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

Deliverable D6.2

Performance and Energy Yield Tools – alpha version

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EXECUTIVE SUMMARY

Deliverable D6.2 "Performance and Energy Yield Tools – alpha version" of the DTOceanPlus project include the details of the Assessment Design Tools module: "System Performance and Energy Yield" (SPEY), and it presents the result of the work developed during the tasks T6.2 and T6.3 of the project. This document serves as the technical manual of the alpha version of the SPEY module, including all the data requirements, main functions, interfaces and all the pertinent technical details.

This document summarises both the functionalities as well as the more technical aspects of the code implemented for the alpha version of this module. The System Performance and Energy Yield tools will provide the user with a set of relevant metrics and assessments pertinent to the performance of the ocean energy system in terms of energy production, power quality, and efficiency. Moreover, a set of alternative metrics (dimensional parameters) have been included, representing the performances of the systems against a set of technical parameters, the rated power, wetted surface and mass of the prime mover, and the cable lengths.

The Business Logic of the code, i.e. the actual functions of the SPEY module, has been implemented in Python 3. Moreover, the code is provided with an Application Programming Interface (API), developed in OpenAPI, in order to interact and communicate with the other modules of the DTOceanPlus platform: A Graphical User Interface (GUI) will be developed, consistently with the other modules, in Vue.js, allowing the user to interact easily with the SPEY 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. A section of examples completes the present document, showing the capabilities of the tool.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

ACE	Annual Captured Energy
ADE	Annual Delivered Energy
ADP	Active Delivered Power
AEF	Average Annual Energy Flux Resource available in the site
API	Application Programming Interface
ATE	Annual Transformed Energy
CD	Characteristic dimension
CL	Level of complexity
DACE	Annual Captured Energy per device
DATE	Annual Transformed Energy per device
DATP	Active Transformed Power per device
DRTP	Reactive Transformed Power per device
EC	Energy Capture
ECL	Export Cable Length
ESA	Environmental and Social Acceptance
ET	Energy Transformation
GUI	Graphic User Interface
HTTP	HyperText Transfer Protocol
IACL	Intra-Array Cable Length
LA	Lease Area (excluding No-Go Areas)
LMO	Logistics and Marine Operations
MDHD	Monthly Downtime Hours per Device
MRH	Monthly resource histogram
ND	Number of devices
PDH	Power Deliver Histogram
PL	Project Life
PMM	Prime Mover Mass
RAMS	Reliability, Availability, Maintainability, Survivability
RDP	Reactive Delivered Power
REST	REpresentational State Transfer
RP	Rated Power (of the Device)
SC	Site Characterisation
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs
SPEY	System Performance and Energy Yield
TT	Technology Type (Tidal or Wave Energy Device)
WD	Energy Delivery
WS	Wetted Surface

1. INTRODUCTION

1.1 SCOPE AND OUTLINE OF THE REPORT

Deliverable D6.2 "Performance and Energy Yield Tools – alpha version" of the DTOceanPlus project includes the details of the Assessment Design Tools module: "System Performance and Energy Yield" (SPEY), and it presents the result of the work developed during the tasks T6.2 and T6.3 of the project. This document serves as the technical manual of the alpha version of the SPEY module, including all the data requirements, main functions, interfaces and all the pertinent technical details. The alpha version of this tool is a fully functional version of the tool in terms of implementation of the calculations covered by the SPEY module (Business Logic). However, it has limited functionality in terms of Application Programming Interface (API), since the other modules that SPEY interacts with are still under development. The alpha version has limited functionality in terms of Graphic User Interface (GUI).

This document summarises:

1) The use cases and the functionalities of the System Performance and Energy Yield tools, namely providing the user with a set of relevant metrics and assessments pertinent to the performance of the ocean energy system in terms of energy production, power quality and efficiency. Moreover, a set of alternative metrics (dimensional parameters) have been assessed, representing the performances of the systems against a set of technical parameters, as the lease area, the rated power, wetted surface and mass of the prime mover, and the cable lengths (Section 2).
2) 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 3). The alpha version of the SPEY module, released with this deliverable and available in a Gitlab Repository, includes: i) a Business Logic of the alpha version of code, i.e. the actual functions of the SPEY module, implemented in Python 3; b) the API developed in OpenAPI, in order to interact and communicate with the other modules of the DTOceanPlus platform. c) It recollects moreover the design of the Graphical User Interface (GUI) that will be developed, consistently with the other modules, in Vue.js, allowing the user to interact easily with the SPEY tool, inputting data and visualising results.
3) 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.
4) A set of extensive examples, to provide the reader with an overall view of the capabilities of the tools (Section 4).

1.2 SUMMARY OF THE DTOCEANPLUS PROJECT

The SPEY tools belong to the suite of tools "DTOceanPlus" developed within the EU-funded project DTOceanPlus [1].

DTOceanPlus will 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 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), comprising metocean, geotechnical, and environmental conditions;
  - Energy Capture (EC), per device and at an array level;
  - Energy Transformation (ET): PTO and control;
  - Energy Delivery (ED): electrical and grid issues;
  - Station Keeping (SK): moorings and foundations;
  - Logistics and Marine Operations (LMO): installation, operation, maintenance, and decommissioning.
- **Assessment Tools**, to quantify key parameters:
  - System Performance and Energy Yield (SPEY);
  - System Lifetime Costs (SLC);
  - System Reliability, Availability, Maintainability, Survivability (RAMS);
  - Environmental and Social Acceptance (ESA).

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

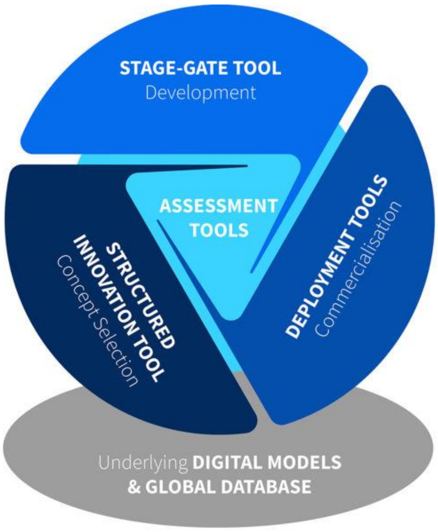

FIGURE 1.1: REPRESENTATION OF DTOCEANPLUS TOOLS

2. USE CASES AND FUNCTIONALITIES

The System Performance and Energy Yield (SPEY) module will:

- Compute several dimensionless (efficiency) and dimensional (alternative metrics) parameters, given the technical design of the ocean energy plant and the power production of the different subsystems, at different level of aggregation (array and device level) and facilitate the visualisation of these outputs to the user.
- Estimate the Energy Production at different level of aggregation (array and device level) accounting for the probabilistic distribution of the downtime throughout the life of the project, within different timescales (lifetime of the plant, annual and monthly energy production) and facilitate the visualisation of these outputs to the user.
- Show results in terms of Power quality (Reactive vs Active power to the grid and as outputs per device) obtained by technical modules.

In Deliverable D6.1 [2], among the objectives of SPEY there was the benchmark with reference data. Following further discussions during the development, the Stage Gate Tool will perform such a benchmark against user supplied thresholds, or a catalogue of target values (state-of-the-art/ art-of-the-possible etc) as provided by the Structured Innovation tool.

2.1 THE USE CASES

The Generic User Case can be generally summarised as shown in Figure 2.1.

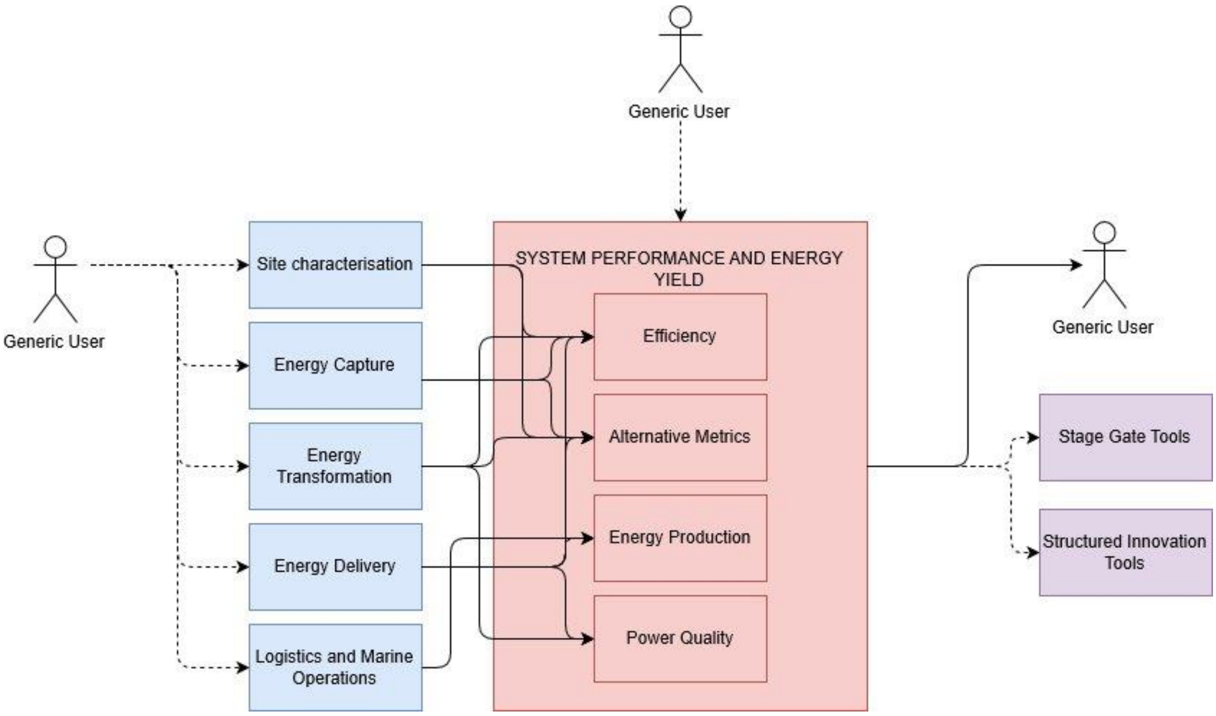

FIGURE 2.1: GENERIC USE CASE FOR USING THE SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS

The User can:

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

By considering the three Use cases above mentioned, Table 2.1 summarises the dependencies of SPEY from/to other modules in DTOceanPlus.

TABLE 2.1: DEPENDENCIES OF SPEY FROM/TO OTHER MODULES IN DTOCEANPLUS

Modules that provide services that SPEY consumes	Modules that are consuming services from SPEY
Site Characterisation (SC), Energy Capture (EC), Energy Transformation (ET), Energy Delivery (ED), Logistics & Marine Operations (LMO)	Structured Innovation (SI), Stage Gate (SG)

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

In this case, the SPEY tool will be run within the framework of the Stage Gate or Structured Innovation Design tools, as seen in Figure 2.2. The following steps are identified for this use case:

1) The user runs the framework of the SI/SG Tools
2) The SI/SG will require eventually some assessments from the SPEY module
3) The SPEY Module will check if the needed information is available and in case it is not, it will request the user to input the information from the relevant Deployment Design Tools
4) The User will complement the information and run the Deployment Design Tools
5) SPEY will be run and perform the assessments
6) SPEY will provide the assessments to SI/SG Tools to complete their framework
7) The outcome will be shown to the User.

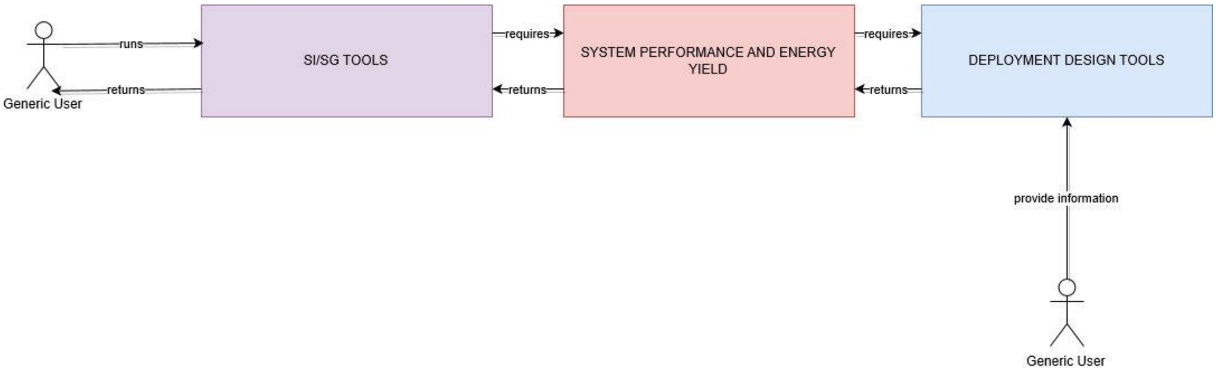

FIGURE 2.2: USE CASE FOR USING THE SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS WITHIN THE FRAMEWORK OF SG/SI DESIGN TOOLS.

2.1.2 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 SPEY module to carry out the assessments in terms of performance and energy yield. The numerical results as well as the graphs/diagrams will be exposed to the user.

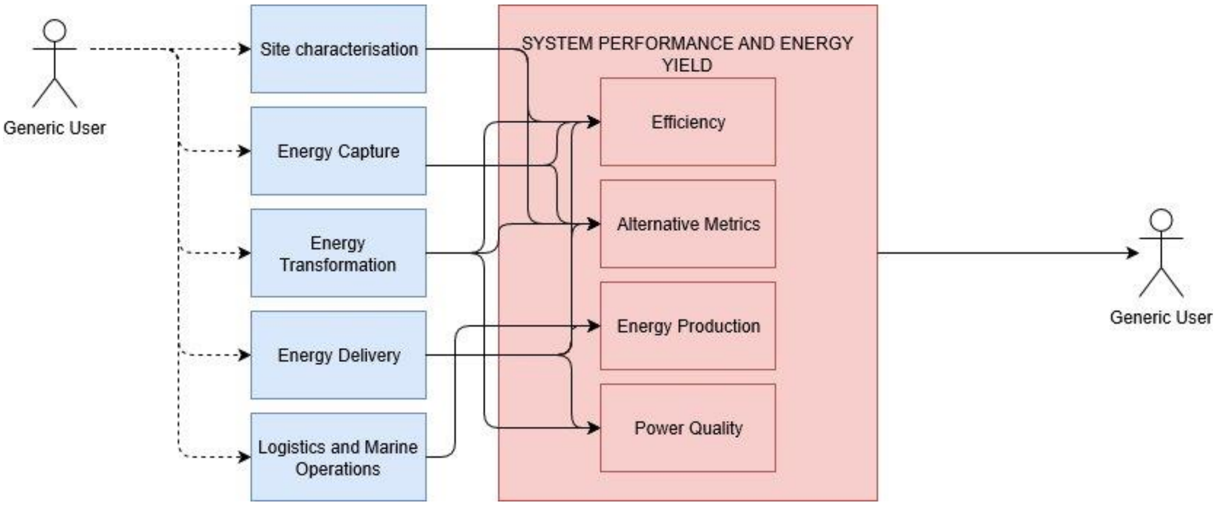

FIGURE 2.3: USE CASE FOR USING THE SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS AFTER RUNNING THE DEPLOYMENT DESIGN TOOLS.

2.1.3 STANDALONE MODE

In this Case, the User wants only to run the SPEY module, to get some assessments in terms of performances and energy yield. The user, in this case, will provide all the required inputs and he/she will be exposed to the overall results of the assessment.

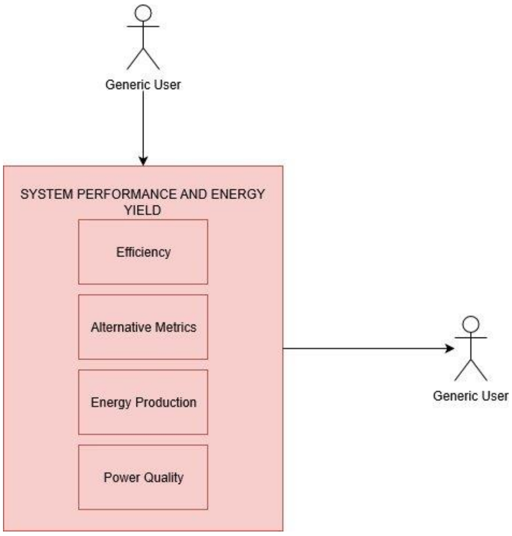

FIGURE 2.4: USE CASE FOR USING THE SYSTEM PERFORMANCE AND ENERGY YIELD TOOLS STANDALONE.

2.2 THE FUNCTIONALITIES

The SPEY Module produces assessments in four big areas:

1) **Efficiency**: a set of dimensionless parameters expressing how well the overall system, as well as the different systems, perform with respect to the available resource and the other subsystems, both at array and at device level of aggregation (see Section 2.2.1);
2) **Alternative metrics**: a set of dimensional parameters expressing how well the overall system, as well as the different sub-subsystems, perform with respect to the other parameters, as for example the lease area, the wetted surface of the prime mover, the mass, the rated power of the device, the characteristic length, and the length of the cabling, both at array and at device level of aggregation (see Section 2.2.2);
3) **Energy Production** estimates the gross and net energy production, during the lifetime, as well as the average annual and monthly production due to the downtime of the system (see Section 2.2.3).
4) **Power Quality**: an estimate of the active power production with respect to the reactive one can be estimated for different subsystems and levels of aggregation (see Section 2.2.4).

The level of complexity of the project and for which the assessments can be carried out has also been accounted for. Indeed, during the implementation (see Section 3), this has been considered at three different levels of complexity. Even if at the moment of writing, the three levels of complexity estimate exactly the same assessments, for future use from other tools (Stage Gate Design tools and Structured Innovation Design tools) the code has been structured in a way that it'll be possible to include differences among the levels of complexity or even add more levels.

In the input tables (Table 2.2, Table 2.3, Table 2.4, Table 2.5), inputs with an "*" in the description are required to carry out the analysis. The other inputs are optional, i.e. the code will not break while running, but instead the user will be informed that a null value is provided, and the outputs set to None.

2.2.1 EFFICIENCY

2.2.1.1 OBJECTIVES

The assessments in terms of Efficiency that the SPEY module can compute aim at providing to the user with a set of dimensionless quantifiable parameters that show how:

- the overall designed system performs with respect the available resource
- each subsystem (energy capture, transformation, delivery) performs, at array and device level, with respect to the available resource and with respect other subsystems

It is important to notice that differences in efficiency per devices are expected due to the hydrodynamic interactions among devices themselves. In the Efficiency assessments no operations or downtime are included in the computations, supposing that the subsystems are working during all the time. This approach was chosen to point out the efficiency of the technology, without any bias due to downtime or reliability.

2.2.1.2 INPUTS, MODELS AND OUTPUTS

Inputs

The inputs needed for carrying out the assessment of the efficiency are in Table 2.2.

TABLE 2.2: INPUTS FOR THE EVALUATION OF THE EFFICIENCY

ID	Brief Description of the Input Quantity	Origin of the Data[1]	Data Model in SPEY	Units
*CL	Level of complexity	User/SG	Number, integer	-
*AEF	Average Annual Energy Flux Resource available in the site	SC	Number, Float	kW/(m) WAVE kWh/(m²) TIDAL
*TT	Technology Type, Tidal or Wave Energy Device	Catalogues	String	"Wave" or "Tidal"
*CD	Characteristic dimension of the Ocean Energy Absorber: in case of Tidal energy device, the rotor diameter has been considered	Catalogues	Number, float	m
*ND	Number of devices	EC	Number, Integer	-
*RP	Rated Power of the Device	Catalogues	Number, Float	kW
ACE	Annual Captured Energy: the total amount of energy captured in one year	EC	Number, Float	kWh
DACE	Annual Captured Energy per device: the total amount of energy captured in one year per device	EC	List of Numbers, Float	kWh
ATE	Annual Transformed Energy: the total amount of energy transformed in one year	ET	Number, Float	kWh
DATE	Annual Transformed Energy per device: the total amount of energy transformed in one year per device	ET	List of Numbers, Float	kWh
ADE	Annual Delivered Energy: the total amount of energy delivered in one year.	ED	Number, Float	kWh

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[1] The module name is indicated in the Use case 1 (within the SG/SI Design Tools framework) or in Use Case 2 (after running the Deployment Design Tools)

Models and outputs

The assessments that the efficiency class in SPEY can compute are the following:

1) "Rated Flux" The ratio between the capacity of the machine (rated power) and the available resource. In order to keep the metrics dimensionless, Eq .1 refers to wave energy converters and Eq. 2 to Tidal energy Converter

If TT is Wave
$$Rated\ Flux = \frac{RP}{AEF*CD}$$
EQ. 1

If TT is Tidal
$$Rated\ Flux = \frac{RP}{AEF*(\pi CD^2/4)}$$
EQ. 2

2) "Array Captured Efficiency" and "Device Captured Efficiency" are respectively the ratio between Annual Array Captured Energy and Rated Power of the Array and the ratio between Annual Device Captured Energy and Rated Power of the Device. This could be expressed as:

$$\text{Captured Efficiency (array)} = \frac{ACE}{ND * RP * 365 * 24}$$
EQ. 3

$$\text{Captured Efficiency (device)} = \frac{DACE}{RP * 365 * 24}$$
EQ. 4

3) Absolute Array and Device Transformation Efficiency, defined respectively as the ratio between Annual Array Transformed Energy and Rated Power of the Array and the ratio between Annual Device Transformed Energy and Rated Power of the Device

$$\text{Absolute Transformed Efficiency (array)} = \frac{ATE}{ND * RP * 365 * 24}$$
EQ. 5

$$\text{Absolute Transformed Efficiency (device)} = \frac{DATE}{RP * 365 * 24}$$
EQ. 6

4) Relative Array and Device Transformation Efficiency, defined respectively as the ratio between Annual Array Transformed Energy and Annual Array Captured Energy and the ratio between Annual Device Transformed Energy and Annual Device Captured Energy

$$\text{Relative Transformed Efficiency (array)} = \frac{ATE}{ACE}$$
EQ. 7

$$\text{Absolute Transformed Efficiency (device)} = \frac{DATE}{DACE}$$
EQ. 8

5) Absolute Array Delivery Efficiency, defined as the ratio between Annual Array Delivered Energy and Rated Power of the Array

$$Absolute\ \text{Delivered Efficiency (array)} = \frac{ADE}{ND * RP * 365 * 24}$$
EQ. 9

6) Relative Array Delivery Efficiency, defined respectively as the ratio between Annual Array Delivered Energy and Annual Array Transformed Energy

$$\text{Relative Delivered Efficiency (array)} = \frac{ADE}{ATE} \qquad \textbf{EQ. 10}$$

2.2.1.3 IMPACT

The Efficiency assessments can be used to:

- Identify if the machine is well dimensioned for the available resource in the site (Rated Flux)
- Identify which stages of the transformation of energy are less efficient and may require a re-design of the subsystem (relative efficiencies)
- Identify how each subsystem relate to the available resource (absolute efficiencies).

2.2.2 ENERGY PRODUCTION

2.2.2.1 OBJECTIVES

The Energy Production assessments of the SPEY module aim at:

- Assess the gross energy that could be produced by the plant, for each device and at array level of aggregation, during the whole lifetime, for each year of life of the plant, and accounting for the monthly distribution of the resource.
- Estimating the losses of energy due to downtime of the plant for each device and at array level of aggregation, during the whole lifetime, for each year of life of the plant, and accounting for the monthly distribution of the resource, as well as the downtime hours for each month for each device.
- Assess the actual net energy delivered onshore for each month, for each device and at array level of aggregation, during the whole lifetime, for each year of life of the plant, and accounting for the monthly distribution of the resource, as well as the downtime hours for each month for each device.
- Assess the ratio between the net energy delivered onshore and the gross energy for each device and at array level of aggregation, during the whole lifetime, for each year of life of the plant, and accounting for the monthly distribution of the resource.
- Assess the ratio between the net energy delivered onshore and the gross energy for each device and at array level of aggregation, during the whole lifetime, for each year of life of the plant, and accounting for the monthly distribution of the resource.

2.2.2.2 INPUTS, MODELS AND OUTPUTS

Inputs

The inputs needed for carrying out the assessment in terms of Energy Production are in Table 2.3.

TABLE 2.3: INPUTS FOR THE EVALUATION OF THE ENERGY PRODUCTION

ID	Brief Description of the Input Quantity	Origin of the Data[1]	Data Model in SPEY	Units
*CL	Level of complexity	User/SG	Number, integer	-
*MRH	Monthly Resource Histogram is the Monthly probability of occurrence of the resource (Hs for Wave Energy, Vc for Tidal Energy)	SC	Dictionary, whose keys are "bins" (the centroid of the bin) and "January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November", "December". The value for each key is a list with the same length of bins	-
*PDH	Power Deliver Histogram, It is the histogram of the power delivery per device.	ED	The bins must be the same as monthly_resource_histogram, and the value for power is a list with same length of bins	kW
*ND	Number of devices	EC	Number, Integer	-
*PL	Project Life	User	Number, Integer	-
MDHD	Monthly Downtime Hours per Device	LMO	Dictionary of Pandas Tables. The keys are the device ids; the pandas tables have set as index the year of the project life (form from 1 to project life) and the columns are names as the month (first capital letter)	hours

Methods and Outputs

The Energy Production functions can compute the gross energy that can be delivered onshore, the lost energy due to downtime and the net energy estimated to be delivered. It is important to notice that the downtime hours are supposed to be distributed uniformly through the sea states.

1) Gross Energy: the general definition of Gross Energy is the one in Eq. 11.

$$Gross\ Energy = Occurrence\ Histrogram * Power\ Histogram * Number\ Hours" \qquad \textbf{EQ. 11}$$

As a function of the level of aggregation and the reference period, the following quantities can be calculated:

$$\text{Monthly Gross Energy per Device} = MRH * PDH * 24 * (\text{Number of Days in the Month})$$

EQ. 12

$$\text{Annual Gross Energy per Device} = MRH * PDH * 24 * 365.25$$

EQ. 13

$$\text{Lifetime Gross Energy per Device} = MRH * PDH * 24 * 365.25 * PL$$

EQ. 14

$$\text{Array Monthly Gross Energy} = \sum_{devices} MRH * PDH * 24 * (Number\ of\ Days\ in\ the\ Month)$$

EQ. 15

$$\text{Array Annual Gross Energy} = \sum_{devices} MRH * PDH * 24 * 365.25$$

EQ. 16

$$\text{Array Lifetime Gross Energy} = \sum_{devices} MRH * PDH * 24 * 365.25 * PL$$

EQ. 17

2) Lost Energy: the general definition of Lost Energy is the one in Eq. 18.

$$Lost\ Energy = Gross\ Energy * \frac{Downtime\ Hours}{Number\ Hours}$$

EQ. 18

As a function of the level of aggregation and the reference period, the following quantities can be calculated:

$$\begin{aligned} &Monthly\ Lost\ Energy\ per\ Device \\ &= Monthly\ Gross\ Energy\ per\ Device\ * \\ &* \frac{MDHD}{24 * Number\ of\ Days\ in\ the\ Month} \end{aligned}$$

EQ. 19

$$Annual\ Lost\ Energy\ per\ Device = \sum_{months} Monthly\ Lost\ Energy\ per\ Device$$

EQ. 20

$$Lifetime\ Lost\ Energy\ per\ Device = \sum_{years} Annual\ Lost\ Energy\ per\ Device$$

EQ. 21

$$Array\ Monthly\ Lost\ Energy = \sum_{devices} Monthly\ Lost\ Energy\ per\ Device$$

EQ. 22

$$Array\ Annual\ Lost\ Energy = \sum_{devices} Annual\ Lost\ Energy\ per\ Device \tag{EQ. 23}$$

$$Array\ Lifetime\ Lost\ Energy = \sum_{devices} Lifetime\ Lost\ Energy\ per\ Device \tag{EQ. 24}$$

3) Net Energy: the general definition of Net Energy is the one in Eq. 25.

$$Net\ Energy = Gross\ Energy - \ Lost\ Energy \tag{EQ. 25}$$

As a function of the level of aggregation and the reference period, the following quantities can be calculated:

$$Monthly\ Net\ Energy\ per\ Device = Monthly\ Gross\ Energy\ per\ Device - \ Monthly\ Lost\ Energy\ per\ Device \tag{EQ. 26}$$

$$Annual\ Net\ Energy\ per\ Device = \ Annual\ Gross\ Energy\ per\ Device - Annual\ Lost\ Energy\ per\ Device \tag{EQ. 27}$$

$$Lifetime\ Net\ Energy\ per\ Device = \ Lifetime\ Gross\ Energy\ per\ Device - \ Lifetime\ Lost\ Energy\ per\ Device \tag{EQ. 28}$$

$$Array\ Monthly\ Net\ Energy = Array\ Monthly\ Gross\ Energy - \ Array\ Monthly\ Lost\ Energy \tag{EQ. 29}$$

$$Array\ Annual\ Net\ Energy = Array\ Annual\ Gross\ Energy - Array\ Annual\ Lost\ Energy \tag{EQ. 30}$$

$$Array\ Lifetime\ Net\ Energy = \ Array\ Lifetime\ Gross\ Energy - \ Array\ Lifetime\ Lost\ Energy \tag{EQ. 31}$$

4) Lost Energy Ratio: in general, it is the ratio between lost energy and gross energy:

$$Lost\ Energy\ ratio = \frac{Lost\ Energy}{Gross\ Energy} \tag{EQ. 32}$$

As a function of the level of aggregation and the reference period, the following quantities can be calculated:

$$Monthly\ Lost\ Energy\ Ratio\ per\ Device = \frac{Monthly\ Lost\ Energy\ per\ Device}{Monthly\ Gross\ Energy\ per\ Device} \tag{EQ. 33}$$

$$Annual\ Lost\ Energy\ Ratio\ per\ Device = \frac{Annual\ Lost\ Energy\ per\ Device}{Annual\ Gross\ Energy\ per\ Device} \tag{EQ. 34}$$

$$Lifetime\ Lost\ Energy\ Ratio\ per\ Device = \frac{Lifetime\ Lost\ Energy\ per\ Device}{Lifetime\ Gross\ Energy\ per\ Device} \tag{EQ. 35}$$

$$Array\ Monthly\ Lost\ Energy\ \ Energy = \frac{Array\ Monthly\ Lost\ Energy}{Array\ Monthly\ Gross\ Energy} \tag{EQ. 36}$$

$$Array\ Annual\ Lost\ Energy\ \ Energy = \frac{Array\ Annual\ Lost\ Energy}{Array\ Annual\ Gross\ Energy} \tag{EQ. 37}$$

$$Array\ Lifetime\ Lost\ Energy\ \ Energy = \frac{Array\ Lifetime\ Lost\ Energy}{Array\ Lifetime\ Gross\ Energy} \tag{EQ. 38}$$

5) Net Energy Ratio: in general, it is the ratio between lost energy and gross energy (see Eq. 39):

$$Net\ Energy\ ratio = \frac{Net\ Energy}{Gross\ Energy} \tag{EQ. 39}$$

As a function of the level of aggregation and the reference period, the following quantities can be calculated:

$$Monthly\ Net\ Energy\ Ratio\ per\ Device = \frac{Monthly\ Net\ Energy\ per\ Device}{Monthly\ Gross\ Energy\ per\ Device} \tag{EQ. 40}$$

$$Annual\ Net\ Energy\ Ratio\ per\ Device = \frac{Annual\ Net\ Energy\ per\ Device}{Annual\ Gross\ Energy\ per\ Device} \tag{EQ. 41}$$

$$Lifetime\ Net\ Energy\ Ratio\ per\ Device = \frac{Lifetime\ Net\ Energy\ per\ Device}{Lifetime\ Gross\ Energy\ per\ Device} \tag{EQ. 42}$$

$$Array\ Monthly\ Net\ Energy\ \ Ratio = \frac{Array\ Monthly\ Net\ Energy}{Array\ Monthly\ Gross\ Energy} \tag{EQ. 43}$$

$$Array\ Annual\ Net\ Energy\ \ Ratio = \frac{Array\ Annual\ Net\ Energy}{Array\ Annual\ Gross\ Energy} \tag{EQ. 44}$$

$$Array\ Lifetime\ Net\ Energy\ \ Ratio = \frac{Array\ Lifetime\ Net\ Energy}{Array\ Lifetime\ Gross\ Energy} \tag{EQ. 45}$$

2.2.2.3 IMPACT

The outputs of the Energy Production assessment tool in SPEY will inform the user about:

- The capacity of the plant to deliver energy onshore in case of no downtime (gross energy).
- The estimated energy lost each month, each year and during the whole lifetime of the plant accounting for downtime (net energy).
- The estimated energy delivered each month, each year and during the whole lifetime of the plant accounting for downtime (net energy).
- The impact of the lost energy due to downtime with respect to the potential energy to be delivered (lost energy ratios).
- The effectiveness of the operations and the estimation of the net energy with respect to the potential energy to be delivered (net energy ratios).

2.2.3 ALTERNATIVE METRICS

2.2.3.1 OBJECTIVES

The Alternative Metrics assessments of the SPEY module aim at:

- Provide the user with a certain number of dimensional parameters.
- Assess the performances of the plant (both at array and at device level) with respect to main design characteristics of the plant (lease area extension, rated power, mass of the prime mover, wetted surface of the prime mover, cable length).

2.2.3.2 INPUTS, MODELS AND OUTPUTS

Inputs

The inputs needed for carrying out the assessment in terms of Alternative Metrics are in Table 2.4.

TABLE 2.4: INPUTS FOR THE EVALUATION OF THE ALTERNATIVE METRICS

ID	Brief Description of the Input Quantity	Origin of the Data[1]	Data Model in SPEY	Units
*CL	Level of complexity	User/SG	Number, integer	-
*AEF	Average Annual Energy Flux Resource available in the site	SC	Number, Float	kWh/(m) WAVE kWh/(m^2) TIDAL
*TT	Technology Type, Tidal or Wave Energy Device	Catalogues	String	"Wave" or "Tidal"
*CD	Characteristic dimension of the Ocean Energy Absorber: in case of Tidal energy device, the rotor diameter has been considered	Catalogues	Number, float	m
*ND	Number of devices	EC	Number, Integer	-
*RP	Rated Power of the Device	Catalogues	Number, Float	kW
*WS	Wetted Surface of the Ocean Energy converter	Catalogues	Number, float	m^2
*PMM	Prime Mover Mass	Catalogues	Number, float	kg
*ECL	Export Cable Length	ED	Number, float	m
*IACL	Total Length of the intra-array cable system	ED	Number, float	m
*LA	Lease Area excluding No-Go Areas	SC	Number, float	km^2
ACE	Annual Captured Energy: the total amount of energy captured in one year	EC	Number, Float	kWh
DACE	Annual Captured Energy per device: the total amount of energy captured in one year per device	EC	List of Numbers, Float	kWh
ATE	Annual Transformed Energy: the total amount of energy transformed in one year	ET	Number, Float	kWh
DATE	Annual Transformed Energy per device: the total amount of energy transformed in one year per device	ET	List of Numbers, Float	kWh
ADE	Annual Delivered Energy: the total amount of energy delivered in one year.	ED	Number, Float	kWh

Methods and Outputs

The functions computing Alternative Metrics in the SPEY module can be grouped as a function of the normalising factors. Therefore, they can be classified in five groups:

1) Wetted Area Parameters: the energy production at different stages of the production chain (captured energy, transformed energy, delivered energy) and at different levels of

aggregation (array, device) is calculated with respect to the wetted surface of the prime mover. The following metrics could be assessed:

$$DACE\ Wetted\ Area\ Parameter = \frac{DACE}{WS} \quad \textbf{EQ. 46}$$

$$ACE\ Wetted\ Area\ Parameter = \frac{ACE}{ND * WS} \quad \textbf{EQ. 47}$$

$$DATE\ Wetted\ Area\ Parameter = \frac{DATE}{WS} \quad \textbf{EQ. 48}$$

$$ATE\ Wetted\ Area\ Parameter = \frac{ATE}{ND * WS} \quad \textbf{EQ. 49}$$

$$ADE\ Wetted\ Area\ Parameter = \frac{ADE}{ND * WS} \quad \textbf{EQ. 50}$$

2) Mass Parameters: the energy production at different stages of the production chain (captured energy, transformed energy, delivered energy) and at different levels of aggregation (array, device) is calculated with respect to the mass of the prime mover. Moreover, also the ratio between the rated power and the mass of the prime mover is calculated. The following metrics could be assessed:

$$DACE\ Mass\ Parameter = \frac{DACE}{PMM} \quad \textbf{EQ. 51}$$

$$ACE\ Mass\ Parameter = \frac{ACE}{ND * PMM} \quad \textbf{EQ. 52}$$

$$DATE\ Mass\ Parameter = \frac{DATE}{PMM} \quad \textbf{EQ. 53}$$

$$ATE\ Mass\ Parameter = \frac{ATE}{ND * PMM} \quad \textbf{EQ. 54}$$

$$ADE\ Mass\ Parameter = \frac{ADE}{ND * PMM} \quad \textbf{EQ. 55}$$

$$Power\ to\ Mass\ Ratio = \frac{RP}{PMM} \quad \textbf{EQ. 56}$$

3) Capture Width and Capture Width parameters: the capture length is calculated for wave energy devices and a set of associated parameters *could* be estimated as well. Moreover, a definition of capture length for tidal energy converters has been introduced, as the equivalent diameter of the rotor, given the captured energy the average energy flux in the site. The following metrics could be assessed:

If TT is Wave

$$CW\ (device) = \frac{DACE}{AEF * 365.25 * 24}$$ **EQ. 57**

If TT is Wave

$$CW\ (array) = \frac{ACE}{AEF * 365.25 * 24}$$ **EQ. 58**

If TT is Tidal

$$CW\ (device) = \sqrt{\frac{4 * DACE}{\pi AEF * 365.25 * 24}}$$ **EQ. 59**

If TT is Tidal

$$CW\ (array) = \sqrt{\frac{4 * ACE}{\pi AEF * 365.25 * 24}}$$ **EQ. 60**

$$CW\ Ratio\ (device) = \frac{CW\ (device)}{CD}$$ **EQ. 61**

$$CWRatio\ (array) = \frac{CW\ (array)}{ND * CD}$$ **EQ. 62**

$$CW\ Ratio\ Rated\ Power\ (device) = \frac{CW\ (device)}{RP}$$ **EQ. 63**

$$CW\ Ratio\ (array) = \frac{CW\ (array)}{ND * RP}$$ **EQ. 64**

4) Cable Length Parameters: the length of the export cable (ECL), of the intra-array cables (IACL) and of the whole cable system is calculated with respect to the rated power. The following metrics could be assessed:

$$Intra\ Array\ Cable\ Ratio = \frac{IACL}{RP * ND}$$ **EQ. 65**

$$Export\ Cable\ Ratio = \frac{ECL}{RP * ND}$$ **EQ. 66**

$$Total\ Cable\ Ratio = \frac{IACL + ECL}{RP * ND}$$ **EQ. 67**

5) Lease Area Parameters: the energy production at different stages of the production chain (captured energy, transformed energy, delivered energy) and at array level of aggregation is calculated with respect to the extension of the lease area excluding no-go areas. The following metrics could be assessed:

$$ACE\ Lease\ Area\ Parameter = \frac{ACE}{LA}$$ **EQ. 68**

$$ATE\ Lease\ Area\ Parameter = \frac{ATE}{LA} \qquad \textbf{EQ. 69}$$

$$ADE\ Lease\ Area\ Parameter = \frac{ADE}{LA} \qquad \textbf{EQ. 70}$$

2.2.3.3 IMPACT

The outputs of the Alternative Metrics assessment tool in SPEY will inform the user about how the system (captured energy, length of cables, etc…) performs with respect to the mass, wetted surface, rated power, characteristic dimension. Moreover, users can take advantage of a novel definition for capture width applied to tidal energy converters.

All this set of metrics are useful indicators to quickly compare different projects and scenarios and they can capture quickly the adequacy of the performances of a certain subsystem with respect to some characteristic of the design.

2.2.4 POWER QUALITY

2.2.4.1 OBJECTIVES

The Power Quality assessments of the SPEY module aim at providing the user with an estimation of the power quality, expressed in terms of phase between active and reactive power at the generator (for device and at array level) and at the onshore landing point.

2.2.4.2 INPUTS, MODELS AND OUTPUTS

Inputs

The inputs needed for carrying out the assessment in terms of Power Quality are in Table 2.5.

TABLE 2.5: INPUTS FOR THE EVALUATION OF THE POWER QUALITY

ID	Brief Description of the Input Quantity	Origin of the Data[1]	Data Model in SPEY	Units
DATP	Active Transformed Power per device: the amount of active power at energy transformation phase per device per sea state	ET	Pandas table, columns are the devices and rows are the sea states (ordered by Sea State)	kW
DRTP	Reactive Transformed Power per device: the amount of reactive power at energy transformation phase per device per sea state	ET	Pandas table, columns are the devices and rows are the sea states (ordered by Sea State)	kW

ID	Brief Description of the Input Quantity	Origin of the Data[1]	Data Model in SPEY	Units
ADP	Active Delivered Power of the array: the amount of active power at energy delivery phase of the array per sea state	ED	Pandas table, just one column (the total array) and rows are the sea states	kW
RDP	Reactive Delivered Power of the array: the amount of active power at energy delivery phase of the array per sea state	ED	Pandas table, just one column (the total array) and rows are the sea states	kW

Methods and Outputs

The Power Quality functions can compute the phase between active and reactive power at the generator (transformation level) for device and array level and at the onshore landing point at array level of aggregation for different sea states.

The following quantities will be estimated:

$$Phase\ at\ generator\ per\ Device = \frac{DATP}{\sqrt{DATP^2 + DRTP^2}} \quad \textbf{EQ. 71}$$

$$Phase\ at\ generator\ per\ Array\ Level = \frac{\sum_{devices} DATP}{\sqrt{\sum_{devices} DATP^2 + \sum_{devices} DRTP^2}} \quad \textbf{EQ. 72}$$

$$Phase\ at\ onshore\ landing\ point\ per\ Array\ Level = \frac{ADP}{\sqrt{ADP^2 + RDP^2}} \quad \textbf{EQ. 73}$$

2.2.4.3 IMPACT

The information about the power quality levels per sea state at generator and/or at the onshore landing point could be used to assess of the quality of the delivered energy at different stages of the generation of energy and identify eventually compliances with grid codes and eventually improve the design.

3. THE IMPLEMENTATION

3.1 THE ARCHITECTURE OF THE TOOL

The DTOceanPlus tools have been implemented considering 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, that either consume the services provided by SPEY or whose services are consumed by SPEY.
- The Graphic User Interface (GUI), allowing interaction with the user in order to show results and receive inputs, besides exporting/importing data to/from files.

3.1.1 BUSINESS LOGIC

The architecture of the Business Logic of SPEY reflects, also in its architecture, the functionality that were described in Section 2.

Four main classes, indeed, have been considered, one for each functionality:

- Efficiency (see Figure 3.1)
- EnergyProduction, corresponding to the Energy Production functionality (see Figure 3.2)
- AlternativeMetrics corresponding to the Alternative metrics functionality (see Figure 3.3)
- PowerQuality corresponding to the Power Quality functionality (see Figure 3.4).

As it could see in the figures, each class has the method "…Cpx#" that addresses to the correct class corresponding to the appropriate Level of Complexity. These classes will have the same name of the mother class, adding the suffix Cpx1, Cpx2, Cpx3, according to the level of complexity. As mentioned before there is no difference among the functions for different levels of complexity (at this point, all replicating the same code). For maintainability and future development reasons, it was preferred to consider a structure in three levels of complexity. Moreover, the possibility of considering further levels of complexity is a simple operation that should not cause any issue.

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

- Class Efficiency (see Figure 3.1)
    - Estimate_rated_flux, estimating quantities in Eq. 1 and Eq. 2
    - Captured_efficiency, estimating quantities in Eq. 3 and Eq. 4
    - Transformed_efficiency, estimating quantities in Eq. 5 to Eq. 8
    - Delivered_efficiency, estimating quantities in Eq. 9 and Eq. 10
- Class EnergyProduction- EnergyProductionCpx1, EnergyProductionCpx2 and EnergyProductionCpx3 (see Figure 3.2)
    - Gross_energy, estimating quantities in Eq. 12 to Eq. 17
    - Downtime

  - _lost_energy, estimating quantities in Eq. 18 to Eq. 24
  - Downtime_net_energy, estimating quantities in Eq. 25 to Eq. 45
- Class AlternativeMetrics (see Figure 3.3)
  - Mass_parameters, estimating quantities in Eq. 51 to Eq. 55
  - Wetted_area_parameters, estimating quantities in Eq. 46 to Eq. 50
  - calculate_PWR, estimating quantities in Eq. 56
  - CL_parameters, estimating quantities in Eq. 57 to Eq. 64
  - Cable_length_parameters, estimating quantities in Eq. 65 to Eq. 67
  - Lease_area_parameters, estimating quantities in Eq. 68 to Eq. 70
- Class PowerQuality (see Figure 3.4)
  - Transformed_phases, estimating quantities in Eq. 71 and Eq. 72
  - Delivered_phases, estimating quantities in Eq. 73.

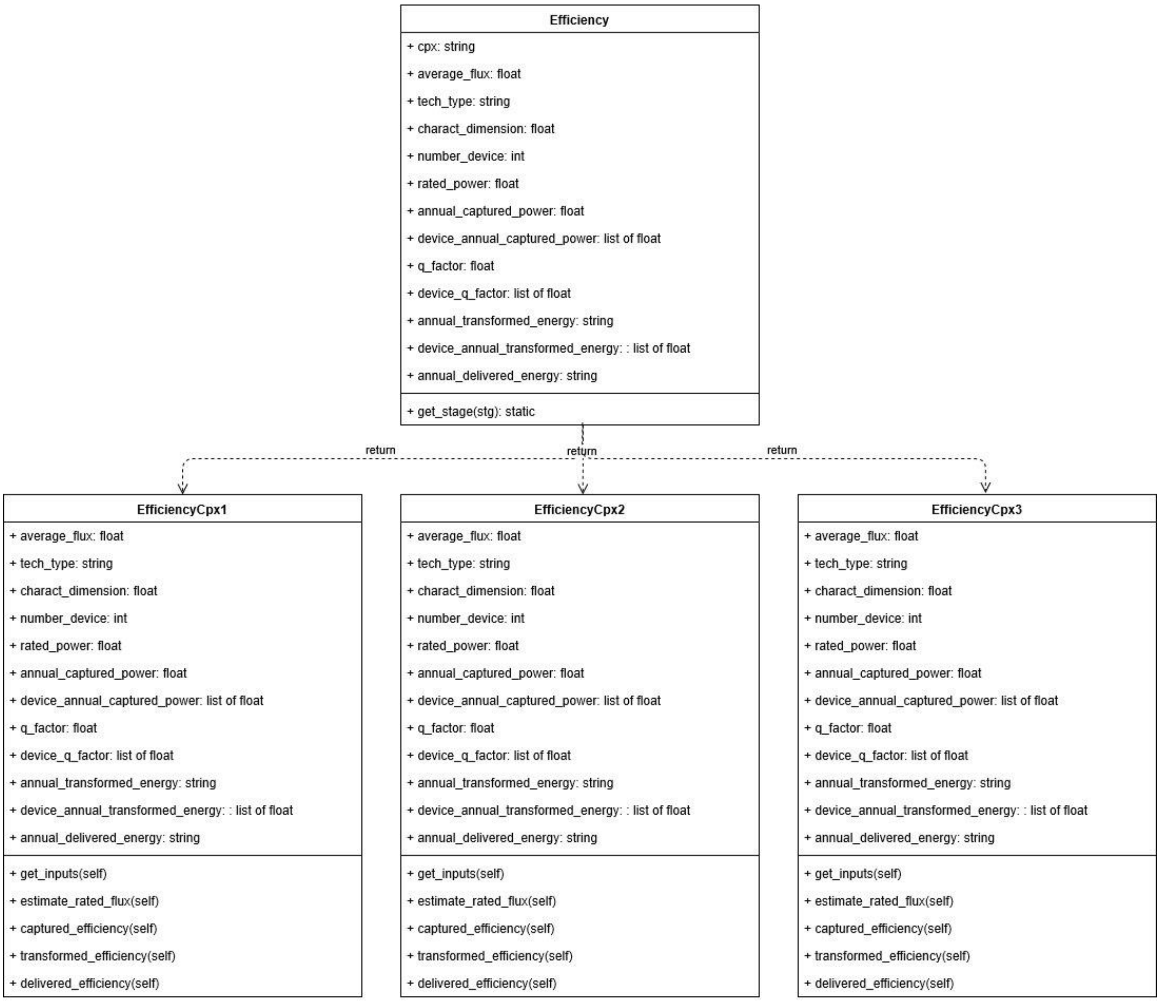


FIGURE 3.1: THE EFFICIENCY CLASS AND THE METHODS FOR LEVEL OF COMPLEXITY.

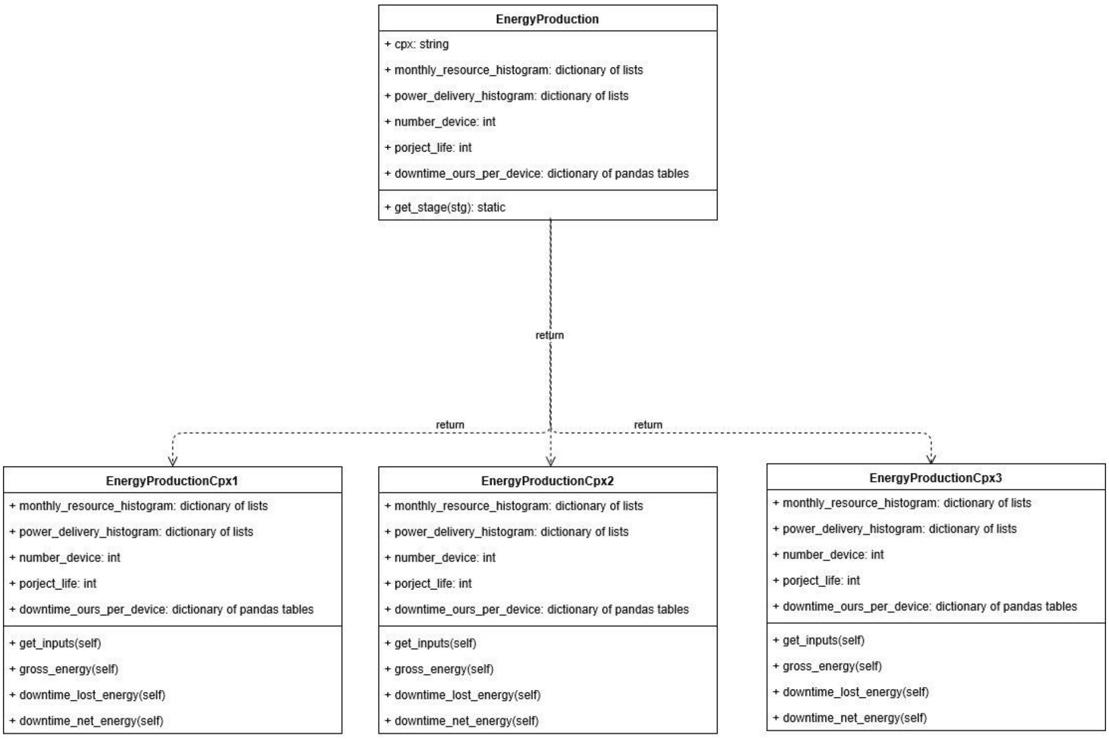


FIGURE 3.2: THE ENERGY PRODUCTION CLASS AND THE METHODS FOR LEVEL OF COMPLEXITY.

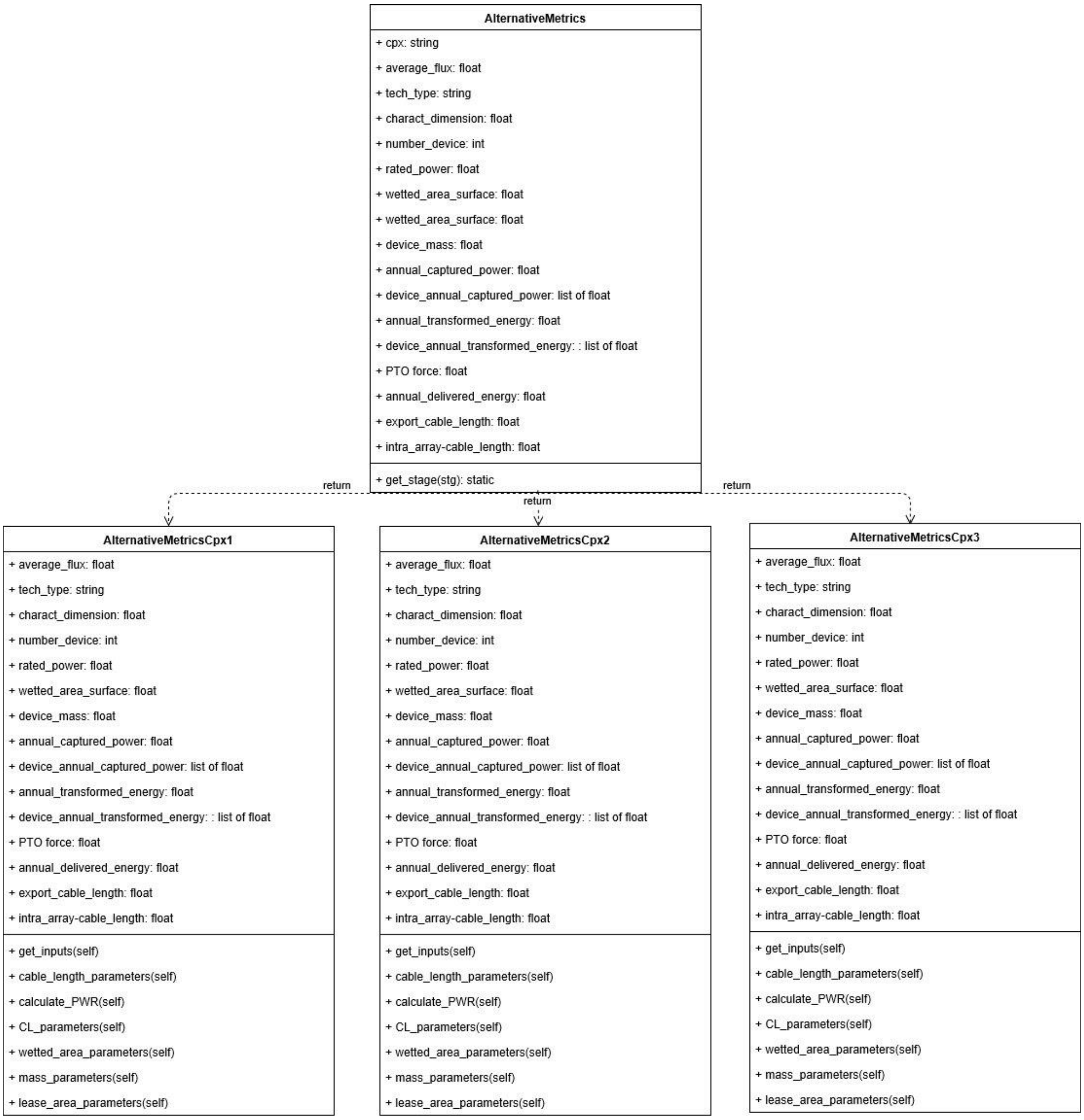


FIGURE 3.3: THE ALTERNATIVE METRICS CLASS AND THE METHODS FOR LEVEL OF COMPLEXITY.

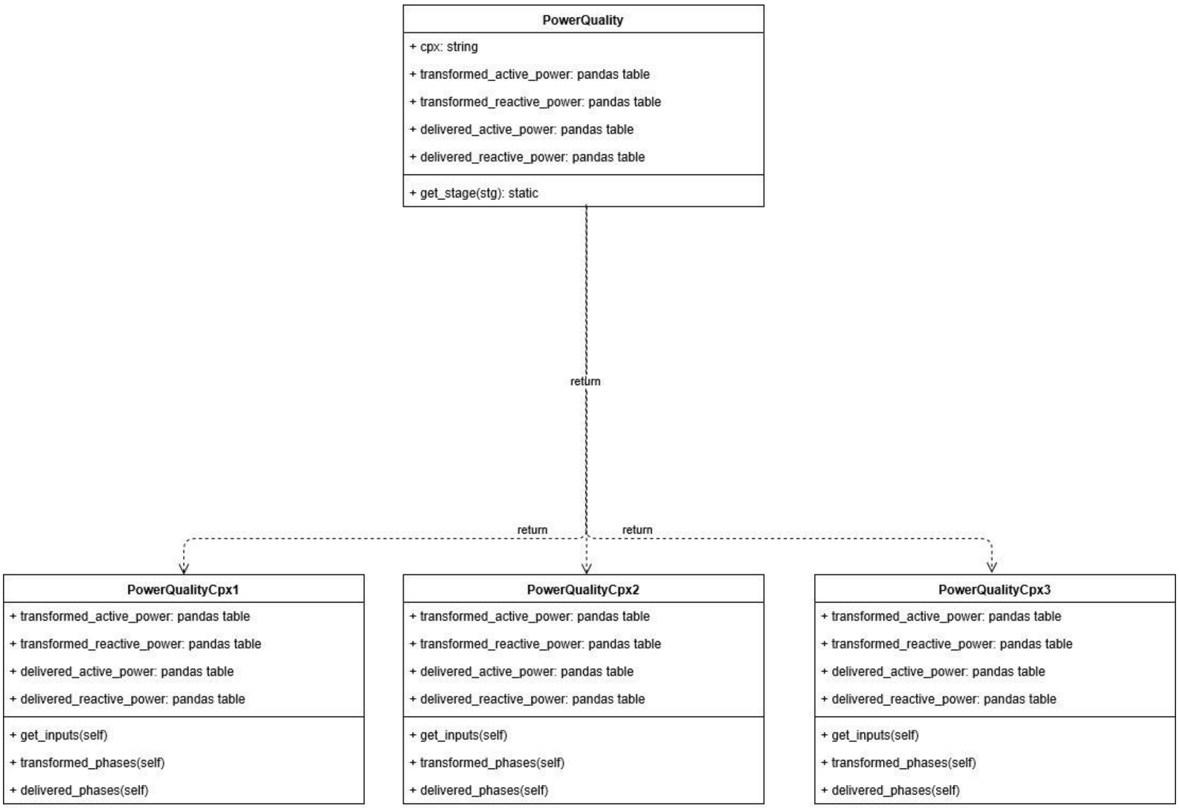


FIGURE 3.4: THE POWER QUALITY CLASS AND THE METHODS FOR LEVEL OF COMPLEXITY.

3.1.2 API

The API of the DTOceanPlus software 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.

The SPEY API follows those principles and indeed the language OpenAPI is adopted. An OpenAPI file was created, in json format, indicating all the paths, the services, and schemas that SPEY will consume, and which will make available for other modules to be consumed.

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.

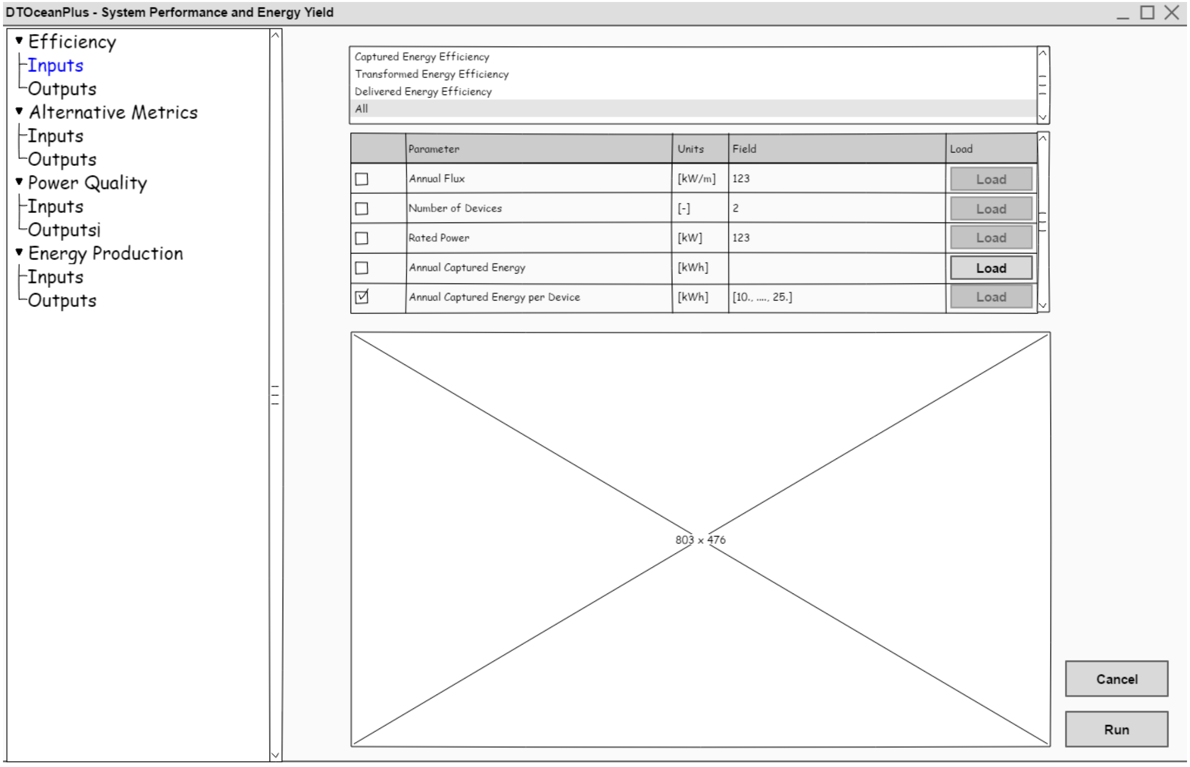
3.1.3 GUI

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

The GUI of the SPEY module will be included into the main module and, as it could be seen in Figure 3.5, will generally consist of two parts. On the left, there will be a tree, with the four main assessments areas: Efficiency, Energy Production, Alternative Metrics and Power Quality. Each assessment could be furtherly expanded into Inputs and Outputs.

The present example is based on the Efficiency assessment, but of course the main concepts will be extended to the other assessments. Selecting Inputs for the Efficiency Assessment, in the central Dashboard, the user will be asked to choose which area of assessments the user is interested at: Captured Energy Efficiency, Transformed Energy Efficiency, Delivered Energy Efficiency or All. This would influence the amount of input data required. While selecting the area, the table below will be filled with the inputs that are available from other modules. In case that one of the inputs is missing, the user may load the missing data, just clicking on the button at the right. It is under discussion whether the user should be able to modify an input of a module, even if it has been calculated by another tool. The decision will depend on the usefulness that such a functionality might have for the user.

In some cases, when values are array or lists, the user could even visualise the inputs in the bottom canvas. Once that the user is ready, he/she can click on the Run button. Not all the inputs are required see Section 2.2 to check them).

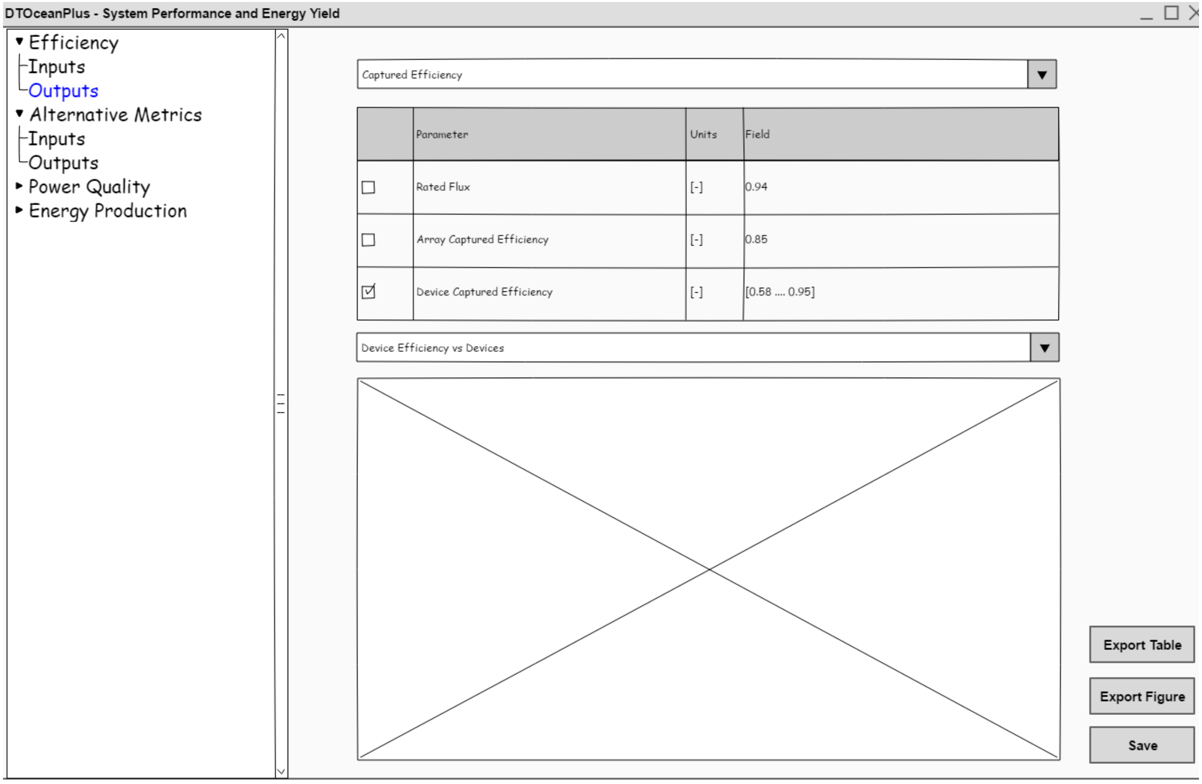


	Parameter	Units	Field	Load
☐	Annual Flux	[kW/m]	123	Load
☐	Number of Devices	[-]	2	Load
☐	Rated Power	[kW]	123	Load
☐	Annual Captured Energy	[kWh]		Load
☑	Annual Captured Energy per Device	[kWh]	[10., ..., 25.]	Load

FIGURE 3.5: WIREFRAME OF THE GUI OF THE SPEY MODULE: INPUTS.

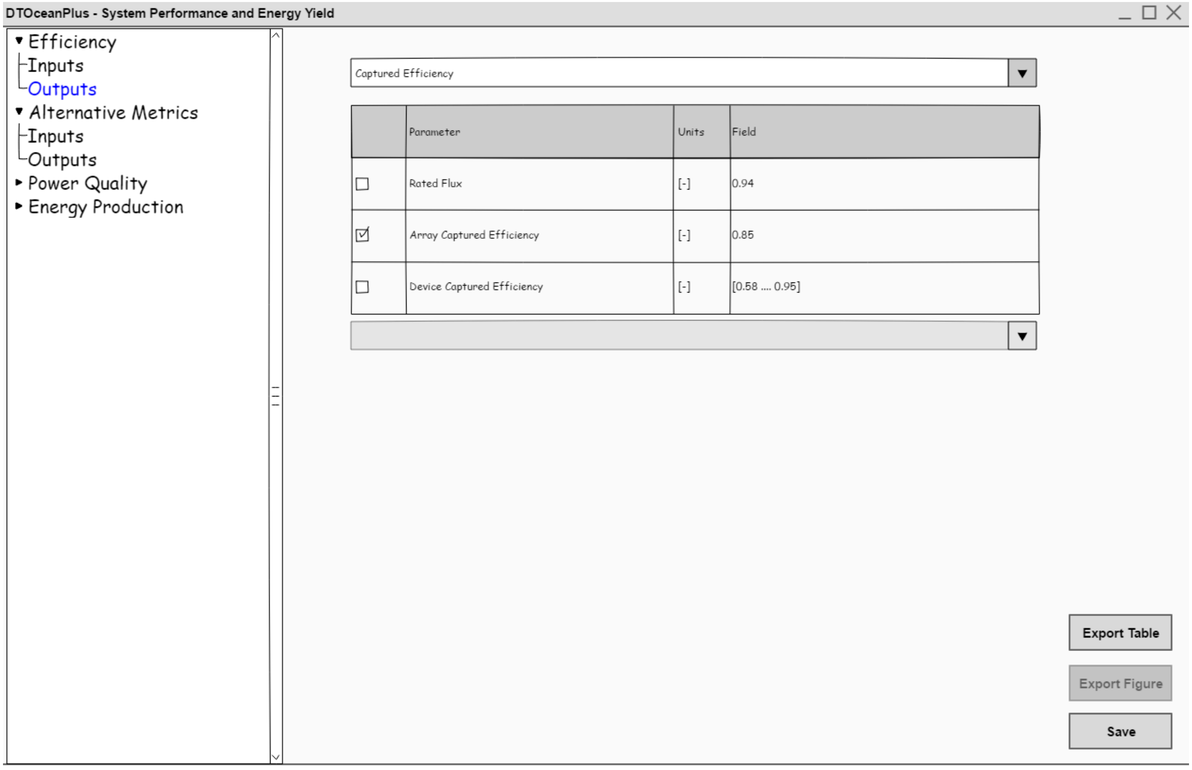
Once the run is finished, the User can access the Output page (see Figure 3.6 and Figure 3.7).

Again, from a Combo Box he can filter which kind of outputs he/she wants to visualise in the underneath table. In some cases, by selecting the outputs (see Figure 3.6) the user will have the possibility to select also a list of diagrams or figures to help visualising the outputs. In some other cases (see Figure 3.7), when dealing with scalar values, this functionality won't be activated.



	Parameter	Units	Field
☐	Rated Flux	[-]	0.94
☐	Array Captured Efficiency	[-]	0.85
☑	Device Captured Efficiency	[-]	[0.58 .... 0.95]

FIGURE 3.6: WIREFRAME OF THE GUI OF THE SPEY MODULE: OUTPUTS (I).



	Parameter	Units	Field
☐	Rated Flux	[-]	0.94
☑	Array Captured Efficiency	[-]	0.85
☐	Device Captured Efficiency	[-]	[0.58 .... 0.95]

FIGURE 3.7: WIREFRAME OF THE GUI OF THE SPEY MODULE: OUPUTS (II).

The user will be able to export the table of outputs in a user-friendly format, or to save the project. In case that a figure is available, then the user will be able to export the figure.

The GUI is still under development during the integration phase of the DTOceanPlus software. The wireframes above present the main functionality that the GUI of SPEY should have, but the exact implementation is subject to change.

Moreover, through the GUI the user could also access easily to a list of SPEY projects already run, and load one of them if he wants to.

3.1.4 THE TECHNOLOGIES

The Business Logic and the API of SPEY have been coded in Python version 3.6. The installation of the module requires the following packages:

- NumPy
- Matplotlib
- Bson
- Flask
- flask-babel
- flask-cors
- requests
- pandas.

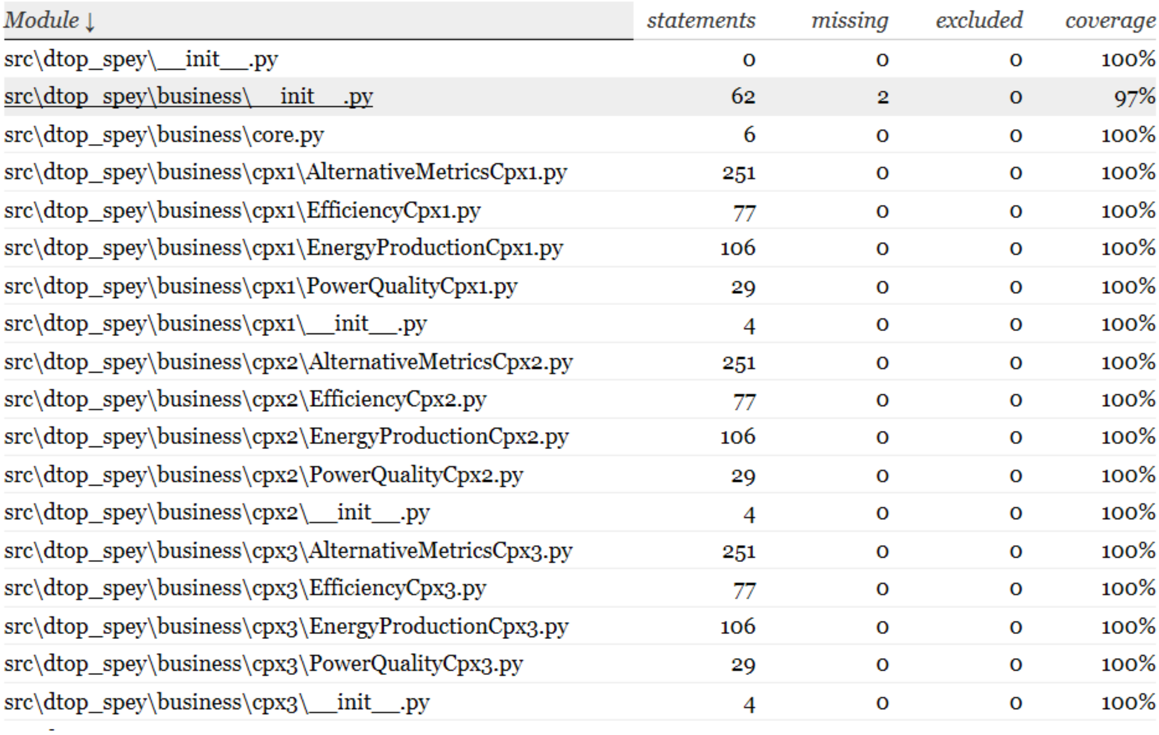
The API will rely on OpenAPI specification v3.0.2.

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

3.2 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 it has been taken into account the situation in which some values are zero, leading to numerical errors because of the division by zero.

In total, a set of 1,469 statements are present in the Business logic. A comprehensive set of "unit test" (232 unit tests of the Business Logic only) has been implemented covering the different functionalities of the Business Logic, and the coverage of these tests, measured by means of the py-cov extension of the py-test library, is 99% of the Business Logic.



Module ↓	*statements*	*missing*	*excluded*	*coverage*
src\dtop_spey__init__.py	0	0	0	100%
src\dtop_spey\business__init__.py	62	2	0	97%
src\dtop_spey\business\core.py	6	0	0	100%
src\dtop_spey\business\cpx1\AlternativeMetricsCpx1.py	251	0	0	100%
src\dtop_spey\business\cpx1\EfficiencyCpx1.py	77	0	0	100%
src\dtop_spey\business\cpx1\EnergyProductionCpx1.py	106	0	0	100%
src\dtop_spey\business\cpx1\PowerQualityCpx1.py	29	0	0	100%
src\dtop_spey\business\cpx1__init__.py	4	0	0	100%
src\dtop_spey\business\cpx2\AlternativeMetricsCpx2.py	251	0	0	100%
src\dtop_spey\business\cpx2\EfficiencyCpx2.py	77	0	0	100%
src\dtop_spey\business\cpx2\EnergyProductionCpx2.py	106	0	0	100%
src\dtop_spey\business\cpx2\PowerQualityCpx2.py	29	0	0	100%
src\dtop_spey\business\cpx2__init__.py	4	0	0	100%
src\dtop_spey\business\cpx3\AlternativeMetricsCpx3.py	251	0	0	100%
src\dtop_spey\business\cpx3\EfficiencyCpx3.py	77	0	0	100%
src\dtop_spey\business\cpx3\EnergyProductionCpx3.py	106	0	0	100%
src\dtop_spey\business\cpx3\PowerQualityCpx3.py	29	0	0	100%
src\dtop_spey\business\cpx3__init__.py	4	0	0	100%

FIGURE 3.8: COVERAGE OF THE TESTING ON THE BUSINESS LOGIC BY MEANS OF UNIT TESTS.

The unit test coverage of the Business Logic of SPEY is very high, ensuring quality of the code and guaranteeing that future developments on the same module won't break the current functionalities.

4. EXAMPLES

In this section, an example for each functionality implemented in SPEY 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 notice that none of the inputs to any of the functions correspond to any specific technology; they are just representative values for the inputs to be used as a demonstration of the computational capability of the SPEY module.

4.1 EFFICIENCY

Let us consider an array of five wave energy converters. The Input data are collected in the following Table 4.1.

TABLE 4.1: INPUTS FOR EXAMPLE OF USE OF THE EFFICIENCY FUNCTIONALITY

Quantity	Sub-Quantity	Value	Unit
Level of Complexity	—	1	1
Average Energy Flux	—	80	kW/m
Characteristic Dimension	—	5	m
Number of devices	—	5	-
Rated Power	—	500	kW
Array Annual Captured Energy	—	15.0e6	kWh
Annual Captured Energy per Device	*Device 1*	3.0e6	kWh
	Device 2	3.6e6	kWh
	Device 3	2.4e6	kWh
	Device 4	3.1e6	kWh
	Device 5	2.9e6	kWh
Array Annual Transformed Energy	—	13.35e6	kWh
Annual Transformed Energy per Device	*Device 1*	2.3e6	kWh
	Device 2	3.5e6	kWh
	Device 3	2.1e6	kWh
	Device 4	2.7e6	kWh
	Device 5	2.75e6	kWh
Array Annual Delivered Energy	—	11.0805e6	kWh

The outputs produced are reported in Table 4.2.

TABLE 4.2: OUTPUTS FOR EXAMPLE OF USE OF THE EFFICIENCY FUNCTIONALITY

Quantity	Sub-Quantity	Value	Unit
Rated Flux	—	1.25	-
Array Captured Efficiency	—	0.684	-
Array Captured Efficiency	*Device 1*	0.684	-
	Device 2	0.821	-
	Device 3	0.548	-
	Device 4	0.707	-
	Device 5	0.662	-
Absolute Array Transformed Efficiency	—	0.609	-
Absolute Device Transformed Efficiency	*Device 1*	0.524	-
	Device 2	0.799	-
	Device 3	0.479	-
	Device 4	0.616	-
	Device 5	0.627	-
Relative Array Transformed Efficiency	—	0.890	-
Relative Device Transformed Efficiency	*Device 1*	0.767	-
	Device 2	0.972	-
	Device 3	0.875	-
	Device 4	0.871	-
	Device 5	0.948	-
Absolute Array Delivered Efficiency	—	0.505	-
Relative Array Delivered Efficiency	—	0.830	-

The outputs will be available also for graphical visualisation to the user.

For example, in Figure 4.2, the absolute array efficiency is plotted by means of a bar graph for different subsystems. In this case all the three subsystems (Energy capture, Energy Transformation and Energy delivery) are available.

In Figure 4.2, the relative efficiency of the array is plotted against the subsystems, again using a bar plot. In the example, the efficiency of the transformation phase against the captured energy and the efficiency of the delivery phase against the transformation phase is plotted.

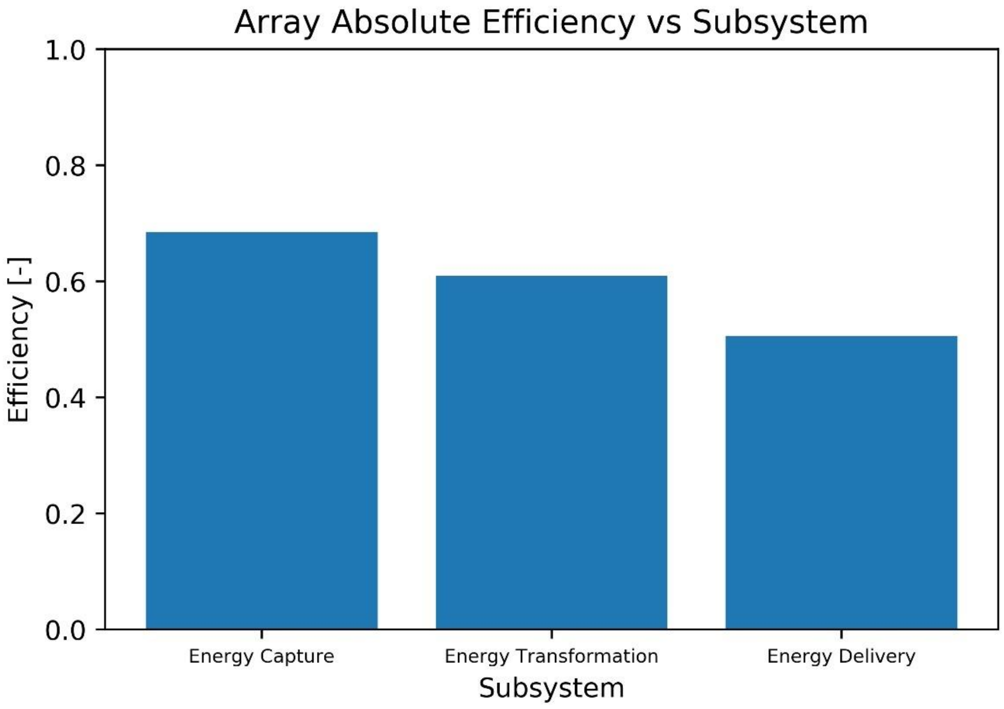


FIGURE 4.1. ARRAY ABSOLUTE EFFICIENCY VS. SUBSYSTEM

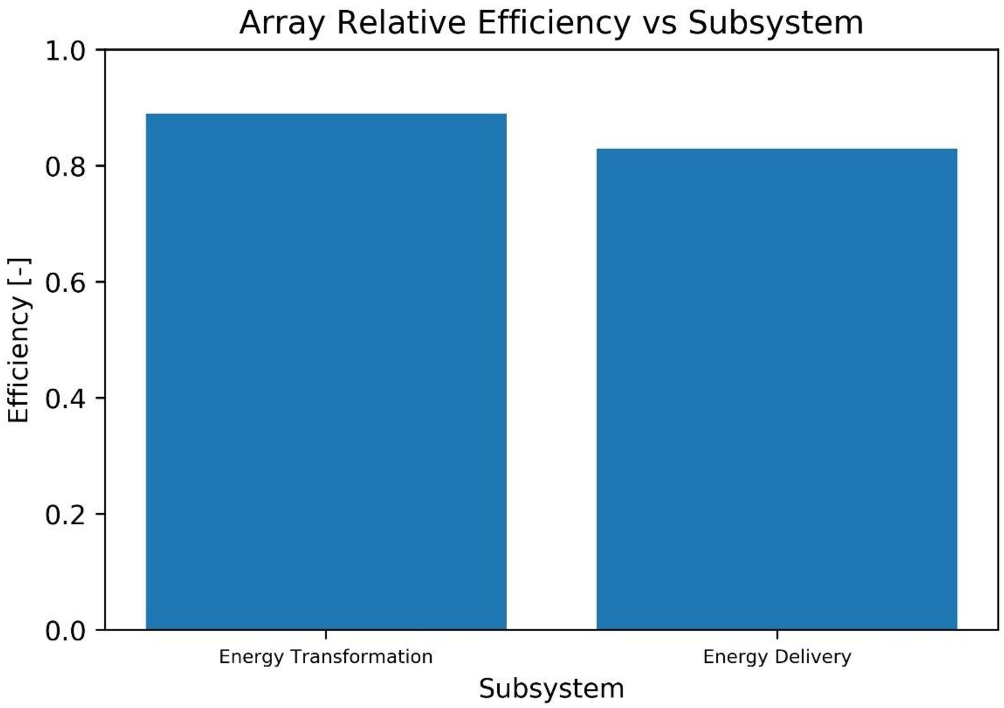


FIGURE 4.2: ARRAY RELATIVE EFFICIENCY VS. SUBSYSTEM

In Figure 4.3, the absolute efficiency per device has been plotted for two stages of the energy production chain. Indeed, the level of aggregation "Device" cannot be broken down for Energy Delivery. Also, in this case, a line plot is used, and each bar represent a stage of transformation. Similarly, in Figure 4.4 the relative efficiency per device is plotted. In this case, only the Energy transformation stage is considered, as no relative efficiency is computed at Energy Capture stage of transformation, and no breakdown per device is available at Energy Delivery level.

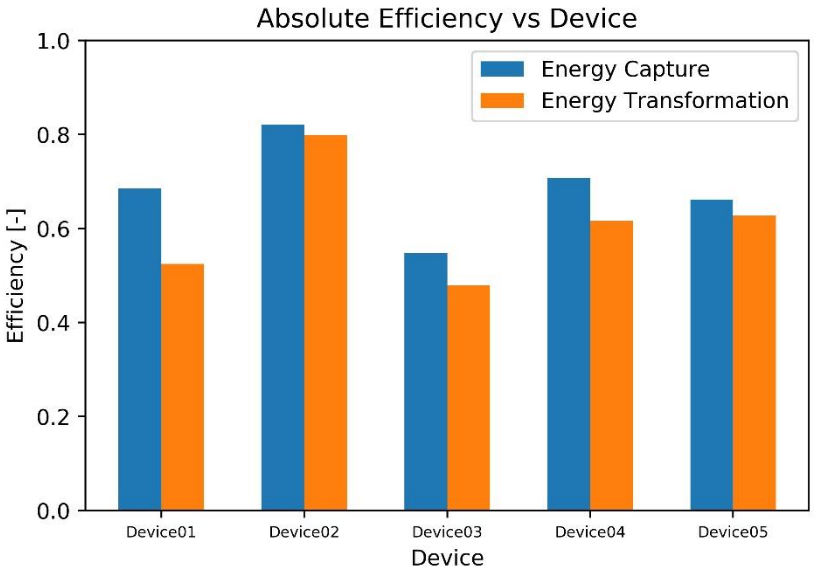


FIGURE 4.3: ABSOLUTE EFFICIENCY VS. DEVICES FOR DIFFERENT SUBSYSTEMS

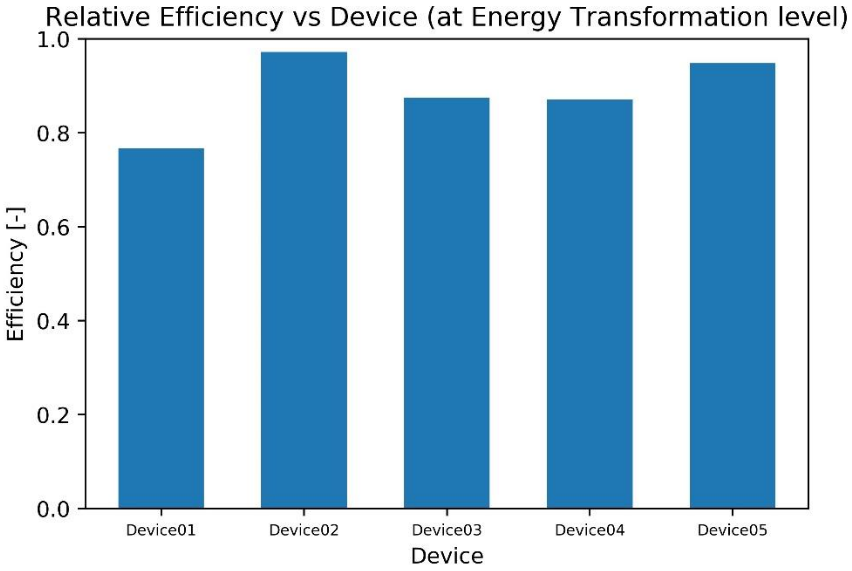


FIGURE 4.4: RELATIVE EFFICIENCY VS. DEVICES

4.2 ENERGY PRODUCTION

For demonstrating the capabilities of Energy Production functions, let us consider a scenario of 3 wave energy converters. The monthly occurrence matrix for the design site is shown in Table 4.3. The power delivery histogram (per device, i.e. the array power delivery histogram divided by the number of devices) is in Table 4.4.

TABLE 4.3: OCCURRENCE MATRIX OF HS [M] FOR THE EXAMPLE OF THE ENERGY PRODUCTION FUNCTIONS

Hs [m]	January	February	March	Abril	May	June	July	August	Septembe r	October	November	December
1.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.1	0.1
2.0	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.3	0.2	0.1	0.1
3.0	0.2	0.1	0.2	0.2	0.4	0.4	0.3	0.2	0.4	0.2	0.1	0.1
4.0	0.3	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.3
5.0	0.3	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.4

TABLE 4.4: OCCURRENCE MATRIX OF HS [M] FOR THE EXAMPLE OF THE ENERGY PRODUCTION FUNCTIONS

Hs [m]	Power [kW]
1.0	350.0
2.0	450.0
3.0	500.0
4.0	150.0
5.0	100.0

For each device, a table of the downtime hours for each year of the project lifecycle (supposing 15 years of project lifetime) will be provided by the Logistics and Marine Operation Module (see Table 4.5, Table 4.6, Table 4.7).

TABLE 4.5: DOWNTIME HOURS [H] OF DEVICE 1 FOR THE EXAMPLE OF THE ENERGY PRODUCTION FUNCTIONS

Year	January	February	March	April	May	June	July	August	September	October	November	December
1	475	256	386	153	369	193	134	77	3	97	205	249
2	385	475	487	91	225	336	2	10	84	256	165	241
3	325	368	418	262	298	184	122	15	64	93	284	151
4	380	379	461	329	238	81	60	121	30	196	123	151
5	289	263	328	263	203	243	137	133	36	100	197	255
6	330	287	313	85	349	147	124	67	129	238	118	145
7	452	470	471	145	256	177	47	39	42	145	102	175
8	302	451	441	306	346	245	35	124	112	220	261	296
9	448	385	349	80	124	211	45	18	58	181	253	167
10	516	214	457	278	326	113	139	24	15	133	92	153
11	327	231	417	179	217	159	86	63	108	280	226	118
12	273	230	271	203	273	307	106	70	41	113	116	279
13	287	243	505	187	178	165	83	105	78	211	202	85
14	450	414	261	260	100	253	50	43	77	153	232	75
15	453	475	344	266	98	196	56	39	109	238	183	130

TABLE 4.6: DOWNTIME HOURS [H] OF DEVICE 2 FOR THE EXAMPLE OF THE ENERGY PRODUCTION FUNCTIONS

Year	January	February	March	April	May	June	July	August	September	October	November	December
1	298	494	311	134	282	234	109	128	113	176	99	139
2	421	387	321	234	213	160	17	27	42	200	155	116
3	397	360	289	113	168	188	76	21	50	128	160	166
4	473	242	359	353	357	253	106	63	45	228	107	272
5	253	223	350	81	258	195	0	109	54	224	215	249
6	366	240	305	174	304	242	77	80	142	111	93	195
7	438	466	353	82	104	326	50	87	81	169	227	234
8	415	342	272	122	211	326	68	126	98	115	128	202
9	455	372	306	169	350	207	136	21	70	241	123	90
10	489	380	474	178	236	187	107	17	126	154	83	288
11	453	310	449	92	370	288	44	106	13	155	170	203
12	381	401	293	80	211	307	93	35	39	199	104	159
13	364	410	324	267	79	294	92	70	10	82	123	118
14	486	255	481	164	247	228	122	17	5	98	228	162
15	468	396	417	280	183	88	127	24	93	251	245	75

TABLE 4.7: DOWNTIME HOURS [H] OF DEVICE 3 FOR THE EXAMPLE OF THE ENERGY PRODUCTION FUNCTIONS

Year	January	February	March	April	May	June	July	August	September	October	November	December
1	454	368	418	251	345	108	75	144	137	261	152	200
2	251	213	368	152	282	84	34	80	129	226	222	238
3	340	255	360	318	283	299	74	114	94	283	128	113
4	253	405	329	334	287	339	94	54	122	271	182	210
5	406	487	441	261	95	167	34	28	98	138	219	139
6	364	357	437	257	368	115	50	142	80	175	75	268
7	454	214	372	165	290	97	3	111	40	131	168	232
8	235	299	375	231	193	101	97	137	131	178	170	135
9	251	368	421	270	344	224	45	8	120	166	142	179
10	389	433	366	231	266	113	112	78	124	157	228	285
11	417	268	326	209	146	99	98	144	107	76	148	206
12	303	412	444	200	158	330	72	140	37	280	165	213
13	475	254	414	340	93	358	58	77	57	169	105	201
14	247	394	249	151	184	224	53	77	108	162	213	176
15	325	437	489	348	333	255	40	16	105	77	192	77

Several results will be computed. For example, the Lifetime Net Energy Production of the Array will be 96125105.0 kWh, while in absence of downtime (Lifetime Gross Energy Production) it should have been 130603050.0 kWh, leading this to a ratio between net energy and gross energy of 73.6% (and of course to a ratio between lost energy and gross energy of 26.4%).

The yearly net energy ratios will be included in Table 4.8

TABLE 4.8: YEARLY ENERGY RATIOS

Year	DEVICE 1	DEVICE 2	DEVICE 3
1	0.73	0.727	0.691
2	0.717	0.768	0.761
3	0.731	0.784	0.704
4	0.738	0.692	0.687
5	0.738	0.768	0.752
6	0.744	0.742	0.715
7	0.744	0.733	0.766
8	0.671	0.737	0.756
9	0.770	0.726	0.728
10	0.740	0.719	0.715
11	0.744	0.716	0.766
12	0.750	0.755	0.708
13	0.752	0.768	0.724
14	0.758	0.741	0.767
15	0.739	0.731	0.714

Similarly to the Efficiency assessment, also the Energy Production functions will expose to the user some graphs or diagrams that we'll inform, in a graphical format, about the performances of the system, for various level of aggregation, over the lifetime of the project, with different level of time detail. For example, in Figure 4.5, the same data of Table 4.8 have been plotted. In Figure 4.6, the monthly lost energy ratio of Device 2 is plotted, while in Figure 4.7 the lifetime energy production is shown for the three devices.

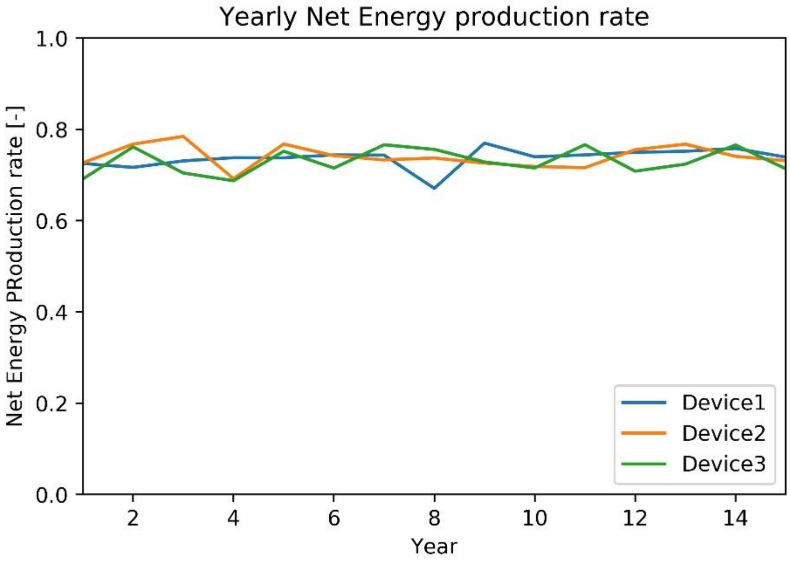


FIGURE 4.5. YEARLY NET ENERGY RATIO PER DEVICE

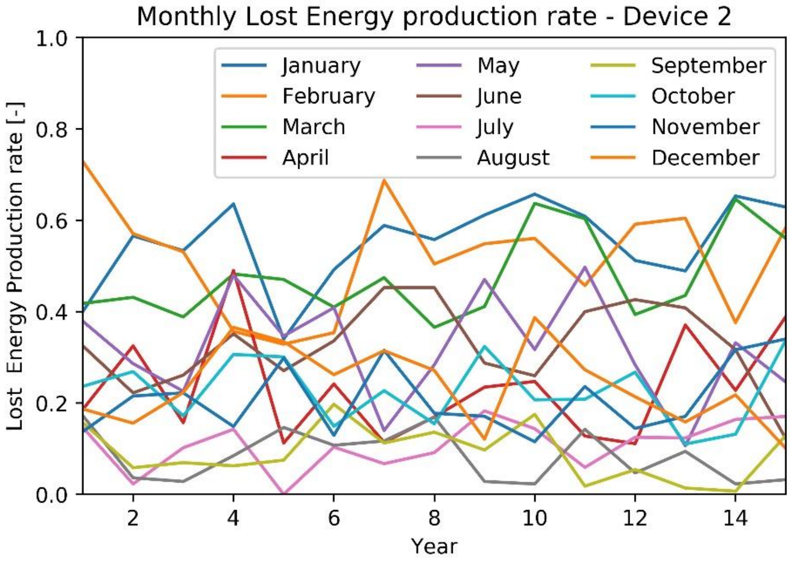


FIGURE 4.6: MONTLY LOST ENERGY RATIO OF DEVICE 2

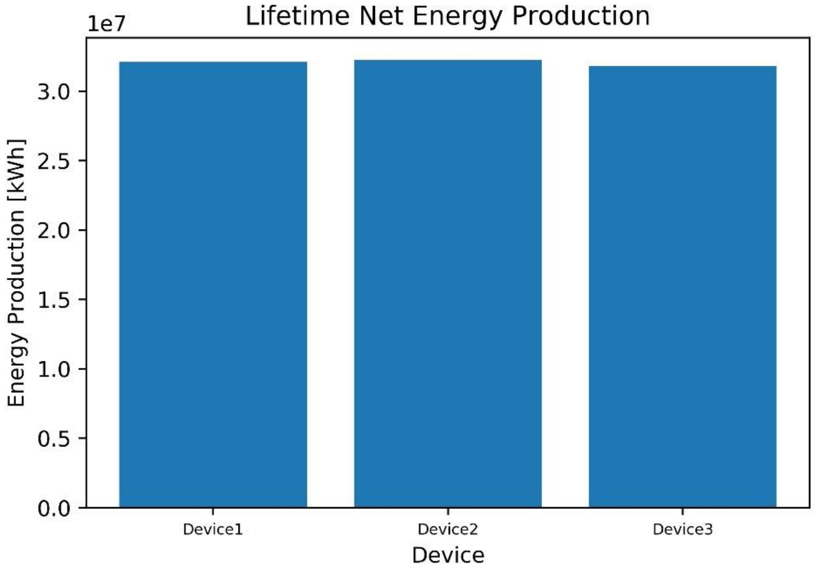


FIGURE 4.7: LIFETIME NET ENERGY PRODUCTION VERSUS DEVICE.

4.3 ALTERNATIVE METRICS

Let us consider the same example as in Section 4.1. In Table 4.9 the inputs required for running the Alternative Metrics tools are reported and they complement those in Table 4.1. The outputs produced are reported in Table 4.10.

TABLE 4.9: INPUTS FOR EXAMPLE OF USE OF THE ALTERNATIVE METRICS FUNCTIONALITY (SEE ALSO TABLE 4.1)

Quantity	Sub-Quantity	Value	Unit
Wetted Surface of the Ocean Energy converter	–	150	m²
Prime Mover Mass	–	50000	kg
Export Cable Length	–	3500	m
Intra array Cables	–	1500	m
Lease Area		10	km²

TABLE 4.10: OUTPUTS FOR EXAMPLE OF USE OF THE ALTERNATIVE METRICS FUNCTIONALITY

Quantity	Sub-Quantity	Value	Unit
DACE Wetted Area Parameter	*Device 1*	20000	kWh/m²
	Device 2	24000	kWh/m2
	Device 3	16000	kWh/m²
	Device 4	20667	kWh/m²
	Device 5	19333	kWh/m²
ACE Wetted Area Parameter	—	20000	kWh/m²

Quantity	Sub-Quantity	Value	Unit
DATE Wetted Area Parameter	*Device 1*	15333	kWh/m²
	Device 2	23333	kWh/m²
	Device 3	14000	kWh/m²
	Device 4	18000	kWh/m²
	Device 5	18333	kWh/m²
ATE Wetted Area Parameter	—	17800	kWh/m²
ADE Wetted Area Parameter	—	14774	kWh/m²
DACE Mass Parameter	*Device 1*	60.0	kWh/kg
	Device 2	72.0	kWh/kg
	Device 3	48.0	kWh/kg
	Device 4	62.0	kWh/kg
	Device 5	58.0	kWh/kg
ACE Mass Parameter	—	60	kWh/kg
DATE Mass Parameter	*Device 1*	46.0	kWh/kg
	Device 2	70.0	kWh/kg
	Device 3	42.0	kWh/kg
	Device 4	54.0	kWh/kg
	Device 5	55.0	kWh/kg
ATE Mass Parameter	—	53.4	kWh/kg
ADE Mass Parameter	—	44.32	kWh/kg
Power to mass Parameter	—	0.01	kW/kg
CL (device)	*Device 1*	4.28	m
	Device 2	5.13	m
	Device 3	3.42	m
	Device 4	4.42	m
	Device 5	4.14	m
CL (array)	—	21.39	m
CL Ratio (device)	*Device 1*	0.855	-
	Device 2	1.027	-
	Device 3	0.684	-
	Device 4	0.884	-
	Device 5	0.827	-
CL Ratio (array)		0.856	
CL Ratio Rated Power (device)	*Device 1*	0.0085	m/kW
	Device 2	0.0102	m/kW
	Device 3	0.0068	m/kW
	Device 4	0.0088	m/kW
	Device 5	0.0082	m/kW
CL Ratio (array)	—	0.0085	m/kW
Intra Array Cable Ratio	—	0.6	m/kW
Export Cable Ratio	—	1.4	m/kW
Total Cable Ratio	—	2.0	m/kW

Quantity	Sub-Quantity	Value	Unit
ACE Lease Area Parameter	-	1.5e6	kWh/km²
ATE Lease Area Parameter	-	1.335	kWh/km²
ADE Lease Area Parameter	-	1.108	kWh/km²

The outputs will be available also for graphical visualisation to the user. For example, Figure 4.8 shows the Capture Width Ratio per Device for the example illustrated in this section.

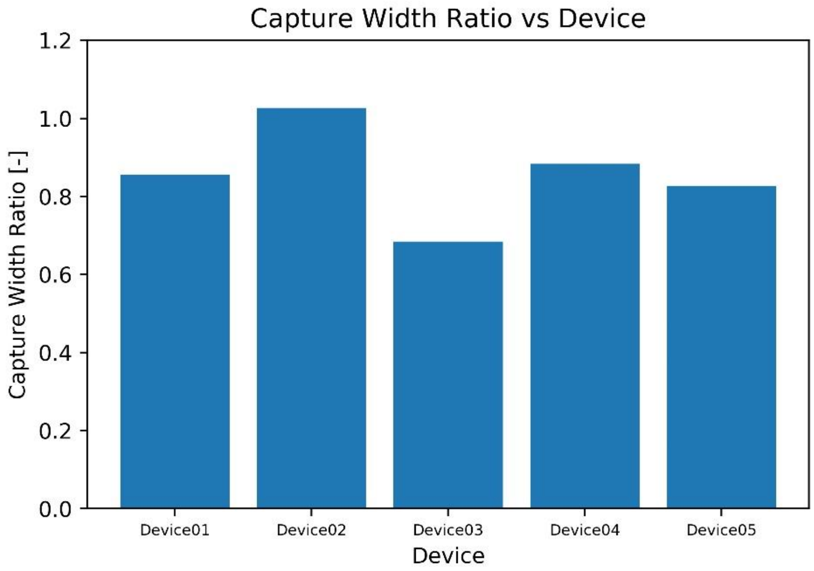


FIGURE 4.8: THE CAPTURE WIDTH RATIO PER DEVICE

4.4 POWER QUALITY

Let us consider a system of two tidal energy devices. The transformed active power and reactive power per sea states (SS1, SS2, SS3, SS4) per device are reported in Table 4.11 and Table 4.12.

TABLE 4.11: TRANSFORMED ACTIVE POWER (IN KW) IN THE EXAMPLE FOR SHOWING POWER QUALITY FUNCTIONALITY

	Device1	Device2
SS1	150.0	100.0
SS2	100.0	200.0
SS3	300.0	150.0
SS4	350.0	200.0

TABLE 4.12: TRANSFORMED REACTIVE POWER (IN KW) IN THE EXAMPLE FOR SHOWING POWER QUALITY FUNCTIONALITY

	Device1	Device2
SS1	50.0	50.0
SS2	50.0	100.0
SS3	150.0	100.0
SS4	150.0	100.0

The delivered active and reactive power for the array is in Table 4.13.

TABLE 4.13: DELIVERED ACTIVE AND REACTIVE POWER (IN KW) IN THE EXAMPLE FOR SHOWING POWER QUALITY FUNCTIONALITY

	Active	Reactive
SS1	200.0	100.0
SS2	100.0	100.0
SS3	400.0	275.0
SS4	300.0	200.0

The Power Quality Module can compute the phases between active and reactive power (in terms of its cosine), at device and array level, and the results are in Table 4.14 and Table 4.15.

TABLE 4.14: PHASE BETWEEN ACTIVE AND REACTIVE POWER PER DEVICE AT ENERGY TRANSFORMATION LEVEL

	Device1	Device2
SS1	0.948683	0.894427
SS2	0.894427	0.894427
SS3	0.894427	0.832050
SS4	0.919145	0.894427

TABLE 4.15: PHASE BETWEEN ACTIVE AND REACTIVE POWER PER DEVICE AT ENERGY TRANSFORMATION LEVEL

	Energy Transformation	Energy Delivery
SS1	0.928477	0.894427
SS2	0.894427	0.708208
SS3	0.874157	0.824042
SS4	0.910336	0.832050

The results in Table 4.15 will be proposed to the user as in Figure 4.9.

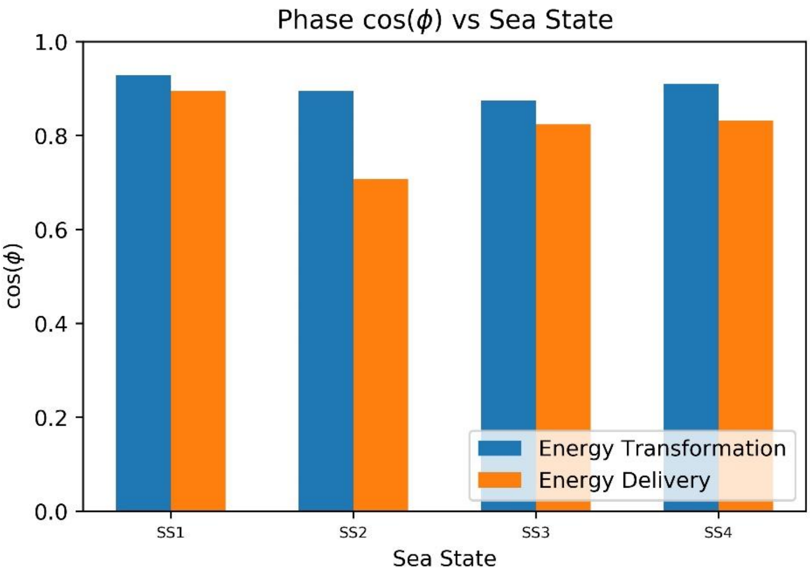


FIGURE 4.9: PHASE OF THE TRANSFORMED AND DELIVERED ENERGY AT ARRAY LEVEL USING THE POWER QUALITY FUNCTIONS OF THE SPEY MODULE.

5. FUTURE WORK

This deliverable captures the main functional and technical aspects of the System Performance and Energy Yield module (SPEY), implemented during the tasks T6.3 and T6.2 of the DTOceanPlus project. While the module can be run in a standalone mode at the moment of writing, some work is required yet to be fully integrated in the suite of tools of DTOceanPlus:

- 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;
- 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.

The remaining work is part of the continuous development/integration methodology described in Deliverable D7.4 "Handbook of software implementation" [3]. These activities will be developed within T6.2 (ongoing task) and T6.7 Verification of the code – beta version (running once that all the other modules have been developed) in order to extend the functionality of the SPEY module from standalone to fully integrated in the DTOceanPlus toolset.

6. REFERENCES

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[2] V. Nava, "D6.1 Technical Requirements for the Assessment Design Tools," DTOceanPlus, 2019.

[3] F. Pons, "D7.4 Handbook of software implementation," DTOceanPlus, 2019.

CONTACT DETAILS

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