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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.

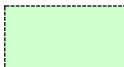


The aims of the COE calculation spreadsheet are as follows:

- 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:

A screenshot of a software interface showing a dropdown menu. The menu is open, displaying two options: 'Standard sea states' and 'Power matrix'. The 'Power matrix' option is highlighted in blue, indicating it is the selected choice.

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.

| Power matrix | | Tz (s) | | 0.0 | 1.0 | 2.0 |
|--------------|------|--------|--------|--------|--------|-----|
| Hs (m) | | 1.0 | | 2.0 | 3.0 | |
| from | to | 0.5 | 1.5 | 2.5 | | |
| 0.00 | 0.50 | 0.25 | 0.0 | 0.0 | 0.0 | |
| 0.50 | 1.50 | 1.00 | 160.0 | 250.0 | 360.0 | |
| 1.50 | 2.50 | 2.00 | 360.0 | 420.0 | 540.0 | |
| 2.50 | 3.50 | 3.00 | 640.0 | 700.0 | 840.0 | |
| 3.50 | 4.50 | 4.00 | 1170.0 | 1260.0 | 1330.0 | |
| 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).

| Sea states | | 1 | 2 | 3 | 4 | 5 | 6 | |
|-----------------------------------|--|-------------------------|--------|--------|--------|--------|--------|-------|
| Location | | DK - North Sea, Point 3 | | | | | | |
| 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 | |
| Pwave (kW/m) | | 2.1 | 11.6 | 32 | 65.6 | 114 | 187 | 17 |
| 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 |
| Hm0 (m) | | 1 | 2 | 3 | 4 | 5 | 6 | |
| 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:

A screenshot of a software interface showing a dropdown menu. The menu is open, displaying two options: 'Absorbed power' and 'Electrical power'. The 'Absorbed power' option is highlighted in blue, indicating it is the selected choice.

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 | | Used | Standard values |
|--|--------------|----------------|---------------------|-----------------|
| | Default | Enter | | |
| 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 refers to:

| | |
|-------------------------|------------------|
| Power matrix | |
| 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 | |