant time. Just above the main area, there is a green coloured region described as 'User label'.

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<u>File E</u> dit <u>V</u> iew	Insert	F <u>o</u> rmat	Tools	s <u>D</u> ata	a <u>W</u> ind	low <u>H</u> e	elp							
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		<i>NL1base</i> Run No:	NLII	NL 12	NL13	NL14	NL 15	NL 16	NL17	NL18	NL19			AL 12 Bun I
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Tanabioo			-			Ū	Ű		0	Ů	10			
Wind conditions														
maws (m/s)		8	8				8							
maws height (m from SEABE	D)	60	60	60	60	60	60							
Extreme windspeed (10,50)		50	50	50			50							_
alpha k		0.14	0.14	0.14	0.14	0.14	0.14							
		0	0				0				-			
		-	-	_	_	-	-	-	-	-	-			
Sea conditions														
Mean sea level		15	15	15			15							
Wave height (RP50)		12.8	12.8	12.8	12.8		12.8							
Wave height (RP1)		9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1			
Farm parameters														
no of turbines		100	100	100	100	100	100	100	100	100	100			
spacing ratio		10	10	10	10		10							
distance to shore (km)		8	8	8	8		8							
distance to grid (km) Turbines per cluster		0	0	0	0		0				-			
rurbines per cluster		10	IU	IU	10	10	IU	10	10	IU IU	IU			
Turbine parameters														
turbine type		1	1	1	1	1	1	1	1	1	1			
Rotor frequency		0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333		0.333			
Master Routir	ie Maste	erSheet /	Calibrat	ion factors	/ Mino	rInputs 7	TowerInp	utSpecs						-
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Figure 4.1-1: The main sheet of the model.

This region allows the user to add a meaningful label to each of their runs, if required.

Once everything is set up, clicking once with the left mouse button on the 'Compute!' button puts the model to work. The model's calculations can be interrupted with the ESC key (it may take a while to respond). The status bar (the grey line right at the bottom of the Excel window) provides brief updates on the progress of the calculations. The main results are deposited in the 'Results' section at the bottom of the main area in the MasterSheet.

User Guide OWECS Cost Model

		_			_						
<u> </u>	Α	В	С	D	E	F	G	Н		J	ĸ
1	Control							Maste	r Shee	t	
2	No to calculate	1									
3	Recalculate support	1						NL1 shore			
4											
5											
6	User Label:		NL1.1	NL1.2	NL1.3	NL1.4	NL1.5	NL1.6	NL1.7	NL1.8	NL1.9
7		Run No:				_		_			
8 9	Variables	1	2	3	4	5	6	7	8	9	10
-	Wind conditions										
	maws (m/s)	8	8	8	8	8	8	8	8	8	8
	maws height (m from SEABED)	60	60	60	60	60	60	60	60	60	60
	Extreme windspeed (10,50)	50	50	50	50	50	50	50	50	50	50
	alpha	0.14	0.14	0.14	0.14	0.14	0.14		0.14	0.14	0.14
15	k .	0	0	0	0	0	0	0	0	0	0
16	c	0	0	0	0	0	0	0	0	0	0
17											
18	Sea conditions										
	Mean sea level	15	15	15	15	15	15	15	15	15	15
	Wave height (RP50)	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8	12.8
21 22	Wave height (RP1)	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
_	Form poromotors										
	Farm parameters no of turbines	100	100	100	100	100	100	100	100	100	100
	spacing ratio	100	100	100	100	100	100	100	100	100	100
	distance to shore (km)	8	8	8	8	8	8		8	8	8
	distance to grid (km)	0	0	0	0	0	0		0	0	0
	Turbines per cluster	10	10	10	10	10	10		10	10	10
29											
30	Turbine parameters										
31	turbine type	1	1	1	1	1	1	1	1	1	1
	Rotor frequency	0.3667	0.3667	0.3667	0.3667	0.3667	0.3667	0.3667	0.3667	0.3667	0.3667
_	No of blades	2	2	2	2	2	2	2	2	2	2
		off 85	off 82.5	off 87.5	off 92.5	off 85	off 85	off 85	off 85	off 85	off 85
36	Hub height	60	02.5	67.5	92.5	60	60	CO	60	60	60
	Structure parameters			[
_	structure type	3	3	3	3	3	3	3	3	3	3
	Structure height	80					0	U			
			77.5	82.5	87.5	80	80	80		-	80
40	no of segments	10	77.5 10	82.5 10	87.5 10	80 10	80 10		80 10	80 10	80 10
	no of segments K_rot	10	10	10	10	10	10		80 10	80 10	10
41 42	K_rot K_lat	10 4.62E+09	10 4.62E+09	10 4.62E+09	10 4.62E+09	10 4.62E+09	10 4.62E+09	10	80 10 4.62E+09	80 10 4.62E+09	10 4.62E+09
41 42 43	K_rot K_lat Start load case	10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1	80 10 4.62E+09 3.09E+10 1	80 10 4.62E+09 3.09E+10 1	10 4.62E+09 3.09E+10 1
41 42 43 44	K_rot K_lat Start load case Stop load case	10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4	80 10 4.62E+09 3.09E+10 1 4	80 10 4.62E+09 3.09E+10 1 4	10 4.62E+09 3.09E+10 1 4
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41 42 43 44 45 46	K_rot K_lat Start load case Stop load case Pile height Pile penetration	10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25	80 10 4.62E+09 3.09E+10 1 4 25 25	80 10 4.62E+09 3.09E+10 1 4 25 25	10 4.62E+09 3.09E+10 1 4 25 25
41 42 43 44 45 46 47	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5	80 10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	80 10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5
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41 42 43 44 45 46 47 48 49	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5	80 10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	80 10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5
41 42 43 44 45 46 47 48 49 50	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5	80 10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	80 10 4.62E+09 3.09E+10 1 4 25 25 25 3.5	10 4.62E+09 3.09E+10 1 4 25 25 3.5
41 42 43 44 45 46 47 48 49 50 51 52	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om%	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 96.50181 2.536723	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	80 10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1	80 10 4.62E+09 3.09E+10 4 25 25 3.5 0.075 -1 -1	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1
41 42 43 44 45 46 47 48 49 50 51 52 53	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom%	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 96.50181 2.536723 10	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 1 10	10 4.62E+09 3.09E+10 4 25 25 3.5 0.075 -1 -1 10	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1	10 4.62E+09 3.09E+10 4 25 25 3.5 0.075 -1 -1 10	10 4.62E+09 3.09E+10 4 25 25 3.5 0.075 -1 -1 1 10	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1	80 10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 10	80 10 4.62E+09 3.09E+10 1 4 25 25 3.5 3.5 0.075 -1 -1 10	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10
41 42 43 44 45 46 47 48 49 50 51 52 53 54	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 96.50181 2.536723 10 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 00 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 1 10 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 1 10 20	10 4.62E+09 3.09E+10 1 4 255 255 3.55 0.075 -1 -1 1 10 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 1 10 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 1 10 20	80 10 4.62E+09 3.09E+10 4 4 255 25 3.5 3.5 0.075 -1 -1 10 0 20	80 10 4.62E+09 3.09E+10 4 4 255 25 3.5 3.5 0.075 -1 -1 100 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 00 20
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 20 0 20	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 20 20 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 96.50181 2.536723 10 20	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 20 20 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 255 255 3.55 0.075 -1 -1 1 10 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 1 10 20	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 255 25 3.5 3.5 0.075 -1 -1 10 0 20	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 00 20
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 20 0 20	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 20 20 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 46 47 48 9 50 51 22 53 54 55 56 57 58	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 20 0 20	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 20 20 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 20 0 20	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 20 20 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 200 5 0	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5 0 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 10 200 5 5 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 200 5 0	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 10 200 5 5 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 66 47 89 50 51 52 53 55 55 57 58 59 60 61	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 200 5 0	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5 0 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 10 200 5 5 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 45 46 47 48 49 50 51 22 35 45 55 56 57 58 59 60 16 26 36 4	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results Energy cost (ECU/kWh) Energy production	10 4.62E+09 3.09E+10 1 4 4 225 3.5 0.075 96.50181 2.536723 10 200 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	10 4.62E+09 3.09E+10 1 4 4 225 3.55 0.075 0.075 0 0.075 0 0 0.050502 7.74E+08	10 4.62E+09 3.09E+10 1 4 4 225 2.55 3.55 0.075 -1 -1 10 0 200 5 0 0 0.049049 	10 4.62E+09 3.09E+10 1 4 4 225 3.5 0.075 -1 -1 100 200 5 0 0 0.047754 8.11E+08	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
41 42 43 44 50 51 52 53 55 55 57 58 59 60 61 62 63 64 65	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results Energy cost (ECU/kWh) Energy production Turbine cost	10 4.62E+09 3.09E+10 1 4 4 225 3.5 0.075 96.50181 2.536723 10 200 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	10 4.62E+09 3.09E+10 1 4 4 225 3.55 0.075 0.075 0 200 5 5 0 0 0 200 0 0 0 0 0 0 0 0 0	10 4.62E+09 3.09E+10 1 4 4 225 2.5 3.5 0.075 -1 -1 -1 10 200 5 5 0 0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0 -0	10 4.62E+09 3.09E+10 1 4 4 225 3.5 0.075 -1 -1 -1 1 10 200 5 0 0.047754 	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 55 66	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results Energy cost (ECU/kWh) Energy production Turbine cost Support cost	10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 96.50181 2.536723 10 20 5 0.048722 0.048722 7.85E+08 1.7E+08 1.1E+08	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 0 0.075 0 0 0.050502 0.050502 0.050502 7.74E+08 1.7E+08 1.25E+08	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 0.075 0.075 0.075 0.075 0.075 0.075 0.049049 0.049049 0.049049 1.7E+08 1.7E+08 1.19E+08	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 1 1 1 0 0 20 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5
41 42 43 44 54 64 77 88 99 51 52 53 54 55 56 57 88 59 60 66 66 67	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results Energy cost (ECU/kWh) Energy production Turbine cost Support cost Grid connection cost	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 96.50181 2.536723 10 20 5 0 0 0 20 5 0 0 0 0 0 0 0 0 0 0 0	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 0 0 5 0.075 0 0 0 0.050502 0 0.050502 0 0.050502 7.74E+08 1.22E+08 7.500016	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 0.075 0.075 0.075 0.075 0.075 0.075 0.0490490000000000	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 100 200 5 0.047754 8.11E+08 1.7E+08 1.7E+08 1.113E+08 75000016	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 25 3.5 0.075 -1 -1 10 200 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 1 10 200 5 5
41 42 43 44 54 64 74 84 90 51 52 53 54 55 57 58 59 60 61 62 63 64 65 66 76 68	K_rot K_lat Start load case Stop load case Pile height Pile penetration Pile diameter Pile wall thickness Economic parameters Availability% om% decom% economic life rate of interest Profit percent Results Energy cost (ECU/kWh) Energy production Turbine cost Support cost Grid connection cost OM cost	10 4.62E+09 3.09E+10 1 4 4 225 25 3.5 0.075 96.50181 2.536723 10 0 20 5 0 0 0 20 5 0 0 0 20 5 7.85E+08 1.7E+08 1.7E+08 1.7E+08 1.7E+08 1.7E+09 96.50181 2.536723 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	10 4.62E+09 3.09E+10 1 4 4 225 3.55 0.075 0 0.075 0 0 0.050502 0 0.050502 0 0.050502 7.74E+08 1.72E+08 1.72E+08 1.72E+08	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 100 200 5 0 0.049049 	10 4.62E+09 3.09E+10 1 4 4 225 25 3.5 0.075 -1 -1 100 20 5 0.047754 8.11E+08 1.13E+08 1.13E+08 1.13E+08 1.13E+08	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 25 25 3.5 0.075 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 25 25 3.5 0.075 -1 -1 -1 10 20 5	80 10 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	80 4.62E+09 3.09E+10 4 4 25 25 3.5 0.075 -1 -1 -1 10 200 5 5	10 4.62E+09 3.09E+10 1 4 4 255 255 3.55 0.075 -1 -1 -1 -1 10 200 5
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Figure 4.1-2: Further details of 'MasterSheet'.

4.2 More on the availability% and om% variables

The availability% and om% variables set respectively the percentage level of availability used in the energy production calculations, and the percentage of the capital cost assumed to be necessary for operation and maintenance. They are special variables within MasterSheet in that they can act as input or output values.

If set to a positive number (e.g. 5, meaning 5%) than these variables act as inputs, the specified value being used in the calculations. If set to -1, then these variables act as outputs, their value being calculated using the Operation and Maintenance model specified in the MinorInputs sheet. In this case the '-1' is replaced with the appropriate estimated value.

4.3 Description of other parameters within 'MasterSheet'

This section will deal with each of the parameters within MasterSheet in more details. Reference to figure 4.2-1 shows the variables to be divided into sections, and the discussion here will be developed in a similar manner.

4.3.1 Wind conditions

The first section of the sheet contains parameters which characterise the wind climate at the site under investigation.

maws

This parameter specifies the mean annual wind speed for the site in m/s, as measured at a height above the sea bed given in 'maws height'.

maws height

The height above the seabed at which the mean annual wind speed has been specified.

extreme wind speed

The extreme, 10 minute, 50 year return period, wind speed for the site, also measured at the height specified in maws height.

alpha

The wind shear constant used in the power law relationship for relating wind speeds at different heights for the same location.

k

The Weibull shape parameter.

С

The Weibull scale parameter ("characteristic wind speed").

4.3.2 Sea conditions

Parameters listed in this section relate to the sea conditions at the OWECS site. The wave heights are used primarily by the support structure designer in evaluating the performance of support structure under 4 absolute load cases. The mean sea level is used throughout the model.

Mean sea level

The mean sea level at the site in metres.

Wave height (RP50)

The 50 year return period wave height in metres.

Wave height (RP1)

The 1 year return period wave height.

4.3.3 Farm parameters

This section of the sheet allows the specification of the 'gross' features of the overall wind farm. Note that it is not possible to specify the topography of the wind farm (e.g. whether the turbines are laid out in a square or rectangular pattern) directly, and the model assumes a 'generic' layout. A number of characteristics that depend on the topography can be specified however, and it may be possible to examine the essential features of differing topographies by setting these values appropriately. The cost model, however, cannot assist in the original determination of these values.

No. of turbines

The total number of turbines in the farm.

Spacing ratio

The distance between each individual OWEC in the farm, expressed as a multiple of the rotor diameter. This value is used both the design the grid connection and to estimate the array efficiency of the overall OWECS.

Distance to shore

The distance of the OWECS power collection point from the shore in kilometres.

Distance to grid

The distance from the place on the shore to which the power is delivered to the nearest electricity grid node able to accept the power produced by the wind farm, in kilometres.

Turbines per cluster

The power collection cables within the wind farm is assumed to be laid out on a 'circuit' basis. This value specified the number of turbines connected to a single circuit.

4.3.4 Turbine parameters

Parameters in this section allow certain features of the turbine employed for the OWECS to be specified. Only a few major parameters are listed here, as more detailed information can be entered in the sheet labelled 'TurbineInputSpecs'.

Turbine type

This parameter is an integer value specifying which of the turbines detailed in the sheet 'TurbineInputSpecs' is to form the basis for the calculations.

Rotor frequency

The rotation frequency of the turbine rotor in units of s⁻¹. This value influences both the design of the support structure (with respect to resonances) and the calculation of the energy production.

No. of blades

An integer, usually 2 or 3, specifying the number of blades that the turbine has. This value only influences the design of the support structure and has no effect on calculation of the energy production.

Rated power

Under most circumstances this value should be set to 'off' which disables the features of the model it controls.

When set to a rated power in kW, it allows the turbine selected with 'Turbine type' to be 'scaled' to the rated power it contains. Thus, if the selected turbine say has a rated power of 1500kW, and this parameter is set to 2000kW, the rotor diameter, cost and weight of the selected turbine will be scaled to values representative of a turbine of 2000kW rated power. The scaling calculation is carried out according to data specified in the sheet 'TurbineVariationData'. For more details of the calculation procedure reference should be made to volume 2 [4.3-1].

This facility is intended to allow simple parameter studies of the effects of small changes in turbine design. By necessity the calculations are very approximate and considerable case must be exercised in its use. In particular, calculations are likely to be wildly inaccurate for rated power variations in excess of 50% around the base value, and for rated powers in excess of 4MW or below 1MW.

Hub height

The hub height of the OWEC in meters above the sea bed. It is open to the user to set this value manually according to requirements. While it is possible to type any value into the sheet, the user should ensure that the specified hub height is geometrically compatible with the other dimensions of the OWEC. The best approach to dealing with this value is to formulate an Excel expression that calculates the hub height as a function of other values in the sheet, for example, setting the hub height equal to the height of the structure plus half of the vertical dimension of the nacelle.

4.3.5 Structure parameters

Structure type

This parameter takes an integer value between 1 and 3 that selects the type of support structure assumed by the model. The significance is as follows:

- 1 selects the gravity base lattice tower. Note that the modelling uses a fixed design for this structure, set for a 3MW turbine in a water depth of 25m. The cost and properties of the lattice tower do not vary with any of the other parameters within the model.
- 2 selects the gravity based monotower. The model automatically designs the structure to take account of other values specified in the inputs to the model, and (attempts to) identify the optimal dimensions and configuration for the structure. The design of the foundation used for the support structure is invariant however. The soil properties used by the design routines are specified manually in parameters 'k_rot' and 'k_lat'.
- 3 selects the monopile design. As with the gravity based monotower, the model automatically designs a near optimal structure. The dimensions of the pile used for the monopile structure have to be specified manually later in the input sheet. The dynamic properties of the pile foundation are estimated, using the specified dimensions, from a look up table in the sheet 'struct1.xls'.

Structure height

The height of the support structure from the sea bed to the base of the nacelle. It is left to the user to ensure that this dimension is geometrically compatible with other parameters within the cost model and acceptable to any regulatory authorities. Note that this parameter has no influence on the gravity base lattice tower.

Number of segments

The support structure design routines for the monotower concepts divide the structure vertically into a number of segments. This is merely for computational convenience, as an approximation to a 'continuous' tower. There is no intention to suggest that a 'stepped' tower should be constructed (refer to volume 2 [4.3-2] for more information).

This value sets the number of segments to be used in the numerical approximation. Using a large number of segments provides a better approximation to a real tower, but at considerable expense in computational effort. For most cases, values between 5 and 10 appear to offer a good compromise.

The number of segments used in the numerical calculations is of course not a parameter influencing the cost of OWECS produced electricity. It is included in the main input sheet merely for the convenience of the user.

k_rot

The rotational soil stiffness used in the design of the gravity base monotower.

k_lat

The lateral soil stiffness used in the design of the gravity base monotower.

Start load case

The structural design calculations considers four load cases when evaluating candidate support structures, as detailed in volume 2. This value is an integer between 1 and 4 specifying the first of the load cased to be considered, thereby allowing some of the load cases to be omitted. This parameter should usually be set to 1.

Stop load case

This parameter specifies the final load case to be considered, and should usually be set to 4.

Pile height

The overall length of the pile to be used for the monopile design, in metres.

Pile penetration

The soil penetration of the pile to be used for the monopile design, in metres.

Pile diameter

The outer diameter of the pile to be used for the monopile design, in metres.

Pile wall thickness

The wall thickness of the pile to be used for the monopile design, in metres.

4.3.6 Economic parameters

Availability%

The percentage availability of the turbines within the wind farm. This is a special variable within MasterSheet in that it can act both as an input and an output value. If set to a positive number (e.g. 5, meaning 5%) then this variable acts as an input, the specified value being used in the calculations. If set to -1, then this variable acts as an output, the value being calculated using the Operation and Maintenance model specified in the MinorInputs sheet. In this case the '-1' is replaced with the appropriate estimated value when the model is run.

OM%

The annual operation and maintenance cost for the OWECS, expressed as a percentage of the wind farms initial capital cost. This is a special variable within MasterSheet in that it can act both as an input and an output value. If set to a positive number (e.g. 5, meaning 5%) then this variable acts as an input, the specified value being used in the calculations. If set to -1, then this variable acts as an output, the value being calculated using the Operation and Maintenance model specified in the MinorInputs sheet. In this case the '-1' is replaced with the appropriate estimated value when the model is run.

Decom%

The final cost of decommissioning the wind farm expressed as a percentage of the initial capital cost.

Economic life

The economic life of the wind farm in years. Note that this value only influences the lifetime used to discount the costs of the OWECS.

Rate of interest

The percentage rate of interest used to discount the costs of the OWECS.

Profit percent

The total profit to be made from the wind farm expressed as a percentage of the initial capital cost.

4.3.7 Results

The values in this section present a summary of the outcome of the model's calculations.

Energy cost

The predicted cost of energy produced by the OWECS in ECU/kWh.

Turbine cost

The total cost of the turbines for the OWECS, in ECU.

Support cost

The total cost of support structures for the OWECS, in ECU.

Grid connection cost

The total grid connection cost for the OWECS, in ECU.

OMcost

The total operation and maintenance cost for the wind farm, calculated as (annual O&M cost) x (economic life). Note particularly that this value has not been discounted back to the present.

Decommissioning

The total cost of wind farm decommissioning, in ECU, again not discounted back to the present.

Project management

The total project management cost, in ECU.

Profit

The total profit, in ECU.

Struct time period

The time period of the selected structure in seconds. This value will be empty when the lattice tower support structure concept has been selected.

5. More advanced use

The model contains a large number of inputs and outputs aside from those in the MasterSheet. This section will describe where they can be found, and explain how they can be used to perform more sophisticated calculations.

The input variables fall into one of two classes: those that can be varied from run to run, and those that remain constant for any particular invocation of the model (but can be varied from operation to operation).

5.1 Input variables that can be changed from run to run

All of the sheets containing these variables adopt the same general format as the MasterSheet, with columns that relate to each run. Note that the user label from MasterSheet is carried forward to most of these sheets automatically to assist the user.

Many of the inputs to these sheets have an obvious meaning. Detailed explanation will only be provided for those values that have more obscure interpretations.

5.1.1 MinorInputs

This sheet, shown in figure 5.1-1 contains 'less important' variables relating to each run.

Site specific data

wave periods: The wave period, in seconds, to be used in each of the absolute load cases. If the value is set to zero the model calculates a reasonable value for the period based on the wave height and water depth.

Ice data

ice present: If set to '1', the model includes the effect of ice loadings in its support structure calculations using the values specified later in the section. If set to '0', the model neglects all ice loadings

ice cone: The angle in degrees of any ice cone incorporated in the support structure. Setting this value to '0' means that no ice cone is present.

Maintenance method

This value selects the technique used to estimate the maintenance costs and availability for the wind farm. If set to '1', the model calculates values from a look up table in another sheet, according to the specifications in the section 'Maintenance schedule'. If set to 2 or 3, a series of empirical analytic relations developed by IvW form the basis of the maintenance calculations using basic data specified in the

section 'Maintenance Information'. The difference between setting '2' and '3' is very small. The latter however is a slightly more sophisticated version of the IvW model and thus this value should normally be set to '3'.

	Α	В	С	D	Е	F	G	н	I	J
1	Minor inputs to eac	h run								
2	•									
3	User Label:	NL1 base	NL1.1	NL1.2	NL1.3	NL1.4	NL1.5	NL1.6	NL1.7	NL1.8
4		Run								
5	Variables	1	2	3	4	5	6	7	8	9
6										
7	Site Specific Data									
8	Air density (kg/m^3)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
9	k1	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
10	Water density (kg/m^3)	1000	1000	1000	1000	1000	1000	1000	1000	1000
11										
12										
13										
14										
	Wave period (LCase 1)	0	0	-	0	-	-	0	-	Ţ
	Wave period (LCase 2)	0	0	0	0	0	0	0	0	0
	Wave period (LCase 3)	0	0	-	0	-	-	0	-	-
	Wave period (LCase 4)	0	0	0	0	0	0	0	0	0
19										
-	Ice Data									
	Ice present (0 or 1)	0	0	0	0	-	-	0	-	-
	Ice cone (0 or degrees)	0	0	0	0	-	-	0	-	-
	Ice thickness (m)	3	3	3	3	-	-	3		-
	Crushing strength (Pa)	2000	2000		2000					
	Buckling strength (Pa)	2010	2010	2010	2010	2010	2010	2010	2010	2010
26									-	
	Maintenance method	3	3	3	3	3	3	3	3	3
	(1=lookup/2=function 1/3=function 3)									
29										
	Maintenance Schedule (look up			D 14	D 144	DIA	DIA	D 144	514	D14
-	Strategy	PM1	PM1	PM1	PM1	PM1	PM1	PM1	PM1	PM1
-	No of crews	2	2	2	2	_		2	_	
	Turbine philosophy	Base	Base	Base	Base	Base	Base	Base	Base	Base
34		16								
	Maintenance Information (fitted		,	07.0	07.0	07.0	07.0	07.0	07.0	07.0
	Maximum availability (%) Fixed yearly cost (MECU/yr)	97.9	97.9	97.9 3.8	97.9 3.8			97.9 3.8		
	Variable cost (MECU/yr)	3.8 2.5	3.8 2.5	3.8	3.8					
		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
39 40										
	Project monogoment of the (9/)				0	0				0
41	Project management costs (%)	2	2	2	2	2	2	2	2	2

Figure 5.1-1: The 'MinorInputs' worksheet.

Maintenance schedule

The values in this section are only used if 'Maintenance method' is set to '1', and refer to the look-up table in sheet 'OM Data'.

Strategy: The maintenance strategy to be assumed. Currently the only valid value for this parameter is 'PM2'

Number of crews: The number of maintenance crews available for work. Currently the only valid value is '2'.

Turbine philosophy: The maintenance design philosophy of the turbine. Currently the only valid values are 'Base', 'Robust1', 'Robust2', 'Light'.

Maintenance information

The values in this section are only used if 'Maintenance method' is set to '2' or '3'.

Maximum availability: The maximum availability of a single isolated turbine expressed as a percentage.

Fixed costs: The fixed costs of operation and maintenance expressed in MECU per year.

Variable costs: The variable costs of operation and maintenance expressed in MECU per year.

5.1.2 TowerInputSpecs

This sheet (figure 5.1-2) contains detailed variables that have an influence on the support structure design.

Fatigue force on nacelle

The values for the three components in this section specify the three components of the equivalent constant amplitude fatigue tower top load to be used in the fatigue design of the support structure. These values are only used if the equivalent fatigue load method has been selected. At present this design method can only be selected by modifying the underlying code of the model.

Fatigue moment on nacelle

The values for the three components in this section specify the three components of the equivalent constant amplitude fatigue tower top moment to be used in the fatigue design of the support structure. These values are only used if the equivalent fatigue load method has been selected. At present this design method can only be selected by modifying the underlying code of the model.

	Α	В	С	D	E	F	G	н	I	J
1	Towe	r design input	NL1 base	NL1.1	NL1.2	NL1.3	NL1.4	NL1.5	NL1.6	NL1.7
2	Units	Run	1	2	3	4	5	6	7	8
3		Fatigue force on nacelle								
4		Component 1	153000	153000	153000	153000	153000	153000	153000	153000
5		Component 2	310000	310000	310000	310000	310000	310000	310000	310000
6		Component 3	324000	324000	324000	324000	324000	324000	324000	324000
7		_								
8										
9		_								
10		Fatigue moment on nacelle								
11		Component 1	1052000	1052000						
12		Component 2	9577000							
13	m	Component 3	3196000	3196000	3196000	3196000	3196000	3196000	3196000	3196000
14		_								
15		_								
16 17		_ Default wall thickness	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
17			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
19		-								
20	-	-								
21	-	Fatigue Safety Factors								
22		Above water line	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
23		Below water line	1.35	1.35	1.35		1.35			1.25
24			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
25		-								
26		-								
27		Material								
28	kg/m^3	Density	7850	7850	7850	7850	7850	7850	7850	7850
29		Youngs Modulus	2.10E+11	2.10E+11	2.10E+11	2.10E+11	2.10E+11	2.10E+11	2.10E+11	2.10E+11
30		Surface roughness	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
31		Yield stress	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08
32		_								
33										
34										
35		Miscellaneous								
36		Air viscosity	1.00E-05	1.00E-05						
37	m/s^2	_g	9.81	9.81	9.81	9.81	9.81	9.81	9.81	9.81
38		_								
39										
40 41		_ Wave loading constants Inertia coefficient (c_m)	1 5	1 5	1 5	1 5	1 5	1 5	1.5	1.5
41		Drag coefficient (c_m)	1.5 0.7	1.5	1.5		1.5	1.5		0.7
42		_Diag coefficient (c_u)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
44		-								
45		-								
46		_								
47										
	cycles	Reference fatigue life (n1)	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06	2.00E+06
49	cycles	Required fatigue life (n2)				2.00E+06				
50		SN slope for scaling	4	4	4		4			
51		(Weld) correction factor	80	80						
52	cycles	Lifetime cycles				2.00E+06				
53	-									
54										
55		Additional Pile Information								
56		Pile properties method	1	1	1	1	1	1	1	1
57		Pile material density	7850	7850	7850	7850	7850	7850	7850	7850

Figure 5.1-2: Details of the 'TowerInputSpecs' Worksheet.

Default wall thickness

The wall thickness to be assumed as a starting point for the design of the support structure.

Fatigue Safety Factors

Above water line: The safety factor to be used during the fatigue design of components above the water line.

Below water line: The safety factor to be used during the fatigue design of components above the water line.

Material

The physical properties of the material from which the support structure is to be constructed.

Wave loading constants

The loading co-efficients to be assumed in calculations derived from the Morrison Equation.

Effective fatigue loadings

This section provides data to be used during calculations based on the effective fatigue loading method.

Reference fatigue life (n1): The lifetime for which the effective fatigue loadings have been calculated. This value can be expressed in any units, as long as the same units are used for the following parameter.

Required fatigue life (n2): The fatigue lifetime for which the support structure should be designed. This value must be expressed in the same units as the preceding parameter.

SN slope for scaling: The slope of the SN curve to be used in scaling the fatigue loadings.

(Weld) correction factor: The weld correction factor.

Lifetime cycles: The number of fatigue cycles for which the effective fatigue loads have been specified.

Additional Pile Information

Pile properties method: The method to be used in order to evaluate the properties of the support structure pile, assuming a pile is used. Currently this parameter must be set to '1'.

Pile material density: The density of the material from which the pile is made.

5.1.3 StructureCostData

The 'StructureCostData' sheet (figure 5.1-3) Contains economic and organisational data relating to the installation and costing of the support structure. See the Phase II report [3] for details of the significance of the most of the values. In the top left hand corner of this sheet is a box labelled 'vary parameters'. This should normally be set to 1. If it is set to zero, then all the structures will be costed using values from the first column only. This has been incorporated as a feature to save time in inputting data.

This sheet is divided into four sections. The first section, from line 9 to line 69 relates only to the gravity based monotower structure. In the second section, at line 71, the exchange rate between the currency in which the costs are provided and the ECU is specified. The cost values in this sheet may be input in any convenient currency, but the same currency must be used in every case. The exchange rate between the currency employed and 1 ECU should be placed in line 73, marked 'Currency/ECU'. A third section, from lines 76 to 118 contains data that relates only to the monopile support structure concept. Finally the fourth section from line 122 is provided so that the cost of any support structures needed specifically for transformers (or indeed any purpose other than supporting a turbine) can be input.

Gravity based support structure: Basic Figures

Units per year: The number of OWEC units that can be constructed and installed in a year.

Units per batch: The number of OWEC units that can be installed in a single batch.

Number of barges: The number of barges required for the installation procedure.

Installation days per batch: The number of days 'at sea' required to install each batch of OWEC units.

Gravity based support structure: Construction costs

Labour costs: The labour costs are broken down into 3 components, for the labour on the tower itself, the foundation and for handling the solid ballast for the foundation. Each is specified in currency units per man hour.

User Guide OWECS Cost Model

	А	В	с	D	E	F	G	н	
	A	Structure Cost Dat			<u> </u>		G		1
1		Structure Cost Dat	ιπραι	Sheel					
3	Vary parameters								
4	0								
5									
6 7		User Label Run Number	NL1 base	NL1.1 2	NL1.2 3	NL1.3 4	NL1.4 5	NL1.5 6	NL1.6
8		Run Number	1	2		4	3	0	
9		GRAVITY BASE							
10	Units								
11		Basic Figures							
12		Units per year	12	12	12	12	12	12	12
13 14		Units per batch No of barges	6	6	6	6	6	6	6
15		Installation days per batch	32	32	32	32	32	32	32
16									
17		_							
18	a /i	Procurement costs	100	100	100			(0.0)	
19 20	£/tonne £/tonne	Cost of steel Cost of ballast	400	400	400	400	400	400 100	400
20			100	100	100	100	100	100	100
22									
23		Construction costs							
24	£	Dock establishment	2500000		2500000	2500000		2500000	2500000
25 26	£	Annual dock operation Labour costs	500000	500000	500000	500000	500000	500000	500000
	£/mh	Tower structure	30	30	30	30	30	30	30
	£/mh	Foundation structure	30	30	30	30	30	30	30
	£/mh	Solid ballast	30	30	30	30	30	30	30
30 31	£	Float away (per batch)	150000	150000	150000	150000	150000	150000	150000
32									
33		Construction time							
34		(per unit)							
35	mh/tonne	Tower structure	50	50	50	50	50	50	50
36 37	mh/tonne mh/tonne	Foundation structure Solid ballast	50 5	50 5	50 5	50 5	50 5	50 5	50 5
38	min/tonne	Solid ballast	5	5	5	5	5	5	5
39									
40		Installation costs							
41	0/1	Offshore spread	10000	40000	40000	40000	40000	40000	10000
	£/day £/day	Mob/demob Installation	10000	10000	10000	10000	10000	10000	10000
44		Weather down time	10000	10000	10000	10000		10000	10000
45		Tugs							
	£/day	Mob/demob	3500	3500	3500	3500	3500	3500	3500
	£/day £/day	Towing (out & back) Installation	3500 3500	3500 3500	3500 3500	3500 3500	3500 3500	3500 3500	3500 3500
	£/day	Weather down time	3500		3500	3500	3500	3500	3500
50		Barge/Tank fabrication							
51	tonnes S/tonno	Material mass	500	500 2000	500	500 2000	500	500	500
52 53	£/tonne £/set	Material cost Total other equipment	2000 500000	2000 500000	2000 500000	2000 500000	2000 500000	2000 500000	2000 500000
54			230000	000000	000000	000000	000000	000000	000000
55									
56		Installation time							
57	days/batch	Offshore spread Mob/demob	5	5	5	5	5	5	5
59	days/batch days/unit	Installation	2	2	2	2	2	2	5
60		Weather down time	0.5	0.5	0.5	0.5	0.5	0.5	0.5
61		Tugs							
	days/batch days/unit	Mob/demob Towing (out & back)	3	3	3	3	3	3	3
63 64	days/unit days/unit	Installation	2	2	2	2	2	2	2
	days/unit	Weather down time	1	1	1	1	1	1	1
66									
67		Managamant							
68 69	% of total	Management Project management etc.	0	0	0	0	0	0	0
69 70	70 UI IUIAI	r roject management etc.	0	0	0	0	0	0	0
		1	1	1	I				

Figure 5.1-3: Details of the 'StructureCostData' worksheet.

Gravity based support structure: Construction time

This subsection details the time, in hours per tonne of material, needed for work on the OWEC units.

Gravity based support structure: Installation costs

This subsection specifies the costs in currency units per hour of installing the OWECS, as well as the costs of constructing any necessary ancillary equipment such as barges.

Gravity based support structure: Installation time

The values in this subsection detail the time in days required for various aspects of the installation work.

Gravity based support structure: Management

Management etc.: A value to be added to the cost of the support structure to account for any project management or other costs not accounted for elsewhere. This values is expressed as a percentage of the overall support structure cost.

Monopile support structure: Foundation

Details of the costs associated with building the piled foundation for the Monopile support structure concept are set in this subsection. Two sets of data, specifically those relating to 'Engineering and Certification' and 'Site Investigation' arguably apply to the whole support structure, rather than the foundation, but have to be included somewhere!

Monopile support structure: Tower

Values here are used for costing of the tower part of the support structure.

5.1.4 Calibration factors

The 'Calibration factors' sheet (figure 5.1-4) allows the output of the cost model to be 'calibrated' to match values associated with any particular 'real' OWECS. The calibration method employed is very simple. Values calculated by the model are multiplied by multipliers specified in this sheet before being output as results or used to calculate an energy cost.

The first set of values headed 'Costs' contains multipliers that act directly on results calculated by the model and used to calculated the levelised energy production costs. These are :

- Energy production
- Turbine cost
- Grid connection cost

- O&M cost
- Decommissioning costs
- Project management costs

	User Label	NL1 base	NL1.1	NL1.2	NL1.3	NL1.4
	Run No:	1	2	3	4	5
	FACTOR	VALUE				
Costs	Energy production	1.184144	1.184144	1.184144	1.184144	1.184144
	Turbine cost	1	1	1	1	1
	Grid connection cost	0.723769	0.723769	0.723769	0.723769	0.723769
	OM cost	4.870392	4.870392	4.870392	4.870392	4.870392
	Decommissioning	1	1	1	1	1
	Project management	1	1	1	1	1
Masses	Structure mass	1.233	1.233	1.233	1.233	1.233
	Foundation mass	0.8	0.8	0.8	0.8	0.8
Others	Availability	1.0468	1.0468	1.0468	1.0468	1.0468
	Time period					

Figure 5.1-4: Details of the Calibration factor worksheet.

A further set of multipliers labelled 'Masses' act on the masses for the OWECS support structure calculated by the model. As these masses form the basis for costing the support structure, the multipliers allow the support structure cost to be calibrated in a rational manner. Two multipliers may be specified:

- One acting on the structure mass
- One acting on the foundation mass.

One of the two 'Other' multipliers is provided for calibration of the wind farm availability. The final time period multiplier is currently not functional, being provided for use in future versions of the model. Despite this, the time period of the fundamental mode of support structure may still be calibrated so long as the effective fatigue load method is employed, by setting a multiplier labelled 'Period Calibration' in the 'controls' worksheet of workbook 'struct1.xls'.

5.1.5 GridConParams

Using this worksheet (figure 5.1-5) the more important details of the grid connection designed by the model may be set. The majority of the parameters are reasonably self explanatory, with details of the options available specified on the sheet itself and thus will not be elaborated on here.

One exception to this is the value on lines 3/4 near the top left hand corner labelled 'Vary Parameters'. If this parameter is set to '0' only the first column of values is used for all computations. If set to '1', the model reads data from the column

appropriate for each calculation. This facility is provided to ease the setting up of computations in which there is no interest in varying these grid connection parameters.

	Α	В	С	D	E	F
1	Grid Connection P	arameter Variat	ions			
2						
3	Vary Parameters					
4	0					
5						
6						
7						
8						
9		User Label	NL1 base		NL1.2	NL1.3
10		Run Number	1	2	3	4
11						
12		Shore to Grid				
13	TRUE or FALSE	OH line	FALSE	FALSE	FALSE	FALSE
14	TRUE or FALSE	DC connection				
15						
16		Park to Shore				
17	TRUE or FALSE	OH Line				
18	TRUE or FALSE	DC Connection	FALSE	FALSE		FALSE
19						
20		Turbine to Cluster				
21	TRUE or FALSE	OH Line	FALSE	FALSE	FALSE	FALSE
22	TRUE or FALSE	DC Connection	FALSE	FALSE	FALSE	FALSE
23	1=star, 2=chain, 3=circuit	Design type	3	3	3	3
24	1=power, 2=load break, 3=isolating link	Switch type	2	2	2	2
25						

Figure 5.1-5: Details of the 'GridConParams' worksheet.

5.2 Variables that remain constant from run to run

All the sheets examined in this section allow specification of values that remain constant for any particular invocation of the model, These values can be changed by the user, and will remain at the values specified for all calculations subsequently undertaken.

5.2.1 TurbineInputSpecs

This sheet (figure 5.2-1) contains details of the various turbines. The reference number at the top of each column is used to select which turbine is used via the 'turbine type' input in 'MasterSheet'. Thus by specifying differing turbine configurations in this sheet, it is possible to perform parameter studies of the influence of changes in turbine design. The user may modify the existing specifications, or add further turbines as required.

Many of the parameters have an obvious interpretation and only the more obscure will be dealt with here.

Cp-L curves.

The model can deal with turbines having complex modes of operation such that more than one Cp-lambda curve is necessary to fully describe their performance. Details of particular Cp-lambda curves are placed into worksheet 'PowerCurves' using a normalised format, and here it is only necessary to specify the reference number of the curves to be used. The reference numbers of each power curve should be inserted in the rows marked 'Operation regime 1', 'Operation regime 2' and 'Operation regime 3', with 'Operation regime 1' specifying the curve for use at the lowest wind speeds and 'Operation regime 3' that for the highest wind speeds. The rows marked 'Cp_max' and 'Lambda at Cp_max' should contain the maximum absolute co-efficient of performance in each operation regime and the tip speed ratio at which that performance is achieved.

Values in the next sub-section specify wind speeds at which the operating regime of the turbine changes and have the following significance.

Limiting speed: The wind speed beyond which further increases in wind speed do not produce increases in the electrical power produced. This is usually equal to the rated speed.

Rated speed: The wind speed at which the turbine produced its rated power output.

Cut-in speed: The minimum wind speed at which the turbine operates.

Transition speed 1: The wind speed above which the turbine operates according the first Cp-lambda curve. This is usually equal to the cut in speed.

Transition speed 2: The wind speed at which turbine operation switches from the first Cp-lambda curve to the second. If only one Cp-lambda curve is used then this value should be set to the cut-out speed.

Transition speed 3: The wind speed at which turbine operation switches from the second Cp-lambda curve to the third. If only one Cp-lambda curve is used then this value my be ignored. If two Cp-lambda curves are used then this value should be set to the cut out speed.

Transition speed 4: This value should be set to the cut out speed of the turbine.

Physical dimensions

Height of nacelle: The vertical dimension of the nacelle.

Area of nacelle: The frontal area presented by the nacelle to the wind.

Nacelle Cd: The drag co-efficient for the nacelle.

	•	В	с	D	E	F				
	Α					Г	G	н	I	J
1		Turbine Desi	gn inp	ut Sne	et					
2		Lingthan the surrouteness of	4h t t	al la autoria						
3		Unlike the master and each calculation, this s								
4		are referred to in the 't					s which			
6			urbine type	parameter	or the ma					
7		NOTE: Cp-lambda cur	ves are dea	alt with sep	aratelv in s	heet 'Powe	rCurves'			
8		NOTE 2: Not all option								
9		•								
10										
11		Reference Number	1	2	3	4	5	6		8
12		Description	WTS-80	1.5MW		KT 4-100	KT	KT	КТ	KT
13 14					to finish	to finish				
	Units	Basic Information								
	kW	Rated power output	3000	1500	4000	4000	3000	3000	3000	3000
17	NVV	No of regimes	1	1300	4000	4000	1	3000	1 1	1
	ECU	Unit cost	1.70E+06	1.00E+06	1.90E+06	1.93E+06	1.50E+06	1.80E+06	2.50E+06	3.00E+06
19		Blade diameter	80	64	90	100	80	80		
20										
21		Cp-L Curves								
22		Operation regime 1	6	8	6		7	7	7	7
23		Cp_max	0.494	0.487	0.494			0.423		
24 25		Lambda at Cp_max	9.22	8.5	9.22	9.22	7.36	7.36	7.36	7.36
25		Operation regime 2	_		-	-	_	-	_	_
27		Cp_max	-		-	-	-	-	-	_
28		Lambda at Cp_max	-		-	-	-	-	-	-
29		. –								
30		Operation regime 3	-		-	-	-	-	-	-
31		Cp_max	-		-	-	-	-		-
32 33		Lambda at Cp_max	-		-	-	-	-	-	-
33 34		Misc wind speeds								
	m/s	Limiting speed	14	18	16	16	16	16	16	16
	m/s	Rated speed	14	18	16					
	m/s	Cut in speed	2.5	3	2.5	-			-	
38	m/s	Transition speed 1	2.5	3	2.5	2.5	2.5	2.5	2.5	2.5
	m/s	Transition speed 2	25	25	25	25	25	25	25	25
	m/s	Transition speed 3	-		-	-	-	-		-
41 42	m/s	Transition speed 4								
42		Physical dimonsions								
	m	Physical dimensions Height of nacelle	10	8	11.25	12.5	10	10	10	10
	sq. m	Area of nacelle	35	0 22.4	44.3					
46		Nacelle Cd	1.2	1.2	1.2					
47	kg	Nacelle mass	130000	75000	141000					
48										
49										
	sq. m	Structure blade area	105.3	67.4	133.3	164.5	105.3	105.3	105.3	105.3
51 52										
52		Misc. information								
54		Power control system	pitch	pitch	pitch	pitch	pitch	pitch	pitch	pitch
55		Drive type	0.9999	0.965	0.9999					
56		Generator type	0.9999	0.967	0.9999					
57		Safety factor	1	1	1	1	1	1	1	1
58										
59		Scaling controls								
60		Diameter	0	0	0	0	0	0		
61		Cost	0	0	0		0			-
62 63		Weight Effective loads	0 0	0	0		0			
63 64	1/0		0	0	0	0	0	0	0	0
65		Fatigue data set	1	1	2	3				
			1		2	J 3				

Figure 5.2-1: Details of the 'TurbineInputSpecs' worksheet.

Nacelle mass: The total mass of the nacelle and equipment, including the rotor.

Structure blade area: The effective area presented by the blades to the wind. This values is used in computing the axial wind force on the blades.

Misc. Information.

Power control system: This parameter is essentially obsolete, but has been left in place as it may be re-activated in a future release of the model. It should be left set to 'pitch'.

Drive type: This value contains the (assumed constant) efficiency of the turbine power transmission mechanism.

Generator type: This value contains the (assumed constant) efficiency of the turbine generator.

Safety factor: This parameter is obsolete and should be left set at '1'.

Scaling controls

If the turbine rated power scaling facility discussed in section 5 and volume 2 [5.2-1] is used, these values control which of the turbines features are scaled. Setting a value to '1' means that a feature will be scaled with the rated power, while setting it to 0 means that the feature is not scaled.

Fatigue data set

This parameter specifies the reference number of the data set to be used for the effective load method of calculating the fatigue loads exerted by the turbine on the support structure.

5.2.2 PowerCurves

Details of the Cp-lambda curves used in the energy production calculations are contained within this sheet (figure 5.2-2). The columns labelled L/LP contain values of the tip speed ratio normalised by the tip speed ratio at which the maximum co-efficient of performance is achieved; while the columns labelled Cp/CpM contain the corresponding co-efficients of performance normalised by the maximum co-efficient of performance. Data must be order from the lowest tip speed ratio to the highest. The final entry for each performance curve should specify a normalised tip speed ratio of 999 and a normalised co-efficient of performance of 0.

The data in the sheet may be modified by the user. Unfortunately, it is not possible to add extra performance curves to the sheet. Implementation of a new curve can only be accomplished by replacement of one of the existing data sets.

Power	[·] Curve	s She	et					
Character	istic Numb	<u>per</u>						
1		2		3				
HOWDEN	55m	OEI&CUR	VERS	WEG 100r	n			
RICHBOR	OUGH			OFFSHORE				
3-blade		3-blade		2-blade				
pitch tip		stall regu	lated	pitch tip				
L/LP	Cp/CpM	L/LP	Cp/CpM	L/LP	Cp/CpM			
0	0	0	0	0	0			
0.014	0	0.17	0	0.2617	0.1378			
0.028	0.002	0.2	0.0148	0.2793	0.1526			
0.042	0.003	0.2152	0.0241	0.2968	0.1692			
0.056	0.004	0.2303	0.0269	0.3144	0.1875			
0.069	0.005	0.2455	0.0259	0.3261	0.2004			
0.083	0.009	0.2606	0.0234	0.3436	0.2208			
0.097	0.011	0.2758	0.0211	0.3612	0.2424			
0.111	0.015	0.2909	0.0206	0.3788	0.2649			
0.125	0.018	0.3061	0.0228	0.3963	0.2882			
0.139	0.02	0.3212	0.0285	0.4139	0.3123			
0.153	0.026	0.3364	0.0382	0.4314	0.3372			
0.167	0.03	0.3515	0.0521	0.449	0.363			

Figure 5.2-2: The 'PowerCurves' worksheet.

5.2.3 RetroFitInput

The 'RetroFitInput' worksheet (figure 5.2-3) allows the user to account for the costs of retrofitting the OWECS part way through its life. Such a procedure might be desirable, if for example, the turbine employed has a 20 year life, but the support structure and grid connection had been designed with a lifetime of 40 years. With the latter circumstance it might be economically advantageous to fit new turbines to the existing OWECS support structures after 20 years of operation.

Five columns are provided for input within the worksheet. The first column, labelled 'year', specifies the number of years after initial commissioning that any retrofitting operations will be carried out. Any number of retrofits may be specified within the sheet, so long as each is planned for an integer number of years from commissioning and that they are arranged in chronological order.

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Retro-fit Cost In	puts					
Include Retrofit	0					
			Either	or		or
	Y	ear	Turbine Factor	Turbine Cost (ECU)	Support Factor	Support Cost (ECU)
	20	0	1		0.5	

Figure 5.2-3: The 'RetroFitInput' worksheet.

The next four columns allow the costs of the retrofit operations to be entered. Retrofits are assumed to entail work on the turbine, and the support structure and separate inputs for the two expenses are provided. The first pair of columns relate to the turbine, and allow costs to be specified in one of two ways. Values in the 'Turbine Factor' column cause the turbine related work to be costed as the original cost of the turbines multiplied by the value entered. Alternatively, values entered in the next column 'Turbine Cost (ECU)' allow the cost of retrofitting the turbine to be specified directly. For any one retrofit operation, values should only be placed in one of the turbine columns.

The final two columns are provided for the costs of retrofit work on the support structure to be entered in a similar manner. Turbine and support structure retrofit costs may be combined in any manner required by the user.

At the top left of the sheet is a parameter labelled 'Include Retrofit'. Irrespective of the contents of the main table, retrofit costs will only be accounted for by the model if this value is set to '1'. When set to '0', this parameter effectively turns the retrofit calculations off.

5.2.4 MiscData

The 'MiscData' sheet contains global values that are not included on other worksheets.

DM/ECU exchange rate: The exchange rate to be assumed between the Deutchmark and the ECU. This value is only used if some obscure features of the grid connection model are used.

No of wind nodes: The number of wind speed 'steps' to be used in calculating the energy production.

Max calc wind speed: The maximum wind speed to be considered in the energy production calculation. Note that this value only influences the calculation technique used by the model, and has no effect on the specification of the turbine.

5.3 Input sheets in struct1.xls

Three input sheets are contained in the structural design workbook 'struct1.xls'. It is not envisioned that the user will have cause to alter this data as, for the most part, the parameters only influence the internal operation of the model.

5.3.1 EffectiveLoadData

The 'EffectiveLoadData' worksheet (figure 5.1-3) specifies the tower top fatigue loads to be used for the effective loads method of designing the support structure. The first data set in the worksheet must not be altered and any data added by the user should be formatted in a similar manner, with a blank line being left between data sets.

Effect	ive Fa	tigue Load Dat	ta						
		first data set							
	Data Set	Description	Quantity						
	1	3MW KT	Fundamental SS freq (Hz)	0.3	0.35	0.39	0.44	0.55	0.67
		Computed by IvW	f_0/f_R	0.82	0.956666667	1.066	1.202666667	1.503333333	1.831333334
			Effective Moment Range (Nm)	5.84E+06	-1.69E+06	-6.50E+04	3.89E+06	2.91E+06	-7.05E+05
			Effective Force Range (N)	1.79E+05	7.82E+05	7.35E+05	2.66E+05	4.11E+05	8.34E+05
	2	4MW-90 KT (20 rpm)	Fundamental SS freq (Hz)	0.273333333	0.32	0.353333333	0.4	0.5	0.61
		Computed by IvW	f_0/f_R	0.82	0.96	1.06	1.2	1.5	1.83
			Effective Moment Range (Nm)	5.13E+06	-2.69E+06	-1.10E+06	3.21E+06	2.09E+06	-1.82E+06
			Effective Force Range (N)	1.97E+05	8.11E+05	7.65E+05	2.84E+05	4.33E+05	8.66E+05

Figure 5.3-1: The 'EffectiveLoadData' worksheet.

The significance of the components of each data set is as follows:

Fundamental support structure freq (Hz): The fundamental support structure natural frequency for which the data point was calculated. This data row is provided for the convenience of the user and plays no role in the model calculations.

f_0/f_R: The fundamental support structure frequency divided by the rotor frequency.

EffectiveMomentRange(Nm): The effective tower top fatigue moment range applied by the turbine to the tower in units of Nm.

EffectiveForceRange(Nm): The effective tower top fatigue force range applied by the turbine to the tower in units of Nm.

Reference should be made to volume 2 for further information on the effective load calculation technique.

5.3.2 Controls

Values in the 'controls' worksheet (figure 5.3-2) influence details of the support structure optimisation calculation performed by the model.

Structura	I Designer Contro	ls
(for effective loa	d method)	
	Control	Value
	Fatigue iteration?	1
	Convergence criterion	0.01
	Maximum no of its	40
	Strength iteration?	0
	Convergence criterion	0.01
	Overall c criterion	0.005
	Period calibration	1.73

Figure 5.3-2: The 'Controls' worksheet.

The first block of parameters controls iteration of the fatigue based support structure design routines.

Fatigue Iteration?: If this value is set to '1' the fatigue calculation is iterated for the number of times specified in 'Maximum no. of its' or until a convergence criterion is met. If set to '0', the fatigue calculation loop is only performed once.

Convergence criterion: The convergence criterion to be applied in assessing if the fatigue calculation iteration is complete. The value specifies the maximum acceptable fractional change in the support structure mass between iterations.

Maximum no. of its: The maximum number of times that the fatigue calculation will be iterated.

The second block of parameters controls iteration of the support structure design calculations based on the absolute load cases specified elsewhere in the model.

Strength iteration?: If this value is set to '1' the strength calculation loop is iterated until a convergence criterion is met. If set to '0', the strength calculation loop is only performed once.

Convergence criterion: The convergence criterion to be applied in assessing if the absolute calculation iteration is complete. The value specifies the maximum acceptable fractional change in the support structure mass between iterations.

The third parameter block, 'Overall c Criterion', sets the overall convergence criterion to be used in assessing whether the overall support structure design loop

has converged. The value specifies the maximum acceptable fractional change in the support structure mass between iterations.

The final parameter block '**Period calibration**' allows the support structure natural period calculated by the model to be calibrated. This parameter is only functional if the effective fatigue load calculation method is selected, and causes the calculated frequency to be multiplied by the value it contains.

5.3.3 Pile data

The 'Pile data' worksheet (figure 5.3-3) contains details of the pile foundations to be used by the model in designing the monopile support structure. The main table acts as a look-up table, with the pile parameters estimated according to the pile diameter specified in 'MasterSheet'. Where the pile diameter in 'MasterSheet' lies between diameters in the look-up table, linear interpolation is used to establish the required values.

Pile Parame	eters								
			Rotational stiffness ca	libration factor =	1	0.265			
No of values=	3								
		Diameter	Transverse stiffness	Rotational stiffness	Effective length	Design Length	J-Tube Mass	Cathodic Prot Mass	Boat Mass
		(m)			(m)	(m)	(tonnes)	(tonnes)	(tonnes)
		2.75	1.48E+10	3.04E+09	13.17		2.5	0.5	3
		3.5	3.09E+10	4.62E+09	15.44		2.5	0.5	3
		4.25	5.62E+10	6.39E+09	17.94		2.5	0.5	3

Figure 5.3-3: The 'PileData' worksheet.

The values included in the look up table are:

Diameter (m): The diameter of the pile in metres.

Transverse stiffness: The transverse stiffness of the foundation provided by the pile.

Rotational stiffness: The rotational stiffness of the foundation provided by the pile.

Effective length (m): The effective length of the foundation provided by the pile in meters. (This value is not currently used by the model and is included for use in future versions of the model.)

Design length (m): The overall design length of the pile in meters. (This value is not currently used by the model and is included for use in future versions of the model.)

J-Tube Mass (tonnes): The mass in tonnes of the J-tubes to be used with the pile. **Cathodic Prot Mass (tonnes)**: The mass in tonnes of the cathodic protection to be used with the pile.

Boat Mass (tonnes): The mass in tonnes of the boat landing equipment to be used with the pile.

Two other parameters are to be found near the top of the worksheet:

No. of values: This value should contain the total number of entries in the look up table.

Rotational stiffness calibration factor: Rotational stiffnesses estimated from the look up table are multiplied by the value of this parameter. This allows the rotational stiffnesses to be calibrated as required.

5.4 Further output sheets

There are four sheets that provide more detailed output than that in MasterSheet.

5.4.1 BasicTowerOutput

This (figure 5.4-1) contains the major details of the optimal support structures designed for each run of the cost model. The columns for each run list, in order, the vertical dimension of each segment in m, the wall thickness if each segment in m, the outer diameter of the segment in m, and the mass of the segment in kilograms. Segment number '1' is the lowest segment in the support structure.

Outline Su	pport Struct	ture Desig	n Outp	out	
	Run 1				Run 2
Segment Number	Segment Height	Wall Thickness	Diameter	Mass	Segment Height
1	5.5	0.025967889	3.500523	12238.21	5.25
2	5.5	0.024818754	3.345617	11179.04	5.25
3	5.5	0.02428809	3.274082	10706.1	5.25
4	5.5	0.023429489	3.158341	9962.546	5.25
5	5.5	0.023180872	3.124827	9752.238	5.25
6	5.5	0.022926809	3.090579	9539.64	5.25
7	5.5	0.022666983	3.055554	9324.643	5.25
8	5.5	0.022401063	3.019707	9107.14	5.25
9	5.5	0.022128675	2.982989	8887.008	5.25
10	5.5	0.021849409	2.945343	8664.113	5.25
11					

Figure 5.4-1: Details of the 'BasicTowerOutput' worksheet.

5.4.2 struct1.xls:StructOutput

'StructOutput' (figure 5.4-2) contains a very detailed breakdown of the most recently designed support structure. The information shown is updated in 'real time' as the model runs, and as such, the sheet provides a means of observing the design process it employs.

It can be advantageous to have this sheet visible while the model is performing computations in order to observe how well the support structure design is progressing. In a very few circumstances the support structure design routine can become unstable and get caught in an 'infinite loop'. Having this sheet visible makes it a straightforward task to catch this condition manually. One approach found useful by the author is to arrange this sheet and 'MasterSheet' as shown in figure 5.4-3.****

1	Α	В	с	D	Е	F	G	н	1	J	к	L	м	Ν
1	Summary Informati	on		Detailed E	Breakdown									
2											Load case 1	•		
3	Overall			No	mid	height	thickness	diameter	mass	inertia	cd	wind_force	wind offset	tmax bm
4				1	2.75	5.5	0.025968	3.500523	12238.21387	123401.9844	0.90425992	19231.0547	2.8057718	3.7E+07
5		3.40921402		2	8.25			3.345617			0.906147599			
6	Struct type =	soft soft		3	13.75			3.274082			0.907568872	22549.7441	13.779783	2.8E+07
7				4	19.25	5.5	0.023429	3.158341	9962.545898	3716860	0.909193158	23103.834	19.274166	2.4E+07
8	t_divider =	134.8019714		5	24.75	5.5					0.910188198	24016.8438		2E+07
9	Current Problem =	none		6	30.25	5.5	0.022927				0.911069155	24776.5215		1.7E+07
10	Iteration number =	23		7	35.75	5.5	0.022667	3.055554	9324.642578	11940982	0.911868334	25413.3398	35.765438	1.3E+07
	Current routine =			8	41.25	5.5					0.912606895	25947.9922	41.263779	1.1E+07
12				9	46.75						0.913299918	26395.1484		8284229
13	Total mass	99360.69043		10	52.25	5.5	0.021849	2.945343	8664.113281	23675412	0.913958192	26765.5215	52.261345	6254296
14														
15														
16														
17	Load Case 1													
18														
	nacelle wind force =	102667.0391												
	applic height =	60												
21														
22	blade force =	1613.076172												

Figure 5.4-2: The 'StructOutput' worksheet.

le <u>E</u> dit	: <u>V</u> iev	v <u>I</u> nsert F <u>o</u> l	rmat 🛾	[ools	<u>D</u> ata	<u>W</u> ind	low <u>H</u> e	elp						
rial		¥ 10 ¥	BI			3999	6, 3	•%	() ()					
							0 9 .00	*.0] (÷÷) =						
	5 Q .	% 👗 🖻 🛍 ダ	n Ca	$\Sigma f_{\mathbf{x}}$				Ŧ	₽ ₽					
D1	1	L Deta	ailed Bre	akdown										_
•		- ·				PF	ERFM38	AXIS						
		A	В	C	D				G I	H	J	K L	м	
Control									Ma	ster She	et			
No to calcu	late		4			Compute!								
Recalculat	e support		1		L	Jomparei			NL1s	shore				
					_									
		User Label:	NL1base	NI 11	NL 12	NL1.	3 NLI	4 NLI	5 NL I	6 NL17	NL18 /	NL 19		NL.
			Run No:											Run
Variables			1		2	3	4	5	6	7	8 9	10		
1.5. 1	P. 61													
<i>Wind ca</i> maws (m/s			8	1	8	8	8	8	8	8	8 8	8		
indens (inis	, 				0	~~~~			~~~~			~~~~~		L
						STR	UC25A.	XLS						•
A		В		2	D	E	F	G	Н	l	J	К	L	
Summary I	Informat	ion		Det	ailed B	reakdown	1					Load case 1		
Overall				No	r	nid	height	thickness	diameter	mass	inertia	cd	wind_force	win
					1	2.75	5.5		5.2560945	21375.6875	215538.18			
Fime period		2.03621912			2	8.25	5.5		5.1523504	20540.19336	1449795.3		32274.01172	
Struct type =		soft stiff			3	13.75 19.25	5.5 5.5		5.0436754 4.814105	19682.85156 17931.8418	377090			
		174.296875			4	24.75	5.5		4.6964178	17931.8418	104969			
divider -	olem =	none			6	30.25	5.5			16171.44922	148386			
		15			7	35.75	5.5			15245.01953	195225			
– Current Prob					8	41.25	5.5	0.0246204	4.2912645	14248.3418	242803	62 0.906357229	36225.50781	41.
_divider = Durrent Prob teration nun Durrent routi	ne =				9	46.75	5.5		4.1248794	13164.86035	288058		35874.78125	
- Current Prob teration nun Current routi	ne =				10	52.25	5.5	0.0226273	3.9438651	12034.77148	328860	0.908690274	35247.30859	52.
– Current Prob teration nun	ne =	167460.8389			10	32.23								

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Figure 5.4-3: Suggested arrangement of worksheets for model use.

5.4.3 sco1.xls:InputSheet

This sheet (figure 5.4-4) displays the details of the most recently designed grid connection.

Most of the variable on this sheet are self-explanatory. For further details reference should be made to other documents dealing specifically with grid connection modelling

<u> </u>			-	-	_	_	-	
1	A General Data:	В	С	D	E Parameter:	F	G	Н
1	Rated Power Farm	300.00	[NA\A/]		r aldinetef:		+	
					0			
3	Rated Power Turbine		[MW]		Capacity F			
4	Turbines per Cluster	8	[#]		Include Loss F		[TRUE/FALSE]	
5	Turbine Spacing	0.8	[km]		tan o	delta 6.00E-04		
6	Distance to Shore	15.00			Invert	Price ECU 46.00	[ECU]	
7	Distance to Grid		[km]					
8	Payed Price	ECU 0.05	[ECU/kWh]		Down Time for repai	r 24	1	
9	Rate of Intrest	5.00%	[%]		Overhead Costs pe	er km ECU 82,000	[ECU]	
10	Life Time	20.00	[years]		Offshore Trafo Supp	ort () [-]	
11			<i>v i</i>					
12	Cable Data:							
13		Voltage [kV]	Matorial	DC Connection	OHI inc	Core (3/1)	Laying Cost (fixed)	Laving cost (variable)
14	Public Grid	380	Material	Do connection	OHLine	0010 (0/17	Laying Cost (incos)	Laying cost (variable)
15			Aluminum	FALSE	FALSE		3 ECU 3,000	ECU 216,000
	Shore to Grid	380	Aluminum		FALSE		5 ECU 3,000	ECU 216,000
16	Park to Shore Cluster to MNP	380	Aluminum	FALSE	FALSE FALSE		ECU 10,000 ECU 10,000	ECU 621,000 ECU 378,000
17	Cluster to MNP	30	Aluminum	[ECU 10,000	ECU 378,000
18	Turb to ClusterConn		Aluminum	FALSE	FALSE		B ECU 10,000	ECU 378,000
19	Turbine	0.5					1	
20								
21								
22								
23							1	
24							1	
25							1	
25	MNP to Grid						+	
		Investment to Chart			Antilana		Annuity Conto	
27			Investment to Grid	L.	Anl Loss	5004	Annuity Costs	.
28	Cable Diameter	300	300	Factor Onshore Factor Offshore	1.22331	5001		
29	Number of Cables	1	1	Factor Offshore		1		
30	Trafo Price	ECU 4,160,000	ECU -					
31	Trafo Support Structure	ECU -	ECU -	<u>[</u>				
32				I		1		
33				Cable to shore	ECU 33	,258 AC Investment	29,240,801.77	
34	CableCost	ECU 10 253 921	ECU 3,000	Cable to Grid Trafo to Shore	ECU		8.02%	
35	CableCost Trafo Cost	ECU 10,253,921 ECU 4,160,000	ECU -	Trafo to Shore	ECU 10	 x Annuity Factor ,765 	0.02/0	
36	Switch Cost	ECU 4,743,000	ECU 4.743.000	Trafo to Grid	FCU	,700		•
37		ECU 19,156,921		That's to Gild		,023	ECU 2,346,358	-
38	Total	ECO 19,130,921	ECU 4,740,000	in LifeTime		,459	ECU 2,346,338	= Total Cost
39	Cluster to MNP				ECU 000	,409	ECO 40,927,153	
							A 1.	
40		Investment			Loss		Annuity	
41	Cable Diameter	240 12.5 x 1		i ¢				
42	Number of Cables	12.5 x 1						
43	Trafo Price	ECU -		1		į		
44	Trafo Support Structure	ECU -]
45	Trafo Price Trafo Support Structure Cable Length	14.24360085]
46								
47	CableCost Trafo Cost	ECU 6,879,526		i		I	1	j
48	Trafo Cost	ECU -		Cable	ECU 31	,751	1	
49	Switch Cost	ECU 277,313		Trafo	ECU	-	1	
50	Total			1		,751	ECU 574,283	1
51		,,		in LifeTime		,022	ECU 11,485,665	= Total Cost
52	Within Cluster						,,	
53		Investment			055		Annuity	
54	Cable Diameter	Investment 185			Loss		1.	
55	Number of Cables	10 5 4 9 4 1					+	
50		12.0 X 0 X 1					4	
56	Cable Length	6.400000095		.				
57								
58				Cable Trafo DownTimeCost	ECU 30 ECU 21 ECU 50	,780 ,590 ,181	1	
59				Trafo	ECU 21	,590		
60	CableCost	ECU 37,474,941		DownTimeCost	ECU 50	,181		
61	Trafo Cost	ECU 3,540,000						
62	Switch Cost	ECU 1,331,100		x avail. Factor	1.0099		I	
63	Total	ECU 42,346,041				,576	ECU 3,397,956	1
64	. 0101	,,,		in LifeTime	ECU 2,071		ECU 67,959,120	= Total Cost
65					,0,1	·		
66							1	
67		ECU 73,405,801			ECU 179	.350	ECU 6,318,597	
		10,400,801		in LifeTime				TOTAL
68				in LifeTime	ECU 3,587		ECU 126,371,938	
69				% of total energy yield	0.42653	7212		Income
70								

Figure 5.4-4: The sco1.xls spreadsheet.

6. Limitations & Suggestion for further work

6.1 Limitations and Suggestions

The model contains a number of 'unexpected features' and omissions that may trap the unwary. These are mostly minor from the programming viewpoint, but may cause serious problems for the casual user. It is intended that future releases of the model will address some of these issues.

The 'features' concerned are:

- 1. In certain rare circumstances, the structure optimiser can get stuck in an infinite loop, forever trying to improve the structure design. This appears to occur in circumstances where no soft-stiff type structure is possible, generally with very short support structures. Unfortunately this is a very difficult condition for the user to spot the support structure routine is very slow at the best of times and it is not obvious when it gets stuck in an infinite loop. The best advice is to keep both 'MasterSheet' in perfmod1.xls and 'StructOuput' in struct1.xls visible while the model is operating as shown in figure 5.4-3. Monitoring the real-time data in 'StructOutput' should assist the user in determining when the routines have got caught in an unending loop.
- 2. No facility exists to turn off the support structure optimiser and allow manual specification of the design. Such a facility will be included in a future release.
- 3. A very few of the options and parameters in the worksheets have little or no effect or might not do what you might expect from the label. Efforts have been made to highlight such entries within this manual, but some may have escaped.
- 4. There are a number of incompatible input options that are not checked for. The onus is placed on the user to ensure that consistent data is input to the model. This approach has been adopted as it may under certain circumstances be useful to simulate OWECS that break physical or regulatory design constraints. A future release of the model may include an optional facility to force input data to comply with regulatory guidelines.
- 5. The model contains a fair amount of redundant test code, which has been left in place to ease further development. The code is not used by the model directly, and its presence does not have a significant influence on the computational performance of the model. Please ignore this code.
- 6. Some recent evaluations have suggested that the annual energy production calculation may be somewhat inaccurate. The nature of the errors are unlikely to affect the outcome of any site or concept comparison work carried out with the model, but do introduce a further uncertainty into the absolute accuracy of the

cost calculations. It is planned to further investigate these errors and correct them with an interim release of perfmod.xls as soon as possible.

- 7. The support structure optimiser routines are capable of developing soft soft support designs. The physical and engineering modelling of the both the fatigue loadings on and the dynamics of the support structure are not sufficiently sophisticated to account for the full range of design drivers that are important for soft-soft supports (by way of example, no account is taken of wave driven fatigue loadings). Thus, for the moment, the user should be careful to avoid specifying configurations that might result in soft-soft designs. It is hoped that it will be possible to develop the model further to allow the promising soft-soft concept to be modelled with sufficient reliability to be useful. Such improvements will require substantial work and are unlikely to be implemented in any releases of the model for the foreseeable future.
- 8. The calculation of support structure natural frequency is undertaken on a very simplistic basis. Experience has shown that, while adequate for qualitative work, the results are wholly inappropriate for use in design work. It would be a comparatively straightforward task to improve this.
- 9. Experience has shown that the assumption of a fixed thickness/diameter ratio over the full extent of the support structure is not really an adequate design simplification. The resulting structures produced by the model, while comparable in broad terms to those produced by an experience structural engineer, differ substantially in detail. Great improvements might be possible if ways of improving this assumption can be distilled.

6.2 Bug Reports

The authors of the Opti-OWECS cost model respectfully request that any bug reports, comments, or suggestions for enhancement be directed primarily to Tim Cockerill at the University of Sunderland (email: tim.cockerill@sunderland.ac.uk) and also to Martin Kühn at the Delft University of Technology.

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