User guide – COE Calculation Tool for Wave Energy Converters

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Quick-start user guide
– The COE Calculation Tool for Wave Energy Converters –
(version 1.6, April 2014)

1 Introduction

Consulting Engineer Julia F. Chozas (contact person at coe@juliafchozas.com) together with Aalborg University and Energinet.dk have released a freely available online spreadsheet to evaluate the Levelised Cost of Energy (LCOE) for wave energy projects.

The aims of the COE calculation spreadsheet are as follows:

- To ensure consistent and transparent calculation methods.
- To provide a framework for performing COE analyses.
- To provide a tool for simple scaling of a machine according to different wave climates.

The spreadsheet is based on a reference machine and gives the opportunity to calculate the scaled equipment and the costs associated to the reference and the scaled machines. The reference machine can be freely set.

The user of the COE Tool must note that he needs to hand in documentation that proves all input values for the tool whenever using the COE Tool. The user must specify the assumptions behind all input data and include information about the WEC's development stage.

The spreadsheet is locked in order to protect the formulas and the tool structure. The colour codes in the cells are as follows:

	Editable cells
	Default values, used if no other values are entered
	Used values

Thus, the green colour cells overwrite the values in the yellow cells.

2 Reference machine

The spreadsheet is based on a reference machine (a wave energy converter), which provides the core information of all calculations. All input data, such as dimensions, weight, minimum and maximum operative wave conditions, WEC rated power, conversion system efficiency, power production and prices, must be based on the same reference machine.

Basically, the *reference machine* is the machine about which the user has knowledge.

2.1 Power known as

Power production of the reference machine can be inserted in the form of a power matrix or by providing the performance of the WEC in several standard sea states.

Power known as: Power matrix

Standard sea states
Power matrix

If *power matrix* is selected, the user must fill in the cells of Matrix B (coloured in green): the intervals of H_{m0} and T_{02} in which the power matrix is defined, as well as the power production (in kW) for each sea state.

B

69	Power matrix						
70		kW		Tz (s)	0.0	1.0	2.0
71		Hs (m)			1.0	2.0	3.0
72		from	to		0.5	1.5	2.5
73		0.00	0.50	0.25	0.0	0.0	0.0
74		0.50	1.50	1.00	160.0	250.0	360.0
75		1.50	2.50	2.00	360.0	420.0	540.0
76		2.50	3.50	3.00	640.0	700.0	840.0
77		3.50	4.50	4.00	1170.0	1260.0	1330.0
78		4.50	5.50	5.00		1450.0	1610.0

If *standard sea states* is selected, the user must include the wave absorption efficiency of the WEC in each sea state (according to the laboratory results).

A

		1	2	3	4	5	6	
	Sea states							
	Location	**DK - North Sea, Point 3**						
1	Sea state	1	2	3	4	5	6	total
	Wave abs. eff (%)	48%	40%	31%	22%	15%	2%	
	(Harvested) Power (kW)	170	794	1700	2494	2907	636	
2	Pwave (kW/m)	2.1	11.6	32	65.6	114	187	17
3	Hours (h/y)	4100	1980	946	447	210	93	7776
	Electricity production (MWh/y)	531.8	1202.1	1230.4	852.2	467.5	45.2	**4329**
4	Hm0 (m)	1	2	3	4	5	6	
5	T02 (s)	4	5	6	7	8	9	
	Incident energy along main active	1463.6	3904.1	5146.7	4982.3	4074.5	2956.5	

2.2 Power matrix refers to

This option is only available when power production is given as a power matrix. The user can indicate whether the power matrix corresponds to absorbed power or electrical power:

Power matrix refers to: Absorbed power

Absorbed power
Electrical power

If *absorbed power* is selected, the tool will assume a constant efficiency for the PTO.

2.3 Measurements and performance

Dimension and performance data for the selected reference machine can be entered.

- Scale is initially set to 1 and is only significant in the scaling process where the relative proportion of the machines is critical to the calculated values.
- The main active dimension is the hydrodynamic functional dimension of the WEC.

- The worksheet includes default values for PTO and generator efficiencies. The user can either use these default values or enter their own.

- The user must also include the rated power of the generator. This value is only used if *power known as power matrix* is selected.

- Annual WEC production is calculated based on the WEC performance at the selected location, as well as on the WEC's availability (which takes into account the scheduled and the unforeseen maintenance), its electricity consumption (which covers the annual energy consumption of the SCADA system, vital control and communication equipment, etc) and extra production (if there is another power production source besides the WEC production).

Dimensions and performance

		Default	Enter	**Used**
Scale		1.00		1.00
Main active dimension			170.0	170.00 m
Secondary dimension (length/width)			300.0	300.00 m
Total dry weight			120	120.0 ton
Mooring weight			250	250.0 ton
Minimum operative Hs		1.00		1.00 m
Minimum operative Tz		2.0		2.0 s
Maximum operative Hs		6.00		6.00 m
Maximum operative Tz		9.0		9.0 s
PTO average efficiency	Water	85%		85%
Generator average efficiency		90%		90%
Generator rated power		2471.0		2471.0 kW
WEC's own consumption (annual)		0.0		0.0 MWh/y
WEC's extra electricity production (annual)		0.0		0.0 MWh/y
WEC Availability		100%	85%	85%
Annual electricity production (with 100% availability)				4329 MWh/y

Annual electricity production (with 85% availability)	**3680 MWh/y**

2.4 Uncertainties

The user should be aware that there are uncertainties in the data handled by the COE Calculation Tool (i.e. in the input data, electricity production and in prices) and, therefore, also in the output results. In order to evaluate these uncertainties, the tool provides an estimation of the overall uncertainty related to the calculations.

The uncertainty depends on the development phase of the WEC and on whether the power production data derives from a power matrix or from the performance in the standard sea states.

The user must select one of the five development phases and one of the nine Technology Readiness Levels (TRLs) that define the WEC development stage.

Project lifetime	20 1	1 year
WEC Development phase (1 to 5 phase)	Phase 4: Prototype validation	
WEC Technology Readiness Level (TRL 1 to 9)	TRL 4: Large-scale laboratory verification	
Related uncertainty to COE	-20 to 20%	-20 to 20% uncertainty

2.5 Costs

The COE Calculation Tool evaluates the economics of the reference and the scaled machines at the selected wave climates, based on the costs of each WEC component.

Costs (CapEx and OpEx)		**Currency**	**EUR**		
		Default	Enter	**Used**	Standard values
Engineering and management		0.0		0 €x1000	
Planning and consenting		0.0		0 €x1000	
Development		491.9		**492 €x1000**	3% CapEx
Main material	Concrete	19.2		19 €x1000	200 €/ton
Tons of Concrete		96.0		96.0 ton	
Other material	Steel	81.6		82 €x1000	3400 €/ton
Tons of Steel		24.0		24.0 ton	
Access system and platform		0.0		0 €x1000	
Machine housing		0.0		0 €x1000	
Others		0.0		0 €x1000	
Total structure				**101 €x1000**	
PTO		0.0		0.0 €x1000	
Generator		0.0		0 €x1000	
Power electronics		0.0		0.0 €x1000	
Control & safety system		0.0		0 €x1000	
Others		0.0		0 €x1000	
Total power take-off system		15000.0		**15000 €x1000**	5000 €/kW
Mooring system		75.0		**75 €x1000**	300 €/ton
Pre-assembly and transport		100.0		100 €x1000	100000 €
Installation on site		100.0		100 €x1000	100000 €
Total installation				**200 €x1000**	
Electrical connection		1020		**1020 €x1000**	340 €/kW
Others		0.0		0 €x1000	
Total Capital Expenditures (CapEx) before contingencies				**16888 €x1000**	

Contingencies	10%		10%	
Total CapEx with 10% contingencies	18576		**18576 €x1000**	

Operation & maintenance costs per year	1013.3		1013 €x1000	6% CapEx
Site lease and insurance	337.8		338 €x1000	2% CapEx
Others	0.0		0 €x1000	
Annual Operational Expenditures (OpEx)			**1351 €x1000**	

The worksheet includes default values on the costs of structure materials, the total PTO system, mooring and installation as well as for O&M, site lease and insurance costs. It is, however, recommended that these default values only be used on projects at a very early development stage. After a certain development stage, the user must put in his costs.

3 Scaled machine

The spreadsheet allows for upscaling or downscaling of the reference machine to a new scaled machine, and for evaluating the production of the scaled WEC in different locations while scaling the WEC to the selected location.

The user must introduce a scale factor. This scale indicates the relationship between the main active dimension of the reference machine and the main active dimension of the new scaled machine.

WEC dimensions, equipment, production and costs are upscaled or downscaled according to the scale introduced and following Froude law.

The scaled machine allows for optimizing a machine for a selected wave climate while evaluating the economic feasibility of the project.

Note that:
- Expenses are scaled by volume.
- Reducing the installed power reduces the production and the cost of PTO and generator.

4 Output of the COE Calculation Tool

The output of the tool is an economic assessment of both the reference and the scaled machines at the chosen locations.

The LCOE is calculated for different discount rates as the WEC costs in present value divided by the electricity generation in present value. The total CapEx, OpEx, payback period and NPV are also shown in the output.

Power known as:	Power matrix	
Power matrix refers to:	Electrical power	
	DK - North Sea, Point 3	Pwave: 15,7 kW/m

Capacity factor	43%
Annual electricity production	3750 MWh/y
Average electricity production	428 kW
Average wave-to-wire efficiency	16%

Update and Show graphs

Currency	**EUR**	Development stage: Phase 4 / TRL 4			[-15 to 15%] uncertainty
	FIT-DK (€/MWh)	80.0	600.0		
	Total CAPEX	5.89 M€		**Yearly OPEX**	477.01 k€/y
	Payback period	Greater than project lifetime			
	Discount rate		0%	4%	15.0%
	LCOE (1 years, in €/MWh)		566	586	640
	NPV (1 years, in k€)		-4114.0	-4182.2	-4345.3