Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment

Deliverable D6.4

System Lifetime Costs tools – Alpha version

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EXECUTIVE SUMMARY

Deliverable D6.4 "System Lifetime Costs Tools – alpha version" of the DTOceanPlus project includes the details of the Assessment Design Tools module: "System Lifetime Costs" (SLC), and it represents the result of the work developed during task T6.5 of the project.

The present document summarises both the functionalities, supporting theory, as well as the more technical aspects of the code implemented for this module. The System Lifetime Costs module will provide the user with a set of metrics and assessments, such as the levelized cost of energy and internal rate of return, relevant to the techno-economic and financial assessments of wave and tidal renewable energy projects at different stages of development. Moreover, a set of complementary metrics have been included, representing the costs of the systems against a set of benchmark values.

The Business Logic of the code, which consist of the actual functions of the SLC module, has been implemented in Python 3. An Application Programming Interface (API) was developed in OpenAPI and provided with the code, in order to interact and communicate with the other modules of the DTOceanPlus design suite. The Graphical User Interface (GUI) of the module will be developed in harmony with the other modules, in Vue.js, allowing the user to interact easily with the SLC tool, inputting data and visualising results. The Business Logic of the code has been fully verified (100%) through the implementation of unit tests, guaranteeing easy maintainability for future developments of the tool.

Supporting theory and assumptions are described, while a section of Examples completes the present document, showcasing the capabilities of the tool.

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ABBREVIATIONS AND ACRONYMS

ACCW	Average Climate Capture Width
ACE	Average Climate Capture Width per Characteristic Capital Expenditure
API	Application Programming Interface
BOM	Bill of Materials
CCE	Characteristic Capital Expenditure
CCF	Cumulative Cash Flow
CD	Characteristic dimension
CL	Level of complexity
DPBP	Discounted Payback Period
DRP	Device Rated Power
EC	Energy Capture
ESA	Environmental and Social Acceptance
ET	Energy Transformation
GUI	Graphic User Interface
HTTP	HyperText Transfer Protocol
IRR	Internal Rate of Return
LCOE	Levelized Cost of Energy
LMO	Logistics and Marine Operations
ND	Number of devices
NPV	Net Present Value
O&M	Operation and Maintenance
PBP	Payback Period
PL	Project Life
RAMS	Reliability, Availability, Maintainability, Survivability
REST	REpresentational State Transfer
SC	Site Characterisation
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs
SPEY	System Performance and Energy Yield
TEA	Techno-economic Assessment
TEC	Tidal Energy Converter
TRL	Technology Readiness Level
TT	Technology Type (Tidal or Wave Energy Device)
WD	Energy Delivery
WEC	Wave Energy Converter
WS	Wetted Surface

1. INTRODUCTION

1.1 SCOPE AND OUTLINE OF THE REPORT

Deliverable D6.4 "System Lifetime Costs Tools – Alpha version" of the DTOceanPlus project includes the details of the Assessment Design Tools module: "System Lifetime Costs" (SLC), and it represents the result of the work developed during task T6.5 of the project.

This document summarises:

1. Supporting theory, definitions and underlying assumptions behind the System Lifetime Costs module (Section 2).
2. The use cases and the functionalities of the System Lifetime Costs module, namely providing the user with a set of metrics and assessments relevant to the techno-economic and financial assessment of the ocean renewable energy projects (Wave and Tidal) at different stages of development. A set of complementary metrics was also included for assessing projects at early stages of development and evaluating against a set of benchmark values (Section 3).
3. The actual implementation of the tool, describing the architecture of the tool, the technologies adopted for the implementation and the results of the testing (Section 4).
4. A set of extensive examples, to provide the reader with an overall view of the capabilities of the module (Section 5).

1.2 SUMMARY OF THE DTOCEANPLUS PROJECT

The System Lifetime Costs module belong to the design suite of tools "DTOceanPlus" [1] developed within the EU-funded project DTOceanPlus (https://www.dtoceanplus.eu/).

DTOceanPlus aims to accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open source suite of design tools for the selection, development, deployment and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays).

At a high level, the suite of tools developed in a modular fashion in DTOceanPlus will include:

- **Structured Innovation Tool† (SI)**, for concept creation, selection, and design.
- **Stage Gate Tool† (SG)**, using metrics to measure, assess and guide technology development.
- **Deployment Tools**, supporting optimal device and array deployment:
  - *Site Characterisation† (SC)*, to characterise the site, including metocean, geotechnical, and environmental conditions.
  - *Energy Capture† (EC)*, to characterise the device at an array level;
  - *Energy Transformation† (ET)*, to design PTO and control solutions;
  - *Energy Delivery† (ED)*, to design electrical and grid connection solutions;
  - *Station Keeping† (SK)*, to design moorings and foundations solutions;
  - *Logistics and Marine Operations† (LMO)*, to design logistical solutions operation plans related to the installation, operation, maintenance, and decommissioning operations.

- **Assessment Tools**, to evaluate projects in terms of key parameters:
  - *System Performance and Energy Yield*† *(SPEY)*, to evaluate projects in terms of energy performance.
  - *System Lifetime Costs*† *(SLC)*, to evaluate projects from the economic perspective
  - *System Reliability, Availability, Maintainability, Survivability*† *(RAMS)*, to evaluate the reliability aspects of a marine renewable energy project.
  - *Environmental and Social Acceptance*† *(ESA)*, to evaluate the environmental and social impacts of a given wave and tidal energy projects.

† denotes individual modules within DTOceanPlus.

These will be supported by underlying common digital models and a global database, as shown graphically in Figure 1.1.

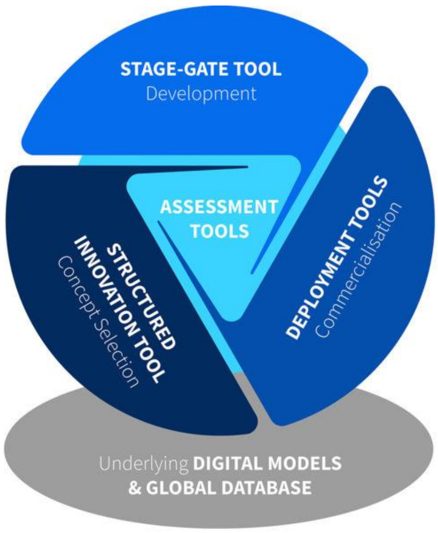

FIGURE 1.1: REPRESENTATION OF DTOCEANPLUS TOOLS

2. THEORY, DEFINITIONS AND ASSUMPTIONS

The System Lifetime Costs module is one of the four assessment modules of the DTOceanPlus design suite of tools. It aims to perform economic and financial assessments of wave and tidal renewable energy projects. Some theoretical definitions are provided below, as well as the base assumptions used in the SLC module.

CURRENCY

The currency used in DTOceanPlus is Euros (€).

DEVICE STRUCTURAL COSTS

Within DTOceanPlus project, device structural costs refer to the cost of materials and fabrication of the structure and prime mover, whereas the costs of the Power Take-Off (PTO) unit(s) are grouped in PTO costs.

CAPITAL EXPENDITURES (CAPEX)

Capital expenditures, commonly known as CAPEX, indicates the total investment cost (in Euros) of a given project. CAPEX is a major driver of the total costs of an ocean renewable energy project. In the context of renewable energy production projects, the CAPEX is frequently expressed in unit costs per installed unit power (i.e. €/kW) [2], which makes possible comparing different technologies in a benchmark analysis.

In the context of DTOceanPlus, it is assumed that the capital expenditures occur at the beginning of the project. Reference values of the CAPEX per kW were obtained from the most recent OES-IEA report [3], for wave energy and tidal stream projects, and presented in Figure 2.1 and Figure 2.2 respectively.

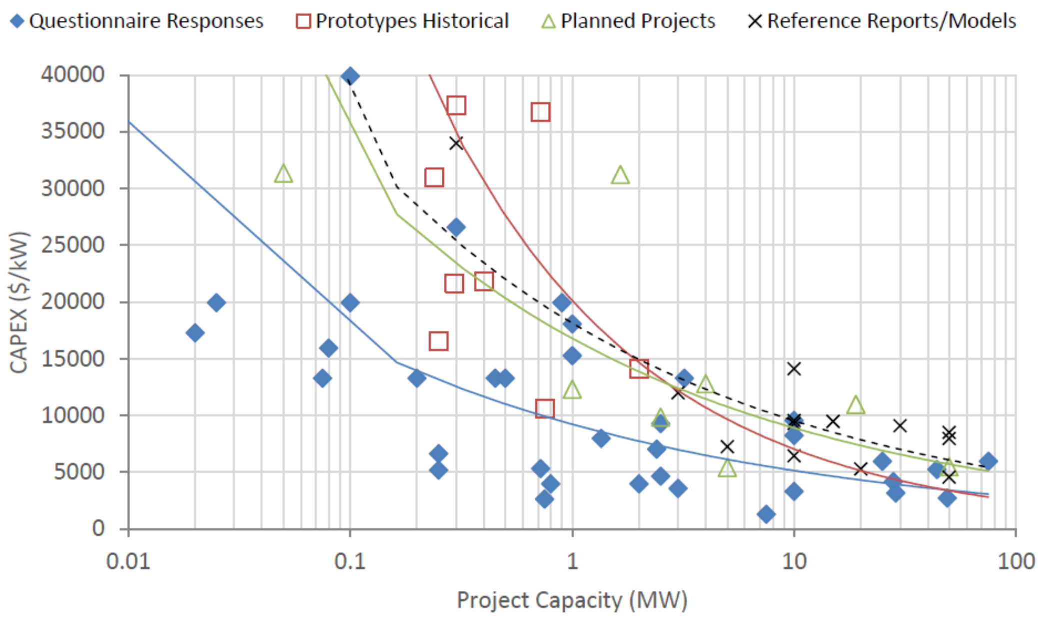

FIGURE 2.1: UNITARY CAPEX VARIATION WITH PROJECT CAPACITY (WAVE)
SOURCE: [3]

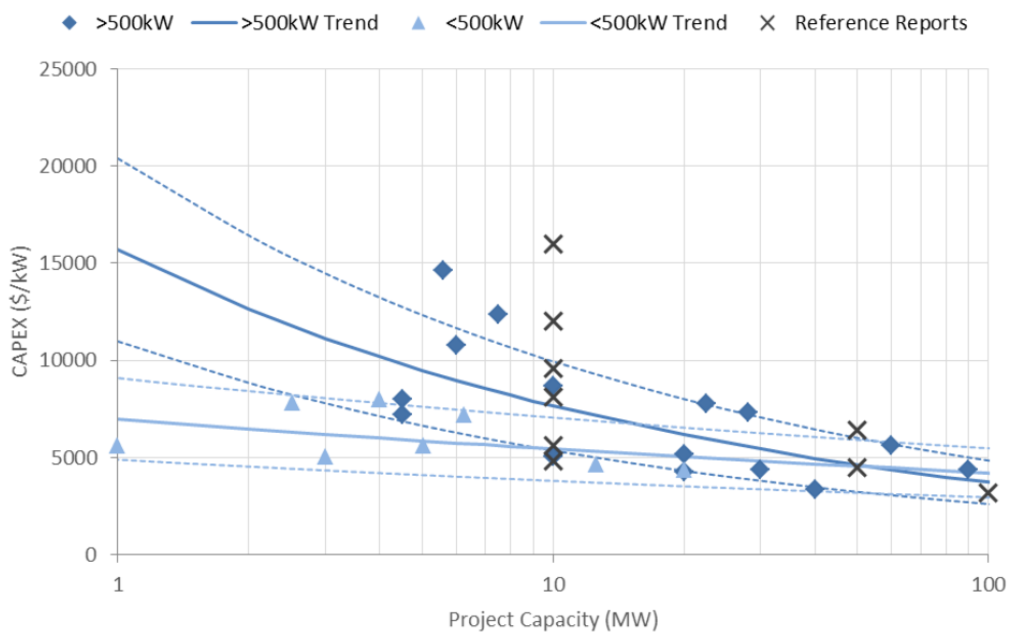

**FIGURE 2.2: UNITARY CAPEX VARIATION WITH PROJECT CAPACITY (TIDAL)
SOURCE: [3]**

OPERATIONAL EXPENDITURES (OPEX)

The operational expenditures (OPEX) of a given project represent the ongoing costs of running the project, e.g. maintenance costs, which are distributed throughout the project lifetime. The OPEX of a renewable energy project can be expressed as the total project OPEX (in Euros), the average annual OPEX (€/year) or in costs per installed unit power per year (i.e. €/(kW year)). Calculating the OPEX in costs per installed power per year, allows comparing projects of different technologies and different sizes in the benchmark analysis.

In Figure 2.3 and Figure 2.4, reference values of the OPEX per kW per year is shown for wave energy and tidal stream projects, respectively.

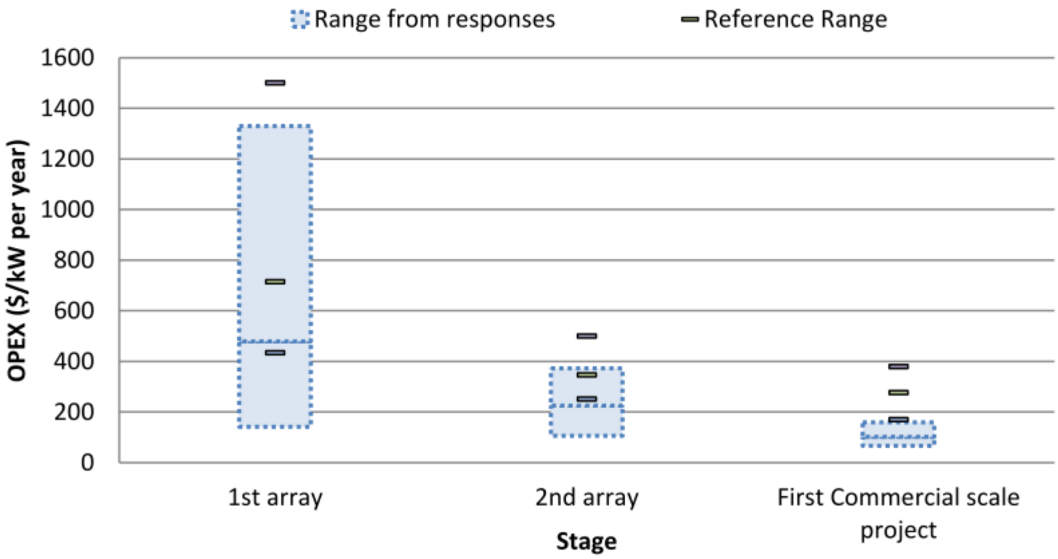

FIGURE 2.3: OPEX COST RANGES FOR WAVE ENERGY PROJECTS AT DIFFERENT STAGES OF DEPLOYMENT.
[NOTE: THE DOTTED LINES REPRESENT THE MAXIMUM/MINIMUM OPEX VALUES PROVIDED FROM THE STAKEHOLDER ENGAGEMENT. THE SHADED AREA IS BASED ON INTERNATIONAL REFERENCE REPORTS AND ANALYSIS]. SOURCE: [3]

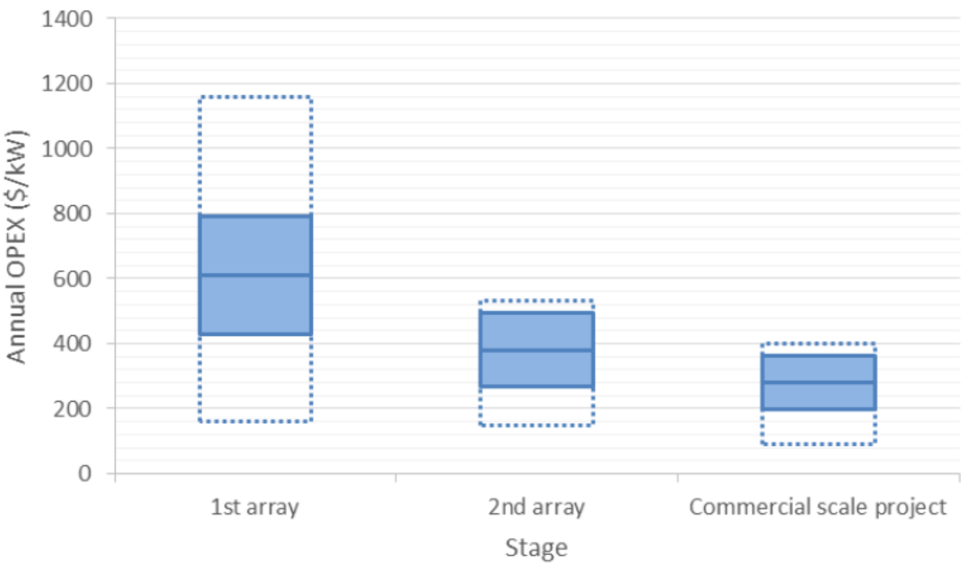

FIGURE 2.4: OPEX COST RANGES FOR TIDAL ENERGY PROJECTS AT DIFFERENT STAGES OF DEPLOYMENT
[NOTE: THE DOTTED LINES REPRESENT THE MAXIMUM/MINIMUM OPEX VALUES PROVIDED FROM THE STAKEHOLDER ENGAGEMENT. THE SOLID LINES WITH SHADED AREA REPRESENT THE INDUSTRY AVERAGED COST WITH AN UNCERTAINTY BOUND OF ±30%]. SOURCE: [3]

LEVELIZED COST OF ENERGY (LCOE)

The levelized cost of energy (LCOE) is a useful parameter to assess the economic feasibility of a technology. It is defined as the sum of all capital costs and lifetime operation and maintenance (O&M) costs (discounted to present value) divided by the value of electricity generation to grid accumulated throughout the technology's lifetime (also discounted to present value). Details of the calculation are given in section 3.2.2 equation (13). The present value of decommissioning costs of tidal and wave energy projects are assumed to have reduced impact on the LCOE of the project (0.5-1% of the CAPEX [4]) and were therefore neglected in the present module [5], [6].

A large share of the LCOE may be attributed to the device CAPEX (both structural and PTO). Estimates of device CAPEX are based on developers' responses as well as on the historical costs of wave energy prototypes published in the OES report. The CAPEX of these prototypes ranged from 7500 €/kW to 40 000 €/kW installed, depending on the technology type and scale (larger scales lead to lower costs per kW). Moreover, the CAPEX of wave and tidal energy projects typically represents 70% and 61% of the overall LCOE, for wave and tidal energy projects, respectively [3], [7]. Finally, the energy production (which can be expressed by capacity factor and availability) is the most critical factor for which there are more differences and uncertainties among developers.

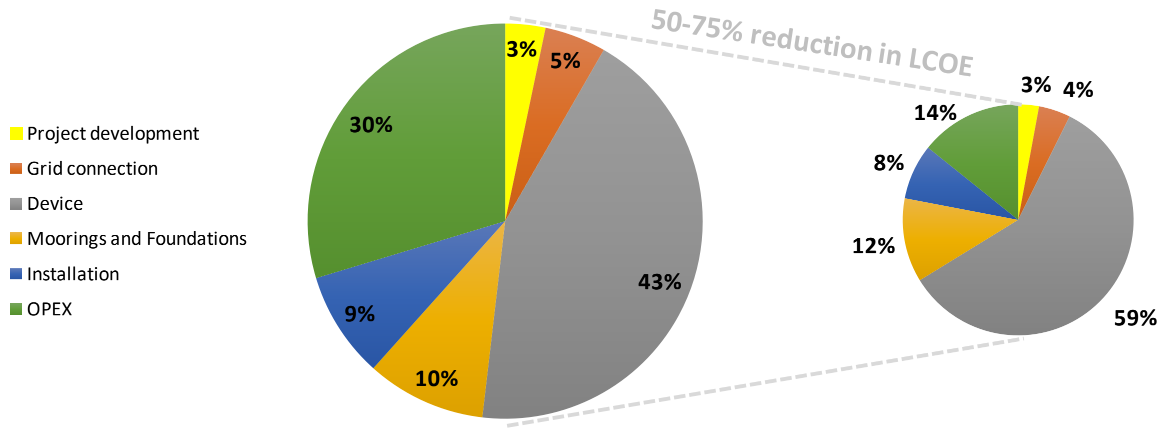

FIGURE 2.5: WAVE LCOE PERCENTAGE BREAKDOWN BY COST CENTRE.
ON THE LEFT, THE CURRENT STAGE OF DEPLOYMENT IS DEPICTED, WHILE ON THE RIGHT THE COMMERCIAL TARGET IS REPRESENTED. SOURCE:[3]

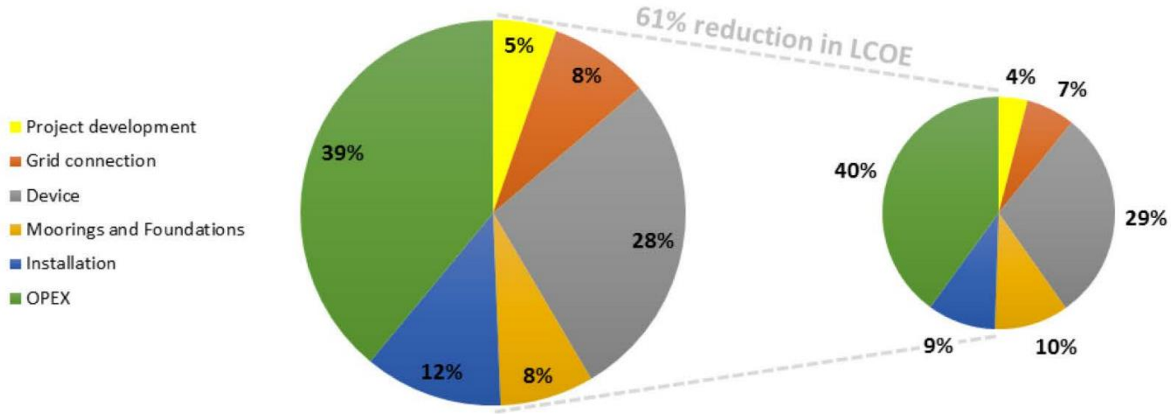

**FIGURE 2.6: TIDAL LCOE PERCENTAGE BREAKDOWN BY COST CENTRE.
ON THE LEFT, THE CURRENT STAGE OF DEPLOYMENT IS DEPICTED, WHILE ON THE RIGHT THE COMMERCIAL TARGET IS REPRESENTED. SOURCE:**[3]

ACE METRIC

For early stages of technology development, it is not always possible to calculate the LCOE. In these cases, cost proxies may be used instead. ACE, short for the ratio of the **A**verage climate capture width (ACCW) to the **C**haracteristic capital **E**xpenditure (CCE), is a benefit-to-cost ratio which can be used to assess the economics of wave and tidal energy systems.

ACE, expressed in meters per Million Euros (m/M€), has been selected as an appropriate metric for comparing low TRL WEC concepts, when there isn't sufficient (reliable) data for calculating the levelized cost of energy for a given device [8]. Under this approach it has been determined that the volume of material, density and material costs track closely to capital costs, which is a major LCOE driver in WEC and TEC technologies today [9]. The relationship between the ACE and the LCOE metric is presented in Figure 2.7 .

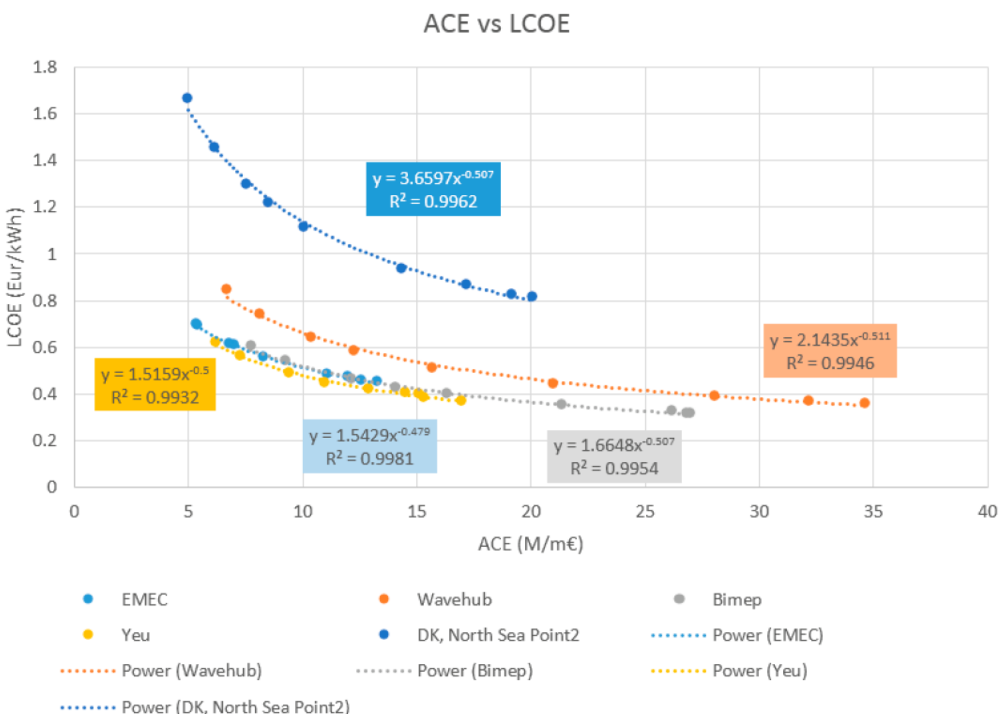

FIGURE 2.7: COMPARISON BETWEEN ACE AND LCOE METRICS FOR WAVE ENERGY CONVERTERS DEPLOYED IN DIFFERENT LOCATIONS.
SOURCE: [10]

OTHER COSTS

Within the SLC module, the user is offered the option of introducing other costs that are not modelled by DTOceanPlus deployment design modules. These include Project Development costs (which typically represent 5-6% of the project LCOE) and Monitoring and Miscellaneous equipment (e.g. sensors, SCADA) which typically also represent about 6% of the project LCOE.

PROJECT LIFETIME

The project lifetime is the project life expectancy, or the target lifetime for the deployed project. Although pilot projects may be designed for shorter lifetimes, offshore renewable energy projects are typically designed for a service lifetime of 20-25 years (there might be differences from project to project, and in different stages of development). For this reason, 20 years is the default project lifetime in SLC, which can be edited by the user.

DISCOUNT RATE

The discount rate refers to the interest rate used when performing a discounted cash flow (DCF) analysis to determine the present value of a future cash flows [11]. A constant discount rate is assumed along the project lifetime. It is used to calculate the LCOE and NPV.

Recent studies related to the discount rates used in marine energy projects range from 7-15%, where the higher rates are applied to less developed technologies, representing higher uncertainty and project risks [2], [5], [10].

PROJECT REVENUES

Within the framework of DTOceanPlus, a marine renewable energy project can generate revenues by selling the produced energy. However, governmental renewable energy grants may also contribute to the financing of strategic projects (in year 0).

Energy delivered to the grid can be either i) subsidized by pre-established Feed in Tariff (FIT) programmes (€/kwh) for a pre-defined number of years, ii) sold through auctions at a fixed price agreed on bilateral contracts, iii) or simply sold in the spot market at market price.

Both FITs and Auctions generally have long-term contracts, usually 15 to 20 years. Within DTOceanPlus, it is assumed that the FIT/Auction value is constant throughout the project lifetime. It is used to calculate the annual revenue, NPV and payback period of the ocean renewable energy project at the selected location [2], [12].

NET PRESENT VALUE (NPV)

For any project which strives towards creating value for the investors or shareholders of a company, the returns must exceed the total costs of the project undertaken by the company. The value of a project is the difference between the revenues generated by the project and the expenses consumed by the project. The Net Present Value (NPV) consists of summing all the expected cash flows throughout the project lifetime discounted to the present using the time value of money [13].

PAYBACK PERIOD

The payback period (PBP) is defined as the point in the project at which the investor gets their investment back (breakeven). It can be calculated by determining when the cumulative cash flow (CFC) reaches zero.

In Figure 2.8, the schematic representation of the cumulative cash flows and project payback period is given. In the figure, A is the last year with negative cumulative cash flow, and C is the first year with positive cumulative cash flow, and B the point where the CFC reaches zero.

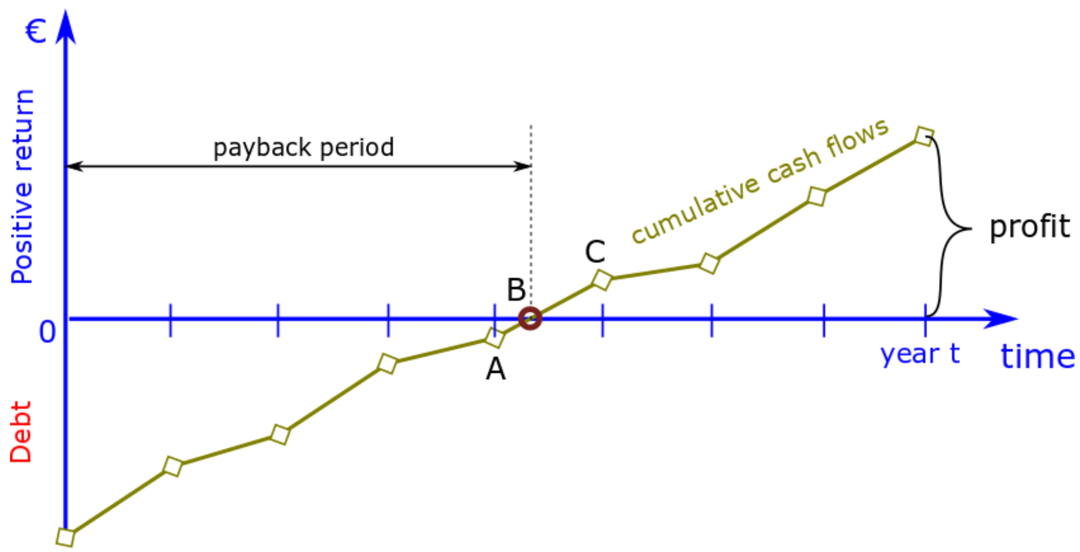

FIGURE 2.8: SCHEMATIC REPRESENTATION OF THE PROJECT PAYBACK PERIOD

DISCOUNTED PAYBACK PERIOD

The discounted payback period (DPBP) is the same as the payback period but taking into consideration the time value of money. The main difference is that the discounted cumulative cash flows are employed instead [13].

3. USE CASES AND FUNCTIONALITIES

The System Lifetime Costs (SLC) module will:

- Produce a complete Bill of Materials, based on the design solutions of previously executed Deployment design modules and introduced user inputs, and show to the user.
- Compute several economic parameters, given the technical design of the ocean energy farm and the power production of the array, and facilitate the visualisation of the outputs to the user.
  - Estimate economical parameters such as total project CAPEX and OPEX, average OPEX per year, CAPEX and OPEX per kW per year for the three complexity levels.
  - The ACE metric (Average Climate Capture Width per Characteristic Capital Expenditure) is provided as an optional cost proxy metric for assessing technologies at early stages.
  - For more advanced stages (high TRLs), calculate the Levelized Cost of Energy (LCOE) of the total project, taking into consideration the solutions of the design modules and user inputs as well as the expected energy production accounting for the downtime of the devices calculated using SPEY's methods [14].
- Estimate financial parameters of the project, namely Net Present Value (NPV), Internal Rate of Return (IRR), Payback Time (PBT) and Discounted Payback Time (DPBT) to assess financial attractiveness of the project.
- Benchmark economical and financial characteristics of the project against reference values available in the literature.

3.1 THE USE CASES

In Deliverable D6.1 [15], the Technical requirements of the SLC module were presented, and the use cases were listed for the different types of users. In this section, the use cases are described from an operational perspective, in respect to what the user decides to do and which modules to run. A Generic use case can thus be generally summarised as shown in Figure 3.1.

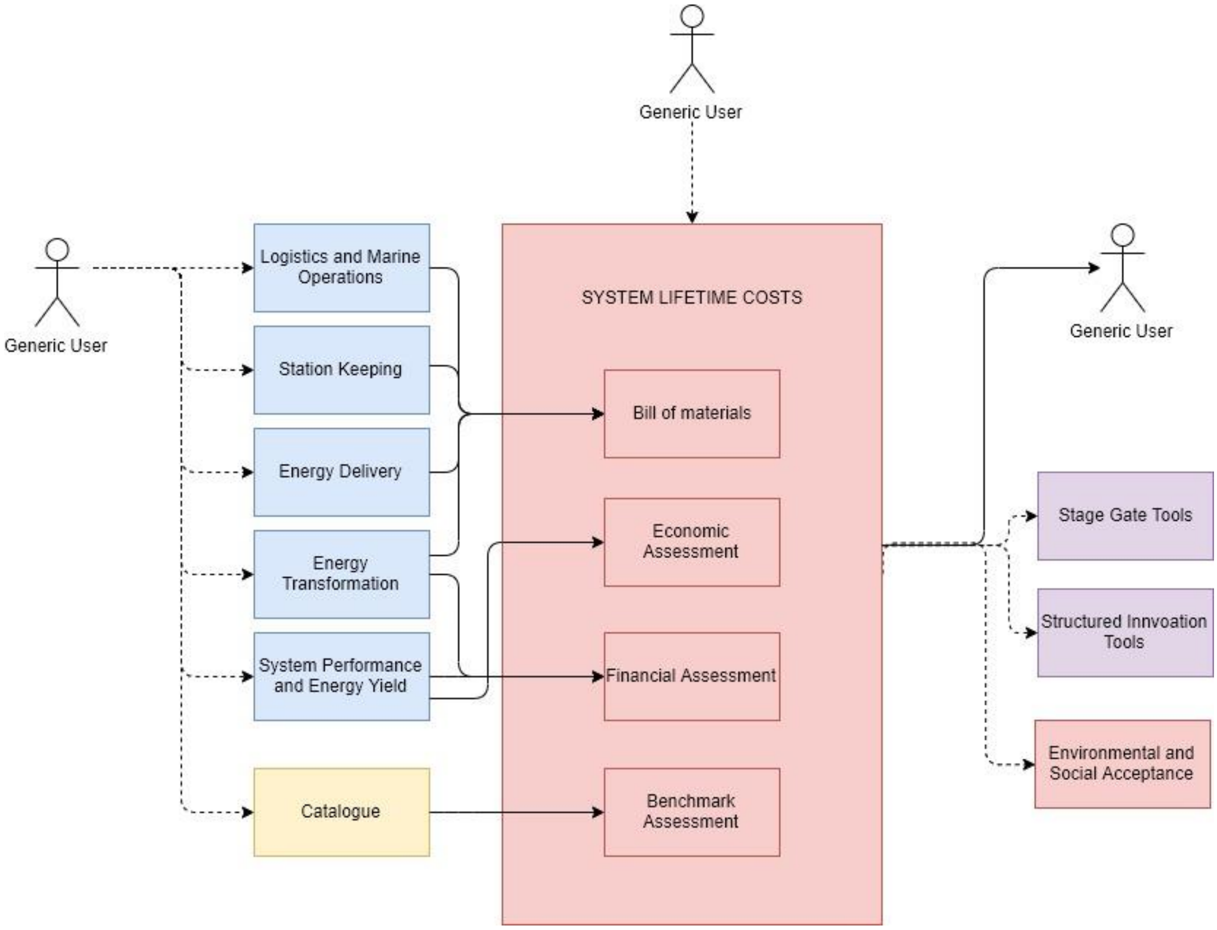

FIGURE 3.1: GENERIC USE CASE FOR USING THE SYSTEM LIFETIME COSTS TOOLS

In this generic use case, the user will be able to:

1) Run SLC within the framework of the Stage Gate (SG) or Structured Innovation (SI) Design tools.
2) Run SLC after running the set of Deployment Design tools of DTOceanPlus.
3) Use in standalone mode.

By considering the three Use cases above mentioned, Table 3.1 summarises the dependencies of SLC from/to other modules in DTOceanPlus.

TABLE 3.1: DEPENDENCIES OF SLC FROM/TO OTHER MODULES IN DTOCEANPLUS

Modules that provide services that SLC consumes	Modules that are consuming services from SLC
Energy Capture (EC)	ESA
Energy Transformation (ET)	SG
Energy Delivery (ED)	SI
Station Keeping (SK)	
Logistics & Marine Operations (LMO)	

3.1.1 USE CASE WITHIN THE FRAMEWORK OF SG/SI DESIGN TOOLS

In this case, the SLC tool will be run within the framework of the Stage Gate or Structured Innovation Design tools, as seen in Figure 3.2. The following steps are identified for this use case:

1) The user runs the framework of the SI/SG Tools.
2) The SLC module will check if the needed information is available (from other modules) and in case it is not, it will request the user to input the information.
3) The user will complement the information and run the SLC Tool.
4) SLC will be run and perform the assessments.
5) SLC will provide the assessments to SI/SG Tools to complete their framework.
6) The SI/SG Tools will show the outcome to the user.

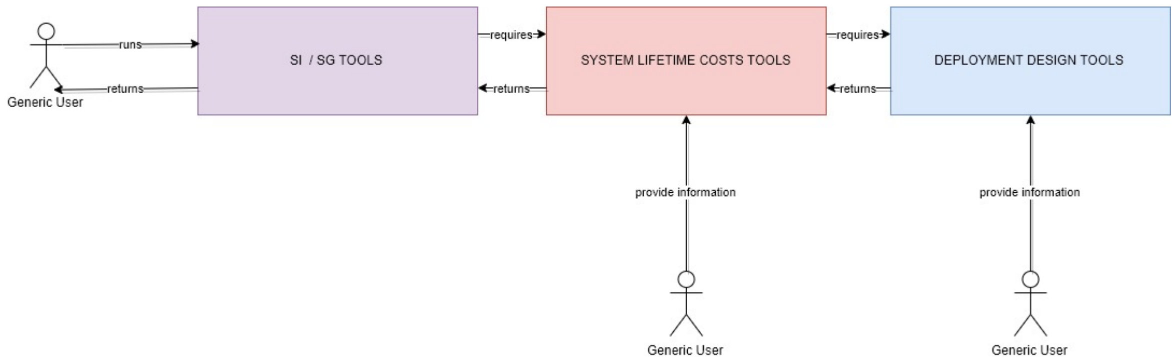

FIGURE 3.2: USE CASE FOR USING THE SYSTEM LIFETIME COSTS TOOLS WITHIN THE FRAMEWORK OF SG/SI DESIGN TOOLS.

3.1.2 USE CASE AFTER DEPLOYMENT DESIGN TOOLS

In this case, the user will run one or more Deployment Design Tools and then he/she will run the SLC module to carry out the economic and financial assessments. The numerical results as well as the graphs/diagrams will be shown to the user.

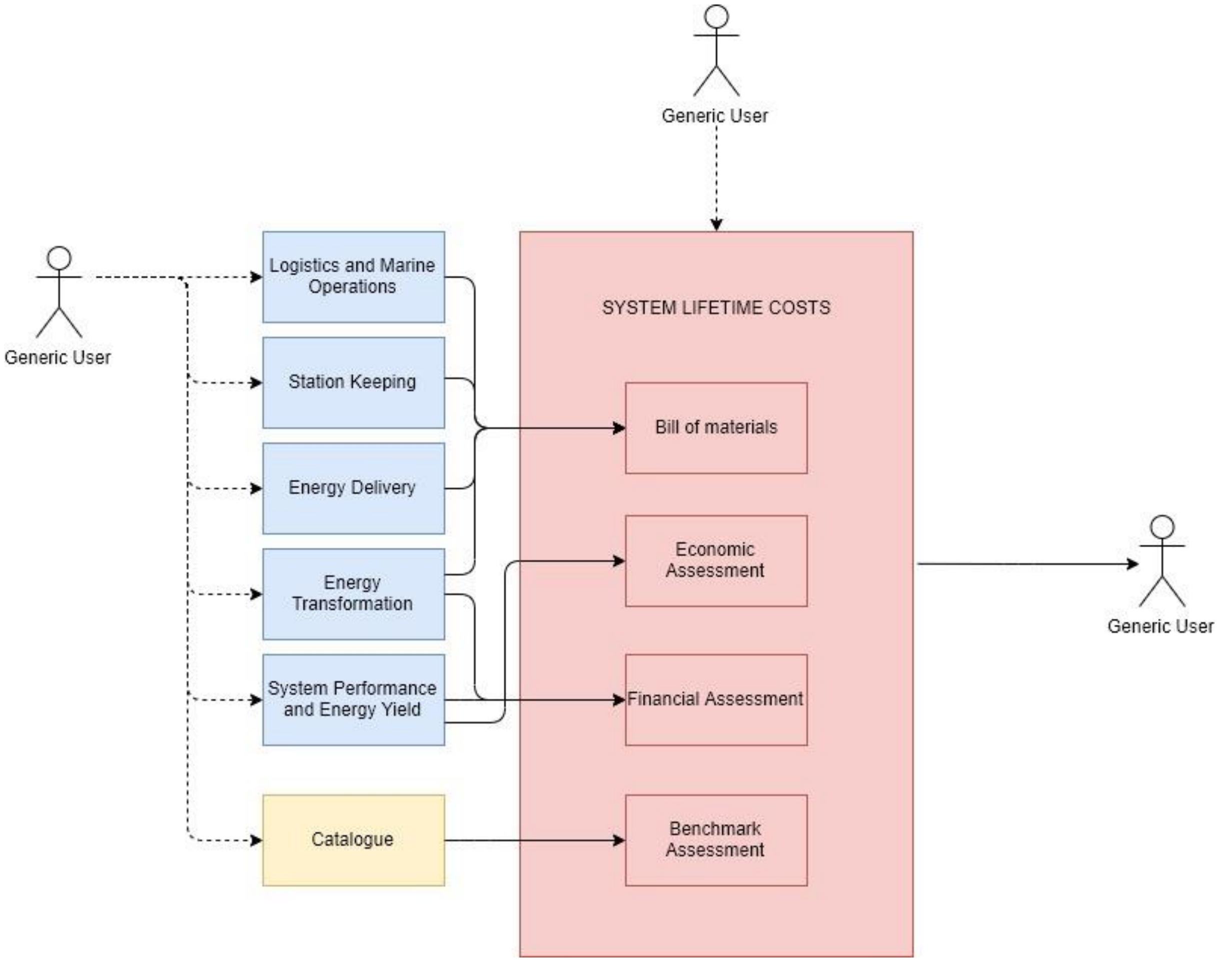

FIGURE 3.3: USE CASE FOR USING THE SYSTEM LIFETIME COSTS TOOLS AFTER RUNNING THE DEPLOYMENT DESIGN TOOLS.

3.1.3 STANDALONE MODE

In this case, the user only wants to run the SLC module in order obtain assessments in respect to the economic and financial performances of the project. In this case, the user will be required to provide every input and will be presented with the overall results of the assessment.

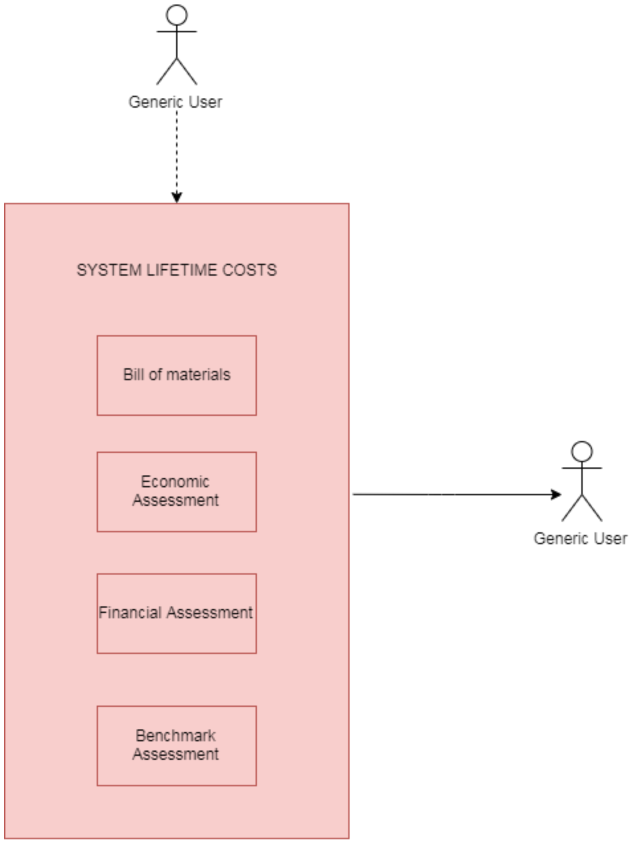

FIGURE 3.4: USE CASE FOR USING THE SYSTEM LIFETIME COSTS TOOLS IN STANDALONE MODE.

3.2 THE FUNCTIONALITIES

The System Lifetime Costs module has four major functionalities:

1) **Bill of materials compilation:** by collecting the list of equipment designed by each module, as well as user specifications, this functionality compiles everything in a bill of materials of the project.
2) **Economic assessment**: consists of the calculation of metrics related to the economics of the marine renewable energy project, which allow assessing economic sustainability and comparison with other energy generation technologies.
3) **Financial assessment**: consists of the calculation of metrics related to the financial aspect of the marine renewable energy projects allowing to assess project profitability from the investment point of view.
4) **Benchmark assessment:** Calculation of suitable metrics for comparing the economic and financial results, as well as cost breakdowns of major subsystems against reference values available in the literature.

The System Lifetime Costs module was designed to support the assessment of technologies and projects at different stages of technology development. However, at different stages of the technology development process, the amount of available information and data changes. In DTOceanPlus, the method used by each module will change to align with this detail. Given that for low TRLs, data availability is limited and uncertainty is high, the SLC module was implemented with three different levels of complexity and slightly different modes of operation. At early stages, little data is available, so the methods were designed to be simple and require minimum inputs. At later stages, more detail is available so the methods used can become more complex. This allowed to deliver meaningful metrics at each stage of development, while avoiding metrics which would require an excessive amount of information from the user too early in the project.

In Table 3.2, the different functionalities of the SLC module are described for the different levels of complexity. While for complexity levels 2 and 3 (Cpx2 and Cpx3), the user can run all the functionalities of the SLC module, for Cpx1 level, some functionalities are limited (Economic and Benchmark) or simply not available (Benchmark). However, in case of limited functionality, proxy metrics such as ACE (Economic assessment) can be calculated instead.

TABLE 3.2: DIFFERENT MODULE FUNCTIONALITIES FOR DIFFERENT LEVELS OF COMPLEXITY.

	BOM compiler	Economic	Financial	Benchmark
Cpx1		no LCOE		no LCOE breakdown
Cpx2				
Cpx3				

Full functionality	
Limited functionality	
No functionality	

For consistency purposes, in the following sections, the names of the parameters will follow as much as practically possible the notation used for the variables in the code.

3.2.1 BILL OF MATERIALS COMPILER

3.2.1.1 OBJECTIVES

The bill of materials (BOM) is the extensive list of the components and installation operations, required to construct the ocean energy farm considered in the project simulation. In DTOceanPlus, the System Lifetime Cost module will collect four different bills of materials produced by each relevant Deployment design module, and project information such as number of devices and device costs from EC module, and compile everything in a final BOM.

Given that the bills of materials produced by each module will have different levels of detail for the different complexity levels, the SLC module will always read the lumped costs per category.

- Output of the ET module: *bom_et*
- Output of the ED module: *bom_ed*
- Output of the SK module: *bom_sk*
- Output of the LMO module: *bom_lmo*

3.2.1.2 INPUTS, MODELS AND OUTPUTS

INPUTS

TABLE 3.3: INPUT TABLE FOR THE BILL OF MATERIALS COMPILING FUNCTIONALITY

ID	Brief Description of the Input Quantity	Origin of the Data	Data Model in SLC	Units
bom_et	Bill of materials from ET	ET	Pandas	-
bom_ed	Bill of materials from ED	ED	Pandas	-
bom_sk	Bill of materials from SK	SK	Pandas	-
bom_lmo	Bill of materials from LMO, featuring installation operations and costs	LMO	Pandas	-
$device\_topology$	Topology of the device	User	String	-
$number\_of\_devices$	Number of devices	EC	Integer	-
$device\_cost$	Cost of a single device	EC	Float	€
$other\_costs$	Other costs, including project development.	User	Float	€

OUTPUTS

$$bom\_compiled = [bom\_et, bom\_ed, bom\_sk, bom\_lmo, number\_of\_devices, device\_cost, other\_costs] \quad (1)$$

$$costs\_of\_equipment = \sum Cost_{bom\_et} + \sum Cost_{bom\_ed} + \sum Cost_{bom\_sk} + device\_cost \times number\_of\_devices \quad (2)$$

$$cost\_of\_installation = \sum bom\_lmo[Costs] \quad (3)$$

$$cost\_other = other\_costs \quad (4)$$

3.2.2 ECONOMIC ASSESSMENT

3.2.2.1 OBJECTIVES

Performing a techno-economic assessment (TEA) is a fundamental step in any engineering project which requires an economic return. In the case of electricity production, TEA frequently uses the levelized cost of energy (LCOE) as the main indicator for benchmarking and assessment as it is understood both by developers and investors. The levelized cost of energy expresses the real cost of the energy production technology throughout project lifetime, taking into consideration the value of time (using the discount rate). However, for early stages of technology development, proxy metrics may be used instead.

3.2.2.2 INPUTS, MODELS AND OUTPUTS

INPUTS

TABLE 3.4: INPUT TABLE FOR THE ECONOMIC ASSESSMENT FUNCTIONALITY

ID	Brief Description of the Input Quantity	Origin of the Data	Data Model in SLC	Units
$complexity$	Level of complexity	User/SG	Number, integer	-
$proj\_life$	Project Life	LMO/User	Number, Integer	years
$disc\_rate$	Discount rate	User	Number, Float	%
$array\_avr\_energy\_prod$	Array average energy production Years	SPEY	Array of floats	kWh
$bom\_compiled$	Aggregated Bill of Materials	SLC	Pandas	-
$cost\_of\_equipment$	Total cost of installed equipment	SLC	Number, Float	€
$cost\_of\_installation$	Total cost of logistic phase "Installation"	SLC	Number, Float	€
$cost\_other$	Other costs, including project development.	User	Number, Float	€
$maintenance\_solution$	Solution with all maintenance operations carried throughout project lifetime, including costs	LMO	Pandas	-
$device\_surface$	Total surface area of a device	User	Number, Float	m^2
$accw$	Average climate capture width	SPEY	Number, Float	Kw/m
$device\_thick$	Structural thickness of the device	User	Number, Integer	m
mat_dens	Density of the main material	User	Number, Float	kg/m^3
mat_cost	Cost of material per kg	User	Number, Float	€/kg

OUTPUTS

- **TOTAL CAPEX**

The total project CAPEX can be calculated as follows. It is assumed that the CAPEX expenses are made at the beginning of the project.

$$capex\_total = cost\_of\_equipment + cost\_of\_installation + other\_costs \quad (5)$$

- **CAPEX SUMMARY TABLE**

A short table summarizing the capital expenditures of the project. In short, it is a pandas DataFrame with the following information: operation ID, year of the project when this investment took place (in DTOceanPlus it is always assumed CAPEX occurs in year 0), the total cost of this operation and the category of the operation for LCOE breakdown purposes. It is used to generate a final pandas DataFrame called $expenses\_overall$.

$$capex\_table = bom[ID, Proj\_year, Total\_cost, Category] \tag{6}$$

TOTAL OPEX

The total OPEX costs of the entire project lifetime can be calculated as:

$$opex\_total = \sum_{i=1}^{N_{maint.op.}} maintenance\_costs(i) \tag{7}$$

OPEX SUMMARY TABLE

A short table summarizing the operation expenditures of the project. In short, it is a pandas DataFrame with the following information: operation ID, year of the project when this operation took place, the total cost of this operation and the category of the operation. As the $capex\_table$, it will also be part of the $expenses\_overall$ variable.

$$opex\_table = maintenance\_solution[ID, Proj\_year, Total\_cost, Category] \tag{8}$$

YEARLY OPEX COSTS

The yearly OPEX costs can be calculated by summing all the maintenance costs of each year.

$$opex\_year(t) = \sum_{i=1}^{N_{maint\_op}(t)} maintenance\_costs(i) \tag{9}$$

AVERAGE OPEX PER YEAR

The average OPEX costs per year are calculated using the equation below:

$$opex\_per\_year = \frac{opex\_total}{proj\_life} \tag{10}$$

EXPENSES OVERALL

The overall expenses can be compiled in a single variable by using a simple concatenation between CAPEX summary table and OPEX summary table. It will be an input for Financial metrics to calculate the cash flows.

$$expenses\_overall = [capex\_table, opex\_table] \tag{11}$$

DISCOUNTED COSTS:

The discounted total costs of the project can be calculated as:

$$disc\_costs = capex\_total + \sum_{t=1}^{proj\_life} \frac{opex\_year(t)}{(1 + disc\_rate)^t} \quad (12)$$

- **LCOE**

The LCOE is being calculated as described in the equation below. It must be noted that the LCOE in the formula below does not include decommissioning costs (see Section 2).

$$lcoe = \frac{capex\_total + \sum_{t=1}^{proj\_life} \frac{opex\_year(t)}{(1 + disc\_rate)^t}}{\sum_{t=1}^{proj\_life} \frac{array\_avr\_energy\_prod(t)}{(1 + disc\_rate)^t}} \quad (13)$$

- **ACE**

In order to calculate the ACE metric, a cost proxy metric which comes as an alternative to LCOE for low TRL technologies, one must calculate the Characteristic Capital Expenditure (CCE) using the equation below.

$$CCE = device\_surface * device\_thick * mat\_dens * mat\_cost \quad (14)$$

Taking into consideration the Average Climate Capture Width (*accw*) output by SPEY (or introduced by the user if SPEY hasn't been run), the ACE metric (*ace*) can be calculated as follows:

$$ace = \frac{accw}{CCE} \quad (15)$$

3.2.3 FINANCIAL ASSESSMENT

3.2.3.1 OBJECTIVES

Financial evaluations are carried out from the perspective of the investor, considering the cash flows generated by the project. The purpose of financial evaluation is to assess the ability of the project to generate adequate incremental cash flows to recover its financial costs (capital and recurrent costs) and assess project profitability.

3.2.3.2 INPUTS, MODELS AND OUTPUTS

INPUTS

TABLE 3.5: INPUT TABLE FOR THE FINANCIAL ASSESSMENT FUNCTIONALITY

ID	Brief Description of the Input Quantity	Origin of the Data	Data Model in SLC	Units
$complexity$	Level of complexity	User/SG	Number, integer	-
$proj\_life$	Project Life	User	Number, Integer	years
$disc\_rate$	Discount rate	User	Number, Float	%
$array\_avr\_energy\_prod$	Array average Energy Production Years	SPEY	Array of floats	kWh
$financial\_grant$	If a grant is awarded as an investment	User	Boolean	-
$financial\_fit$	If a Feed-In-Tariff or Auction are considered	User	Boolean	-
$grant\_value$	Grant value	User	Integer, Float	€
fit_value	Feed-In-Tariff/Auction value of the project	User	Number, Float	€
fit_years	Number of years of Feed-In-Tariff/Auction contract	User	Number, Float	Years
$market\_price$	Energy market price	User	Number, Float	€/kWh
$expenses\_overall$	Overall expenses of the project (CAPEX and OPEX)	SLC	Pandas DataFrame	-

AUXILIARY METRICS

- **CASH FLOWS (CF)**

To calculate the cash flows ($cash\_flows$), first one must calculate the price of electricity for each year ($price\_elect\_year$). The price of electricity may be imposed by the market price, or by the feed-in-tariff (fit_value) and number of years of FIT (fit_years). For year t, the $price\_elect\_year$ can be calculated as:

$$price\_elect\_year(t) = \begin{cases} market\_price, & if\ t > fit\_years \\ fit\_value, & if\ t \leq fit\_years \end{cases} \quad (16)$$

The project revenues and expenses can be calculated in Euros, respectively. For the cases where the project receives or not grant funding, the revenues of year t can be calculated as:

$$revenues(t = 0) = \begin{cases} grant\_value, & if\ \ financial\_grant = TRUE \\ 0 \quad , & if\ financial\_grant = FALSE \end{cases} \quad (17)$$

$$revenues(t) = array\_avr\_energy\_prod(t) * price\_elect\_year(t), \quad for \quad t > 0 \quad (18)$$

While the expenses incurred during year t can be defined as:

$$expenses(t) = \sum_{t=0}^{proj\_life} expenses\_overall_t[Total\_cost] \quad (19)$$

where $revenues(t)$ and $expenses(t)$ are arrays.

Finally, the cash flow ($cash\_flow$) of year t can be calculated as the difference between the revenues due to energy production and the expenses due to equipment purchase, installation or maintenance.

$$cash\_flow(t) = revenues(t) - expenses(t) \quad (20)$$

OUTPUTS

NET PRESENT VALUE (NPV)

For any project which strives towards creating value for the investors or shareholders of a company, the returns must exceed the total costs of the project undertaken by the company. The value of a project is the difference between the revenues generated by the project and the expenses consumed by the project. The Net Present Value (NPV) consists of summing all the expected cash flows throughout the project lifetime discounted to the present using the time value of money [13].

The expression for calculating the NPV is the one below:

$$npv = \sum_{t=0}^{proj\_year} \frac{cash\_flow(t)}{(1 + disc\_rate)^t} \quad (21)$$

However, in the SLC module, the NPV was calculated using a NumPy Python method, `numpy.npv`, which has as inputs, the discount rate ($disc\_rate$) and the array of cash flows ($cash\_flow$) for the whole project life.

$$npv = numpy.npv(disc\_rate, cash\_flow) \quad (22)$$

INTERNAL RATE OF RETURN (IRR)

The internal rate of return (IRR) is a metric used to assess the profitability of potential investments. The internal rate of return consists of the discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. IRR calculations rely on the same formula as NPV does[13].

In the SLC module, the IRR was calculated using `numpy.irr`, a NumPy Python method. This method only requires as inputs the yearly cash flows.

$$irr = numpy.irr(cash\_flow) \quad (23)$$

PAYBACK PERIOD

The payback period (pbp) can be calculated as:

$$pbp = year[A] + \frac{CCF[A]}{CCF[C] - CCF[A]}, \tag{24}$$

where A is the last year with negative cumulative cash flow (CCF), and C is the first year with positive cumulative cash flow.

DISCOUNTED PAYBACK PERIOD

The discounted payback period ($dpbp$) is the same as the payback period but taking into consideration the time value of money. The main difference is that the discounted cumulative cash flows ($dCCF$) are employed [13].

$$dpbp = year[A] + \frac{dCCF[A]}{dCCF[C] - dCCF[A]}, \tag{25}$$

3.2.4 BENCHMARK ANALYSIS

3.2.4.1 OBJECTIVES

The objective of a benchmark analysis is to compare economic and financial results of the project against reference values for wave and tidal renewable energy projects. The metrics used for the benchmark analysis depends on the availability of reference data.

3.2.4.2 INPUTS, MODELS AND OUTPUTS

INPUTS

TABLE 3.6: INPUT TABLE FOR THE BENCHMARK ANALYSIS FUNCTIONALITY

ID	Brief Description of the Input Quantity	Origin of the Data	Data Model in SLC	Units
$proj\_life$	Project Lifetime	LMO/User	Number, Int	years
$bom\_compiled$	Aggregated Bill of Materials	SLC	Pandas	-
$capex\_total$	Total Capital Expenses of the project	SLC	Number, Float	€
$opex\_total$	Total Operation Expenses of the project	SLC	Number, Float	€
$disc\_costs$	Discounted total costs of the project	SLC	Number, Float	€
$device\_power$	Rated power of each device	EC/User	Number, Float	kW
$number\_of\_devices$	Total number of devices in the array	EC/User	Number, Integer	-

OUTPUTS

CAPEX PER KW

By using the CAPEX per unit power, it is possible to compare different technologies in a benchmark analysis. The CAPEX per kW can be calculated as follows:

$$capex\_per\_kw = \frac{total\_capex}{number\_of\_devices \times device\_power} \quad (26)$$

OPEX PER KW PER YEAR

The OPEX per kW per year can be calculated as follows:

$$opex\_per\_kw\_per\_year = \frac{total\_opex}{number\_of\_devices \times device\_power \times proj\_life,} \quad (27)$$

LCOE BREAKDOWN

The following LCOE breakdowns can be calculated using the total project costs discounted to the present value.

- PERCENTUAL CONTRIBUTION OF OTHER COSTS SUCH AS TO PROJECT LCOE

$$other\_costs\_over\_lcoe = \frac{other\_costs}{disc\_costs} \quad (28)$$

- PERCENTUAL CONTRIBUTION OF GRID CONNECTION COSTS TO PROJECT LCOE

$$grid\_costs\_over\_lcoe = \frac{grid\_costs}{disc\_costs} \quad (29)$$

- PERCENTUAL CONTRIBUTION OF DEVICE COSTS TO PROJECT LCOE

$$device\_costs\_over\_lcoe = \frac{device\_costs}{disc\_costs} \quad (30)$$

- PERCENTUAL CONTRIBUTION OF MOORINGS AND FOUNDATION COSTS TO PROJECT LCOE

$$moor\_found\_costs\_over\_lcoe = \frac{moor\_found\_costs}{disc\_costs} \quad (31)$$

- PERCENTUAL CONTRIBUTION OF INSTALLATION COSTS TO PROJECT LCOE

$$installation\_costs\_over\_lcoe = \frac{installation\_costs}{disc\_costs} \quad (32)$$

- PERCENTUAL CONTRIBUTION OF OPEX COSTS TO PROJECT LCOE

$$OPEX\_over\_lcoe = \frac{total\_opex}{disc\_costs} \quad (33)$$

4. THE IMPLEMENTATION

4.1 THE ARCHITECTURE OF THE TOOL

Each module of the DTOceanPlus suite of design tools was organized in three layers:

- The Business Logic, including a set of modules, classes, libraries implementing all the functionalities of the modules
- The Application Programming Interface (API) that will constitute the gate of the module to the other modules. SLC module will mainly consume services from design modules and provide metrics for SG, SI and ESA.
- The Graphic User Interface (GUI) which provides the means for interacting with the user, in respect to collecting inputs from the users and displaying results, besides exporting/importing data to/from files.

4.1.1 BUSINESS LOGIC

The architecture of the Business Logic of SLC was organized in a similar manner as the functionalities described in Section 3.2. Before the three main classes are executed, a core function is run to compile all the BOMs from the Deployment design modules. This core function is called:

- Core.bom_compiler (see Figure 4.1)

Three main classes were then defined, one for each functionality:

- Economic (see Figure 4.2)
- Financial (see Figure 4.3)
- Benchmark (see Figure 4.4)

As shown in the figures, each class has the method related to each complexity level (cpx1, cpx2, cpx3). These classes will have the same number of the mother class, adding the suffix "1", "2" or "3", according to the level of complexity (1-low; 2-medium; 3-high).

At the time of writing, some modules are expected to add a fourth level of complexity. In the case of the System Lifetime Costs module, this is was found unnecessary. However, if needed, the operation of adding a new complexity level to the current coding structure will be a simple procedure.

Some metrics, such as the LCOE, will only be calculated at the second and third complexity levels. Similarly, metrics from the Financial class will not be computed at the first stage. However, for maintainability purposes, the overall structure with three levels of complexity was fixed and the subclass "Financial1" was kept, even though it is empty.

Each class has several methods, each of them computing different quantities.

- Function BOM Compiler (see Figure 4.1)
  - A core function that shall run before the other functionalities.

- It will compile all the of bill of materials from the ET, ED, SK and LMO modules, as well as user inputs related to type of device, device costs and number of devices in order to produce a final bill of materials.

- Class Economic (see Figure 4.2)
  - *capex_compiler()*, for estimating quantities in Eq.(5) and (6) and
  - *opex_compiler()*, for estimating quantities in Eq. (7), (8), (9), and (10)
  - *cost_compiler()*, for estimating quantities in Eq. (11)
  - *lcoe_compiler()*, (only for Economic2 and Economic3), for estimating quantities in Eq. (13)
  - *ace_compiler()*, for estimating quantity in Eq.(14) and (15).

- Class Financial (see Figure 4.3)
  - *cashflows_compiler()*, for estimating metric in Eq. (16), (17), (18), (19) and (20).
  - *net_present_value()*, for estimating quantity in Eq. (21).
  - *internal_rate_return()*, for estimating quantities in Eq. (23)
  - *payback_period(disc_pbp)*, for estimating quantities in Eq. (24) and in Eq. (25)

- Class Benchmark (see Figure 4.4)
  - *Calculate_metrics*, for estimating quantities in Eq. (26), (27), (28), (29), (30), (31), (32) and (33)
  - *Compare_cost_breakdowns*, for comparing metrics with reference benchmarks.

Besides these individual metrics, every class has metrics to print, check and convert inputs:

- *get_inputs()*
- *print_inputs()*
- *convert_check_inputs()*

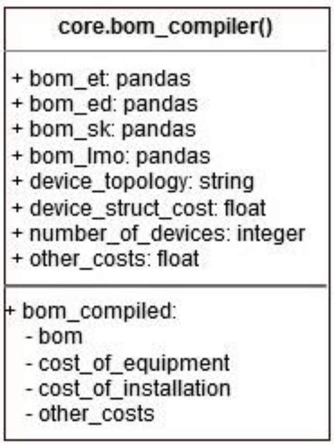

FIGURE 4.1: THE BOM CORE FUNCTION FOR THE THREE LEVELS OF COMPLEXITY

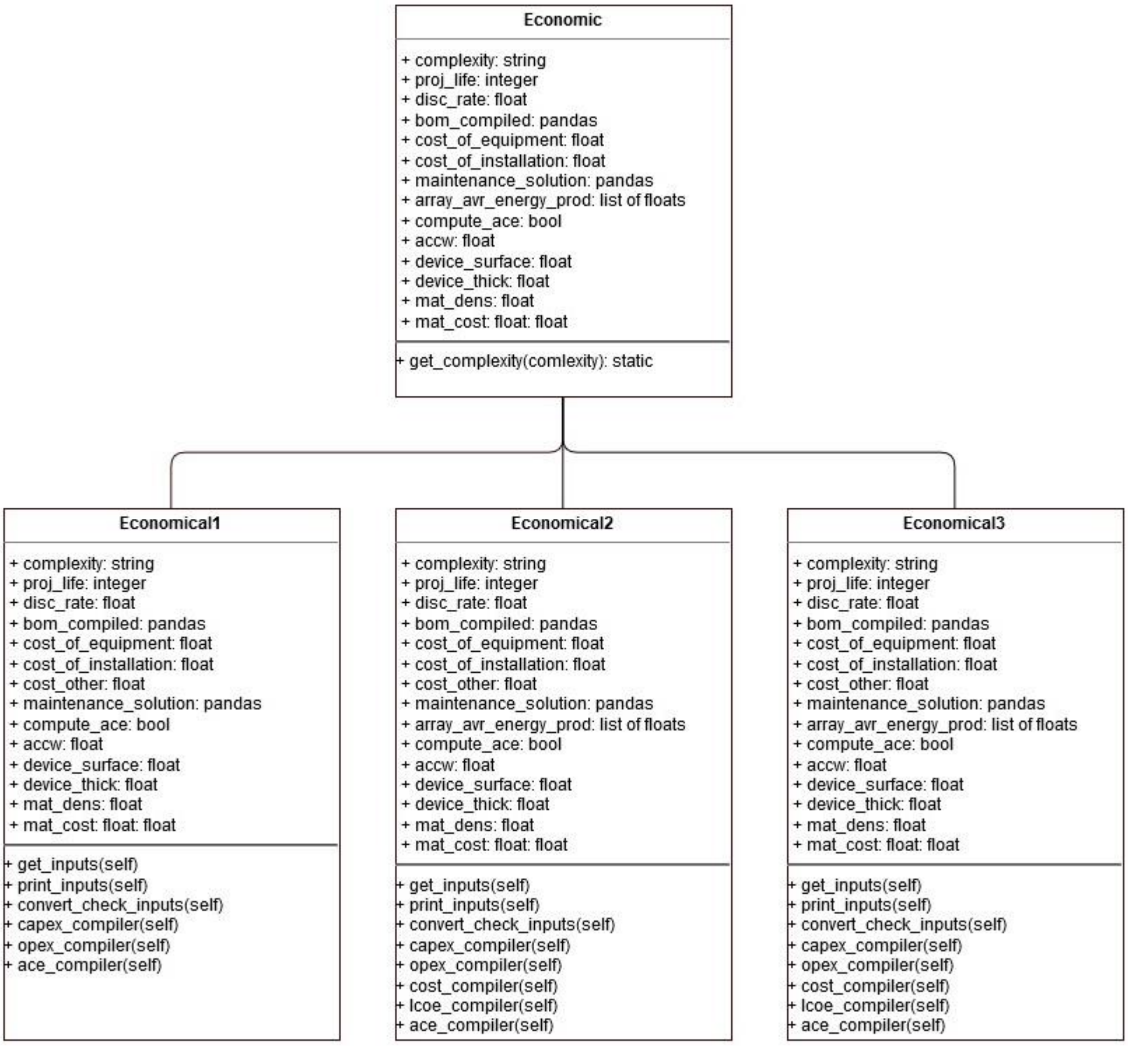

FIGURE 4.2: THE ECONOMIC CLASS AND METHODS FOR THE THREE LEVELS OF COMPLEXITY.

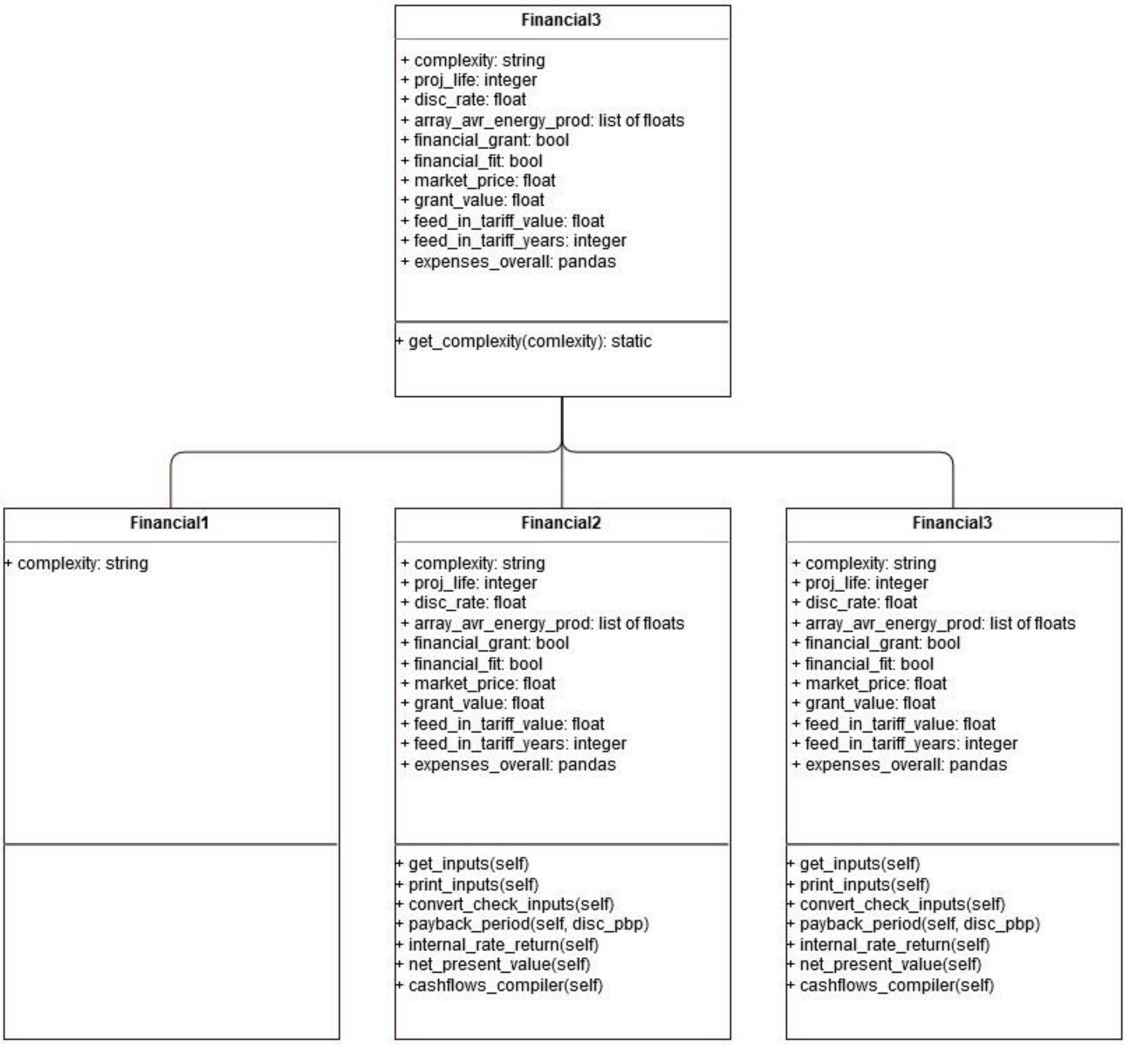

FIGURE 4.3: THE FINANCIAL CLASS AND METHODS FOR THE THREE LEVELS OF COMPLEXITY

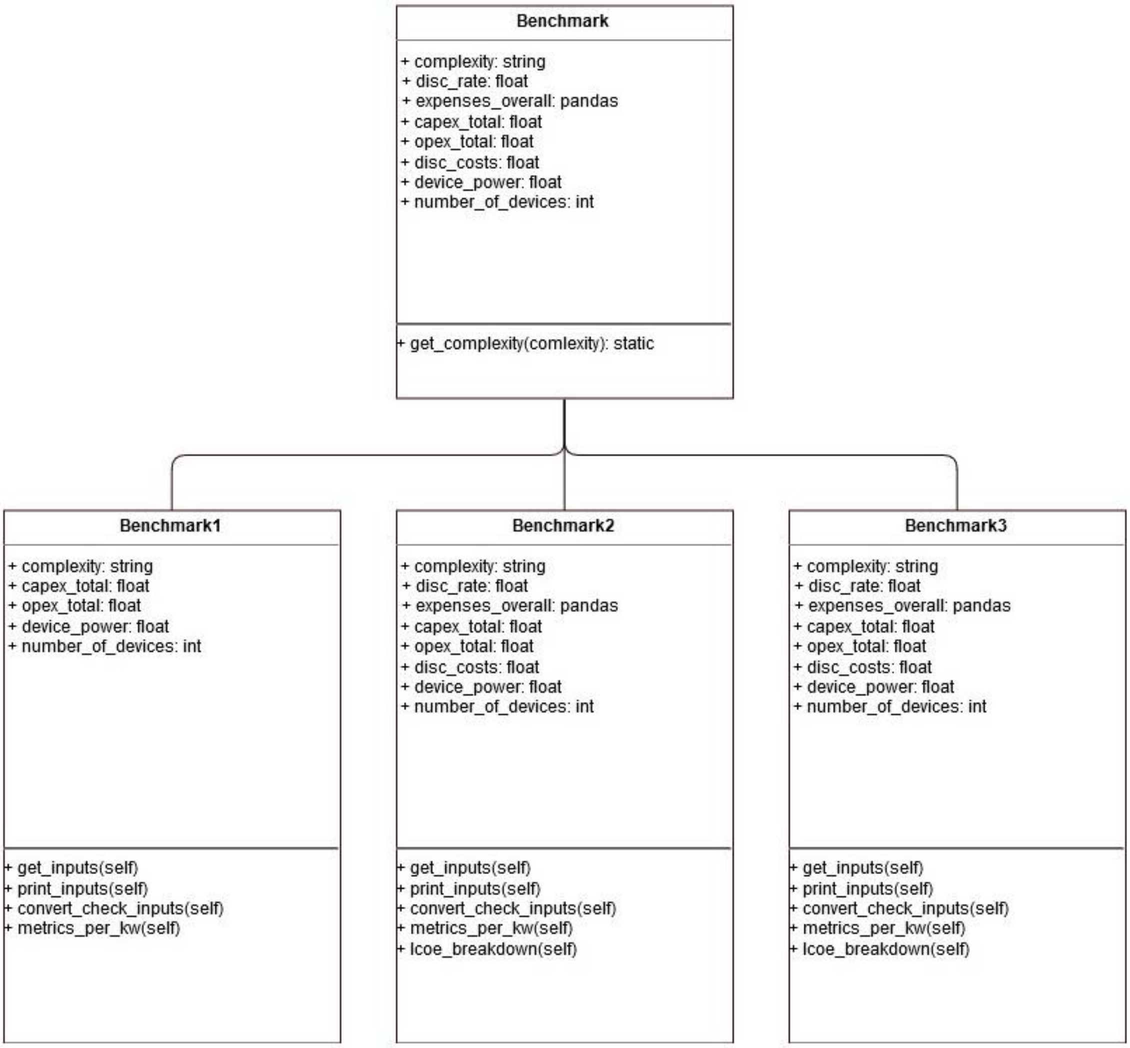

FIGURE 4.4: THE BENCHMARK CLASS AND METHODS FOR THE THREE LEVELS OF COMPLEXITY

4.1.2 API

Within the DTOceanPlus software, the API follows a representational state transfer (REST) approach and it uses HTTP as the transport protocol. Its robustness is due to strict design principles whose development it has been based on.

Similar to other DTOceanPlus modules, the SLC API follows the same principles and the language OpenAPI is adopted. An OpenAPI file was created, in json format, describing in detail all the paths, services, and schemas that SLC will consume and supply for the other modules to consume.

The backend of the module will receive the services from the other modules, running the Business Logic and then preparing the outputs for the other modules and the users. This will be coded in Python, using Flask Blueprints.

4.1.3 GUI

The GUI of the modules of DTOceanPlus will be all based on the same libraries to guarantee a consistent visual look.

The GUI of the SLC module will be included into the main module, and as it could be seen in Figure 4.5 and Figure 4.6, it generally consists of two parts. On the left, there will be a tree, with the three main functionalities: Bill of Materials, Economic, Financial and Benchmark. Each functionality could be furtherly expanded into Inputs and Outputs.

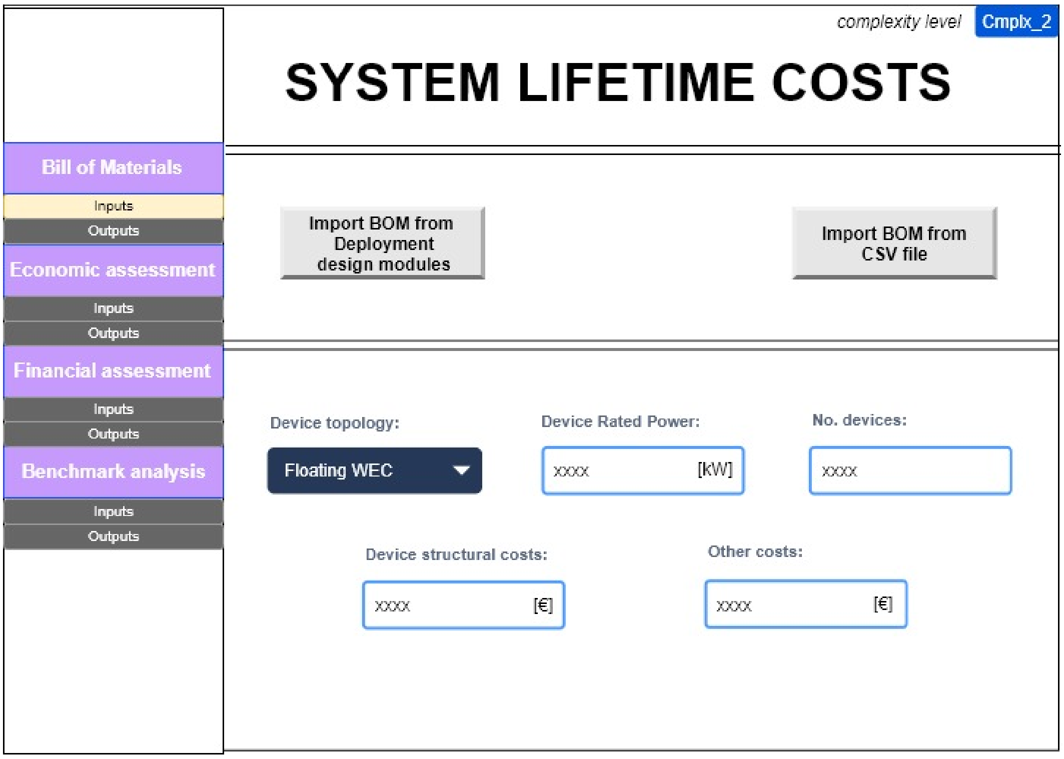

FIGURE 4.5: MOCK-UP OF THE SYSTEM LIFETIME COSTS MODULE, IN THE BILL OF MATERIALS INPUT VIEW.

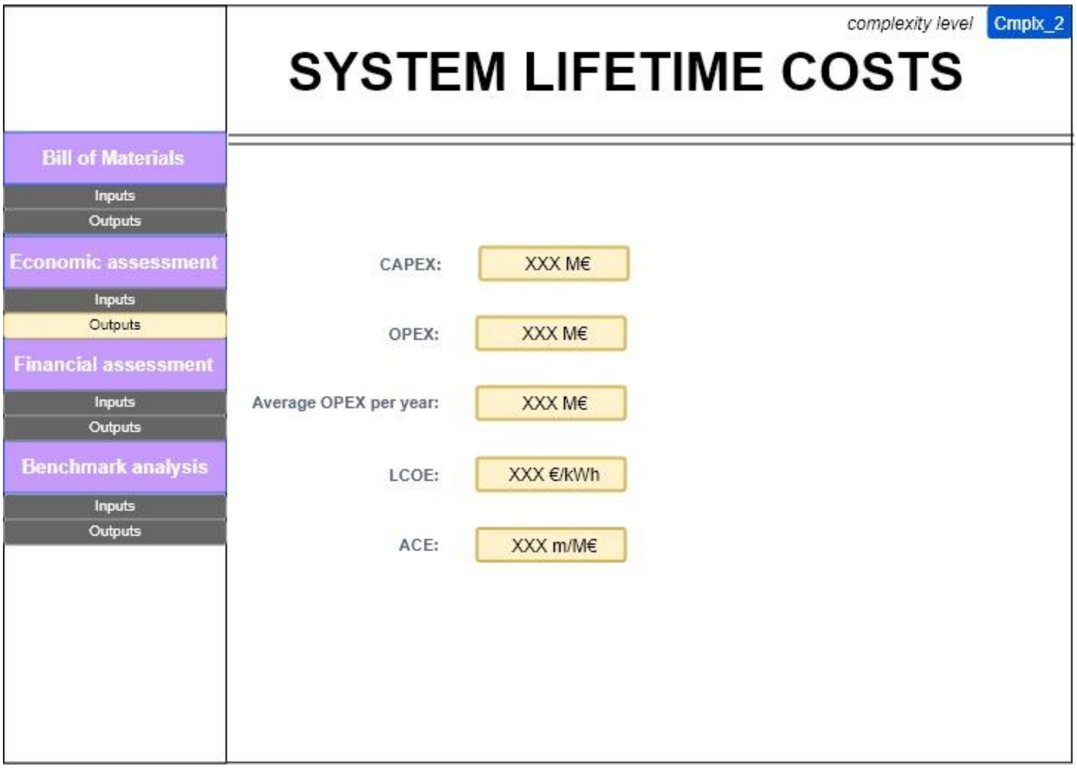

FIGURE 4.6: MOCK-UP OF THE SYSTEM LIFETIME COSTS MODULE, IN THE ECONOMIC ASSESSMENT OUTPUT VIEW.

4.1.4 THE TECHNOLOGIES

The Business Logic and the API of SLC were coded in Python version 3.7. The installation of the module requires the following packages:

- NumPy
- Matplotlib
- Pandas
- json
- Flask
- flask-babel
- flask-cors
- flask-url_for
- flask-requests
- flask-Blueprint
- flask-jsonify
- Pytest

The API will rely on OpenAPI specification v3.0.2.

The GUI of the module will be developed in Vue.js, using the library Element-UI.

4.2 TESTING AND VERIFICATION

The Business Logic implemented a validation of the data inputs, checking whether the required inputs for each method are set to "None" values. Similarly, in the Business Logic, the situations in which some values are zero, ultimately leading to numerical errors due to divisions by zero, were tested.

In total, a set of 1489 statements were developed, out of which 1306 are attributed to the Business logic. A comprehensive set of "unit test" were implemented to test the code, and the coverage of said tests was measure using the py-cov extension of the py-test library. As presented Figure 4.7, the business logic was 100% tested.

```
---------- coverage: platform win32, python 3.7.4-final-0 ----------
Name                                          Stmts   Miss  Cover
-----------------------------------------------------------------
src\dtop_slc\__init__.py                          0      0   100%
src\dtop_slc\business\__init__.py                42      0   100%
src\dtop_slc\business\core.py                    93      0   100%
src\dtop_slc\business\cpx1\__init__.py            3      0   100%
src\dtop_slc\business\cpx1\benchmark1.py         50      0   100%
src\dtop_slc\business\cpx1\economical1.py       145      0   100%
src\dtop_slc\business\cpx1\financial1.py          9      0   100%
src\dtop_slc\business\cpx2\__init__.py            3      0   100%
src\dtop_slc\business\cpx2\benchmark2.py         98      0   100%
src\dtop_slc\business\cpx2\economical2.py       220      0   100%
src\dtop_slc\business\cpx2\financial2.py        161      0   100%
src\dtop_slc\business\cpx3\__init__.py            3      0   100%
src\dtop_slc\business\cpx3\benchmark3.py         98      0   100%
src\dtop_slc\business\cpx3\economical3.py       220      0   100%
src\dtop_slc\business\cpx3\financial3.py        161      0   100%
```

FIGURE 4.7 COVERAGE OF THE TESTING ON THE BUSINESS LOGIC BY MEANS OF UNIT TESTS

5. EXAMPLES

In this section, an example for each functionality implemented in SLC has been carried out and the outputs are presented as they will be integrated in the DTOceanPlus suite of tools when released.

It is important to stress that specified inputs were generated for illustration purposes only and do not correspond to any specific project or technology. Consequently, the obtained outputs do not hold any meaning and are not necessarily realistic. These were chosen as merely representative values to be used as a demonstration of the computational capabilities of the SLC module.

5.1 BOM COMPILER

5.1.1 INPUTS

The inputs used in the example are the following.

TABLE 5.1: INPUT TABLE EXAMPLE FOR THE BOM COMPILER FUNCTIONALITY

Quantity	Sub-Quantity	Source	Value	Unit
Level of complexity	—	SG/User	2	—
BOM_ET	—	ET	(See Table 5.2)	—
BOM_SK	—	SK	(See Table 5.3)	—
BOM_ED	—	ED	(See Table 5.4)	—
BOM_LMO	—	LMO	(See Table 5.5)	—
Device topology	—	EC	Floating wave	—
Number of devices	—	EC	5	—
Device structural costs	—	USER	7.5	M€
Other costs	—	USER	1.5	M€

TABLE 5.2: EXAMPLE BOM OF ENERGY TRANSFORMATION MODULE FOR COMPLEXITY LEVEL CPX2.

id	name	qnt	uom	unit_cost	total_cost
CAT_turbine[1]	Air turbine	20	-	40000	800000
CAT_gen	Generator_x	20	-	30000	600000
CAT_b2b	Back to back converter	20	-	20000	400000
Tot_ET	***Total ET system***				**1800000**

TABLE 5.3: EXAMPLE BOM OF ENERGY DELIVERY MODULE FOR COMPLEXITY LEVEL CPX2.

id	name	qnt	uom	unit_cost	total_cost
CAT_Cable001	Cable xyz	3000	m	2300	6900000
CAT_Cable062	Cable xyz239	9000	m	1100	9900000
CAT_colpoint	Subsea hub	2	-	1000000	2000000
CAT_con001	Connector wet-mate	3	-	1000000	3000000
Tot_onshoreinf	***Total onshore infrastructure***	-	-	-	**500000**
Tot_transm	***Total Transmission network***	-	-	-	**12900000**
Tot_network	***Total Array network***	-	-	-	**6900000**
Tot_colpoint	***Total Collection point***	-	-	-	**2000000**

[1] Consistent *catalogue ids* have not yet been defined at the time of writing, so the generic "CAT_ID" was used.

TABLE 5.4: EXAMPLE BOM OF STATION KEEPING MODULE FOR COMPLEXITY LEVEL CPX2.

Id	name	qnt	uom	unit_cost	total_cost
CAT_Anchor001	Anchor	30	-	5000	150000
CAT_ML001	Mooring line	1500	m	300	450000
Tot_SK	***Total costs of SK system***	-	-	-	**600000**

TABLE 5.5: EXAMPLE BOM OF LOGISTISC MODULE FOR COMPLEXITY LEVEL CPX2

id	name	qnt	uom	unit_cost	total_cost
Tot_Inst_Dev	***Total cost of installation of devices***	-	-	-	**9000000**
Tot_Inst_Anc	***Total cost of installation of Anchors***	-	-	-	**300000**
Tot_Inst_Moor	***Total cost of installation of Moorings***	-	-	-	**4000000**
Tot_Inst_Cable	***Total cost of installation of cables***	-	-	-	**50000000**
Tot_Inst_Col	***Total cost of installation of Collection points***	-	-	-	**8500000**

5.1.2 RESULTS

The calculated outputs after running the code were presented in Table 5.6. However, the compiled BOM output is further expanded in Table 5.7.

TABLE 5.6: EXAMPLE OUTPUTS FROM THE BOM COMPILER

Quantity	Sub-Quantity	Value	Unit
Compiled BOM	—	(See Table 5.7)	—
Cost of equipment	—	*62200000*	€
Cost of installation	—	*71800000*	€
Other costs	—	*1500000*	€

TABLE 5.7: COMPILED BILL OF MATERIALS.

id	name	qnt	uom	unit_cost	total_cost	category
id_dev	Floating WEC	5	-	7500000	37500000	Device
Tot_DEV	***Total dev***	-	-	-	**37500000**	**Device**
CAT_ID	Air turbine	20	-	40000	800000	Device
CAT_ID	Generator_x	20	-	30000	600000	Device
CAT_ID	Back to back converter	20	-	20000	400000	Device
Tot_ET	***Total ET system***	-	-	-	**1800000**	**Device**
CAT_Cable001	Cable xyz	3000	m	2300	6900000	Grid
CAT_Cable062	Cable xyz239	9000	m	1100	9900000	Grid
CAT_colpoint	Subsea hub	2	-	1000000	2000000	Grid
CAT_con001	Connector wet-mate	3	-	1000000	3000000	Grid
Tot_onshoreinf	***Total onshore infrastructure***	-	-	-	**500000**	**Grid**
Tot_transm	***Total Transmission network***	-	-	-	**12900000**	**Grid**
Tot_network	***Total Array network***	-	-	-	**6900000**	**Grid**
Tot_colpoint	***Total Collection point***	-	-	-	**2000000**	**Grid**
CAT_Anchor001	Anchor	30	-	5000	150000	Moor_Found
CAT_ML001	Mooring line	1500	m	300	450000	Moor_Found
Tot_SK	***Total costs of SK system***	-	-	-	**600000**	**Moor_Found**
Tot_Inst_Dev	***Total cost of installation of devices***	-	-	-	**9000000**	**Installation**
Tot_Inst_Anc	***Total cost of installation of Anchors***	-	-	-	**300000**	**Installation**
Tot_Inst_Moor	***Total cost of installation of Moorings***	-	-	-	**4000000**	**Installation**
Tot_Inst_Cable	***Total cost of installation of cables***	-	-	-	**50000000**	**Installation**
Tot_Inst_Col	***Total cost of installation of Collection points***	-	-	-	**8500000**	**Installation**
Tot_Inst_Col	***Total cost of installation of Collection points***	-	-	-	**8500000**	**Installation**
Tot_Other	***Total other costs***	-	-	-	**1500000**	**Other**

5.2 ECONOMIC ASSESSMENT

Considering an array of five wave energy converters, the input data could be collected as in the following sections.

5.2.1 INPUTS

TABLE 5.8: EXAMPLE INPUTS FOR TESTING THE ECONOMIC ASSESSMENT FUNCTIONALITY

Quantity	Source	Value	Unit
Level of Complexity	USER	2	—
Compiled BOM	SLC	(See Table 5.7)	—
Device topology	EC	Floating wave	—
Number of devices	EC	5	—
Device Rated Power	EC	500	kW
Device costs	USER	7.5	M€
Array Annual Net Energy	SPEY	(See Table 5.10)	kWh
Maintenance solution	LMO	(See Table 5.9)	—
Project lifetime	LMO	20	years
Funding scheme	USER	[FIT]	—
Years of Feed-in Tariff	USER	20	years
Auction/FIT price	USER	0.300	€/kWh
Market price of electricity	USER	0.055	€/kWh
Discount rate	USER	7	%
Compute ACE?	USER	True	—
*ACCW	SPEY	30	m
*Structural thickness of the device	USER	0.1	m
*Device surface area	USER	628	m^2
*Density of the main material	USER	7850	kg/m^3
*Cost of manufactured material per kg	USER	2.7[2]	€/kg

[2] Reference price related to manufactured steel was taken from the reference below (3$/kg) and converted to Euro at present exchange date (1$ = 0.90€): https://waveenergyprize.wordpress.com/2016/08/18/how-does-the-wave-energy-prize-calculate-ace/

TABLE 5.9: EXAMPLE OF RELEVANT COLUMNS OF THE MAINTENANCE SOLUTION FROM THE LOGISTICS MODULE

operation_id	name	tech_group	operation_type	technologies	start_date	end_date	proj_year	duration_total	vessel_consumption	vec	operation_cost	base_port_id	port_cost	downtime	fail_date	replaced_parts	replaced_parts_cost	cost_label
[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	[h]	[ton]	[-]	[€]	[-]	[€]	[h]	[-]	[-]	[€]	[-]
OP13_0	Minor repair	Electrical	Planned maintenance	[ED1]	01/05/2022	04/05/2022	1	58	40000	VEC_EC1	10500000	P103	5000	n/a	n/a	n/a	0	OPEX
OP12_0	Inspection	Station Keeping	Planned maintenance	[D11_ML1;D11_ML2;D11_ML3]	31/05/2022	31/05/2022	1	24	25000	VEC_SC3	1020000	P103	8000	n/a	n/a	n/a	0	OPEX
OP13_1	Major repair	Station Keeping	Unplanned maintenance	[D11_ML1]	06/06/2022	10/06/2022	2	96	180000	VEC_M2	700000	P103	13000	456	44338	D11_ML1	9000	OPEX
OP12_1	Inspection	Electrical	Planned maintenance	[SC1;SC2;SC3]	09/06/2025	09/06/2025	4	24	8000	VEC_M2	700000	P103	40000	n/a	n/a	n/a	0	OPEX
OP13_2	Minor repair	Electrical	Planned maintenance	[ED1]	01/05/2026	04/05/2026	4	58	40000	VEC_EC1	10500000	P103	5000	n/a	n/a	n/a	0	OPEX
OP12_2	Inspection	Station Keeping	Planned maintenance	[D11_ML1;D11_ML2;D11_ML3]	31/05/2026	31/05/2026	4	24	25000	VEC_SC3	1020000	P103	8000	n/a	n/a	n/a	0	OPEX
OP13_3	Major repair	Station Keeping	Unplanned maintenance	[D11_ML1]	06/06/2027	10/06/2027	6	96	180000	VEC_M2	700000	P103	13000	456	44338	D11_ML2	9000	OPEX
OP12_3	Inspection	Electrical	Planned maintenance	[SC1;SC2;SC3]	09/06/2031	09/06/2031	10	24	8000	VEC_M2	700000	P103	40000	n/a	n/a	n/a	0	OPEX
OP12_4	Inspection	Station Keeping	Planned maintenance	[D11_ML1;D11_ML2;D11_ML3]	31/05/2032	31/05/2032	10	24	25000	VEC_SC3	1020000	P103	8000	n/a	n/a	n/a	0	OPEX
OP13_4	Major repair	Station Keeping	Unplanned maintenance	[D11_ML1]	06/06/2033	10/06/2033	12	96	180000	VEC_M2	700000	P103	13000	456	44338	D11_ML3	9000	OPEX
OP12_5	Inspection	Electrical	Planned maintenance	[SC1;SC2;SC3]	09/06/2037	09/06/2037	16	24	8000	VEC_M2	700000	P103	40000	n/a	n/a	n/a	0	OPEX
OP12_6	Inspection	Station Keeping	Planned maintenance	[D11_ML1;D11_ML2;D11_ML3]	31/05/2038	31/05/2038	16	24	25000	VEC_SC3	1020000	P103	8000	n/a	n/a	n/a	0	OPEX
OP13_5	Major repair	Station Keeping	Unplanned maintenance	[D11_ML1]	06/06/2039	10/06/2039	18	96	180000	VEC_M2	700000	P103	13000	456	44338	D11_ML1	9000	OPEX
OP12_7	Inspection	Electrical	Planned maintenance	[SC1;SC2;SC3]	09/06/2041	09/06/2041	20	24	8000	VEC_M2	700000	P103	40000	n/a	n/a	n/a	0	OPEX

TABLE 5.10: EXAMPLE ARRAY ANNUAL NET ENERGY, INPUT FROM SPEY

Year	Array Annual Net Energy
1	8.651E+07
2	9.613E+07
3	9.613E+07
4	8.651E+07
5	8.651E+07
6	8.651E+07
7	8.651E+07
8	8.651E+07
9	1.057E+08
10	1.057E+08
11	9.613E+07
12	9.613E+07
13	8.651E+07
14	1.057E+08
15	9.613E+07
16	8.651E+07
17	9.613E+07
18	9.613E+07
19	1.057E+08
20	8.651E+07

5.2.2 RESULTS

The results of the Economic Assessment functionalities can be compiled in the following tables.

TABLE 5.11: RESULTS FROM ECONOMICAL METHODS USING EXAMPLE INPUTS

Quantity	Value	Units
Total CAPEX	135500000.0	€
OPEX	30970000.0	€
Average OPEX per year	1548500.0	€
Project Overall Expenses	(See Table 5.12)	-
Discounted costs	158976304.2	€
LCOE	0.150	€/kWh
ACE	22.539	m/M€

TABLE 5.12: OVERALL EXPENSES RESULTANT FROM ECONOMICAL ASSESSMENT EXAMPLE

	id	cost	proj_year	category
0	Tot_Device	37500000	0	Device
1	Tot_ET	1800000	0	Grid
2	Tot_onshoreinf	500000	0	Grid
3	Tot_transm	12900000	0	Grid
4	Tot_network	6900000	0	Grid
5	Tot_colpoint	2000000	0	Grid
6	Tot_SK	600000	0	Moor_Found
7	Tot_Inst_Dev	9000000	0	Installation
8	Tot_Inst_Anc	300000	0	Installation
9	Tot_Inst_Moor	4000000	0	Installation
10	Tot_Inst_Cable	50000000	0	Installation
11	Tot_Inst_Col	8500000	0	Installation
12	Tot_Other	1500000	0	Other
13	OP13_0	10505000	1	OPEX
14	OP12_0	1028000	1	OPEX
15	OP13_1	722000	2	OPEX
16	OP12_1	740000	4	OPEX
17	OP13_2	10505000	4	OPEX
18	OP12_2	1028000	4	OPEX
19	OP13_3	722000	6	OPEX
20	OP12_3	740000	10	OPEX
21	OP12_4	1028000	10	OPEX
22	OP13_4	722000	12	OPEX
23	OP12_5	740000	16	OPEX
24	OP12_6	1028000	16	OPEX
25	OP13_5	722000	18	OPEX
26	OP12_7	740000	20	OPEX

5.3 FINANCIAL ASSESSMENT

5.3.1 INPUTS

The inputs for testing the Financial assessment functionality are compiled in Table 5.13.

TABLE 5.13: EXAMPLE INPUTS FOR TESTING THE FINANCIAL ASSESSMENT FUNCTIONALITY

Quantity	Source	Value	Units
Level of complexity	User/SG	2	[-]
Project Lifetime	User	20	Years
Array Annual Net Energy	SPEY	(See Table 5.10)	kWh
Discount rate	User	7	%
Financial Grant?	User	False	—
Financial Feed-in-tariff?	User	True	—
Energy market price	User	0.055	€/kWh
Feed-in-tariff of the project	User	0.300	€/kWh
Number of years of Feed-in-Tariff	User	20	Years
Project overall expenses	SLC	(See Table 5.12)	—

5.3.2 RESULTS

The results obtained from running the Financial assessment functionality with the inputs described previously can be compiled in Table 5.14.

TABLE 5.14: RESULTS FROM FINANCIAL METHODS USING EXAMPLE INPUTS

Quantity	Value	Units
NPV	136195295.59	€
IRR	17.22	%
Payback Period	6.971	Years
Discounted Payback Period	8.795	Years

5.4 BENCHMARK

5.4.1 INPUTS

The example inputs used for demonstrating the Benchmark functionality were compiled in Table 5.15.

TABLE 5.15: EXAMPLE INPUTS TO TEST BENCHMARK METHODS

Quantity	Source	Value	Units
Project Life	USER	20	Years
Compiled BOM	SLC	(See Table 5.7)	—
Total CapEX	SLC	135500000	€
Total OpEX	SLC	30970000	€
Discounted costs	SLC	158976304.2	€
Device rated power	EC	500	kW
Number of devices	EC	5	—

5.4.2 RESULTS

The outputs obtained from running the Benchmark functionality were compiled in Table 5.16.

TABLE 5.16: RESULTS FROM BENCHMARK ANALYSIS USING EXAMPLE INPUTS

Quantity	Value	Units
CAPEX per kW	54200	€/kW
OPEX per kW	12388.0	€/Kw
Cost-of-Device/LCOE	24.72	%
Cost-of-Grid/LCOE	14.03	%
Cost-of-Moor_Found/LCOE	0.38	%
Cost-of-Installation/LCOE	45.16	%
Other-Costs/LCOE	0.94	%
OPEX/LCOE	14.77	%

6. FUTURE WORK

The present deliverable collects the main functional and technical aspects of the System Lifetime Costs module (SLC), implemented during the tasks T6.5 and T6.2 of the DTOceanPlus project. At the time of writing, the module can be run in a standalone mode. However, in order to fully integrate it with the remaining modules of the DTOceanPlus suite of design tools, the following steps are required:

- The OpenAPI file should be "linked" to the other module's equivalent files, in order to guarantee a smooth, robust and consistent data flow among the different pieces of the tool;
- The API should be further developed in order, again, to integrate the module with the other tools.
- Given that multiple tools may be run in a sequence at different levels of complexity, coordination is required to guarantee compatibility between the outputs of each tool at each stage.
- The GUI will be developed to be consistent with the other tools and to provide the user with an easy access to the tool and its functionalities.

These activities will be developed within tasks T6.2 "Software development and testing" (ongoing) and T6.7 "Verification of the code (beta version)", the latter only starting once that all the other modules have been developed. These subsequent tasks will extend the functionalities of the System Lifetime Cost module from the current standalone version to the final one which will be fully integrated in the DTOceanPlus toolset.

7. REFERENCES

[1] European Commission, 'Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment | Projects | H2020 | CORDIS', 17-Jan-2018. [Online]. Available: https://cordis.europa.eu/project/rcn/214811_en.html. [Accessed: 11-Dec-2019].
[2] J. F. Chozas, J. P. Kofoed, and N. E. H. Jensen, *User guide - COE Calculation Tool for Wave Energy Converters: ver. 1.6 - April 2014*, 1st ed. Denmark: Department of Civil Engineering, Aalborg University, 2014.
[3] OES - IEA, 'International Levelised Cost of Energy for Ocean Energy Technologies', 2015.
[4] S. Astariz, A. Vazquez, and G. Iglesias, 'Evaluation and comparison of the levelized cost of tidal, wave, and offshore wind energy', *Journal of Renewable and Sustainable Energy*, vol. 7, no. 5, p. 053112, Sep. 2015.
[5] V. S. Neary *et al.*, 'Methodology for Design and Economic Analysis of Marine Energy Conversion (MEC) Technologies', Sandia Report, 2014.
[6] M. B. R. Topper *et al.*, 'Reducing variability in the cost of energy of ocean energy arrays', *Renewable and Sustainable Energy Reviews*, vol. 112, pp. 263–279, Sep. 2019.
[7] The Carbon Trust, 'Accelerating Marine Energy - The potential for cost reduction - insights from the Carbon Trust Marine Energy Accelerator', 2011.
[8] F. Driscoll *et al.*, 'Methodologies of Determining the ACE Wave Energy Prize Metric', in *Proceedings of the Twelfth European Wave and Tidal Energy Conference*, 2017.
[9] J. Weber, 'WEC Technology Readiness and Performance Matrix – finding the best research technology development trajectory', 2012.
[10] A. D. de Andres, J. Maillet, J. Todalshaug, P. Möller, D. Bould, and H. Jeffrey, 'Techno-Economic Related Metrics for a Wave Energy Converters Feasibility Assessment', *Sustainability*, vol. 8, p. 1109, 2016.
[11] W. Short, D. Packey, and T. Holt, 'A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies', *NASA STI/Recon Technical Report N*, vol. 95, 1995.
[12] M. Mendonça, *Feed-in tariffs: Accelerating the deployment of renewable energy*. 2012.
[13] F. K. Crundwell, *Finance for engineers: evaluation and funding of capital projects*. London: Springer, 2008.
[14] V. Nava *et al.*, 'Performance and Energy Yield Tools – alpha version', DTOceanPlus, 2019.
[15] V. Nava *et al.*, 'Technical Requirements for the Assessment Design Tools', DTOceanPlus, 2019.

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