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

Deliverable D6.5

Environmental and Social Acceptance Tools – alpha version

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EXECUTIVE SUMMARY

Deliverable D6.5 "Environmental and Social Acceptance Tools – alpha version" of the DTOceanPlus project include the details of the Assessment Design Tools module: "Environmental and Social Acceptance" (ESA), and it represents the result of the work developed during the tasks T6.2 and T6.6 of the project.

This document summarises both the functionalities as well as the more technical aspects of the code implemented for this module. ESA tools will provide the user with four assessments:

i. Identification of the potential presence of endangered species in the area (i.e. species included in the IUCN red list);
ii. Environmental impacts estimated using relevant metrics such as the underwater noise or the collision risk between vessels/devices and the marine wildlife;
iii. Estimation of the carbon footprint of the project in terms of two mid-point indicators, i.e. Global Warming Potential (GWP) and Cumulative Energy Demand (CED); and
iv. Information to improve the social acceptance of the project considering cost of consenting and jobs creation.

The Business Logic of the code, i.e. the actual functions of the ESA 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 ESA tool, inputting data and visualising results.

The Business Logic of the code has been verified (85%) 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.

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ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
BOM	Bill of Materials
CED	Cumulative Energy Demand
CL	Complexity Level
ED	Energy Delivery
EIA	Environmental Impact Assessment
EIS	Environmental Impact Score
ES	Endangered Species
ESA	Environmental and Social Acceptance
ET	Energy Transformation
GUI	Graphic User Interface
GWP	Global Warming Potential
HTTP	HyperText Transfer Protocol
IUCN	International Union for Conservation of Nature
LMO	Logistics and Marine Operations
NTU	Nephelometric Turbidity Unit
PPP	Probability of Presence of Protected species
PSa	Pressure Score adjusted
PTO	Power Take Off
RAMS	Reliability, Availability, Maintainability, Survivability
RR	Resource reduction
RS	Receptor Sensitivity
RSS	Receptor Sensitivity Score
SC	Site Characterisation
SG	Stage Gate
SI	Structured Innovation
SK	Station Keeping
SLC	System Lifetime Costs

1. INTRODUCTION

1.1 SCOPE AND OUTLINE OF THE REPORT

Deliverable D6.5 "Environmental and Social Acceptance Tools – alpha version" of the DTOceanPlus project includes the details of the Assessment Design Tools module: "Environmental and Social Acceptance" (ESA), and it represents the result of the work developed during the tasks T6.2 and T6.6 of the project.

This document summarises:

1) The use cases and the functionalities of the ESA tools (Section 2) namely providing the user with four assessments:
    i) Identification of the potential presence of endangered species in the area (i.e. species included in the IUCN red list);
    ii) Environmental impacts estimated using relevant metrics such as the underwater noise or the collision risk between vessels/devices and the marine wildlife;
    iii) Estimation of the carbon footprint of the project in terms of two mid-point indicators, i.e. Global Warming Potential (GWP) and Cumulative Energy Demand (CED) ; and
    iv) Information to improve the social acceptance of the project considering cost of consenting and jobs creation.
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).
3) 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 Environmental and Social Acceptance module belongs to the suite of tools "DTOceanPlus" developed within the EU-funded project DTOceanPlus. DTOceanPlus aims to accelerate the commercialization 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) and at various levels of complexity (Early/Mid/Late stage).

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 Characterization (SC):* to characterize the site, including metocean, geotechnical, and environmental conditions.
    - *Machine Characterization (MC):* to characterize the prime mover;
    - *Energy Capture (EC):* to characterize 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.

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

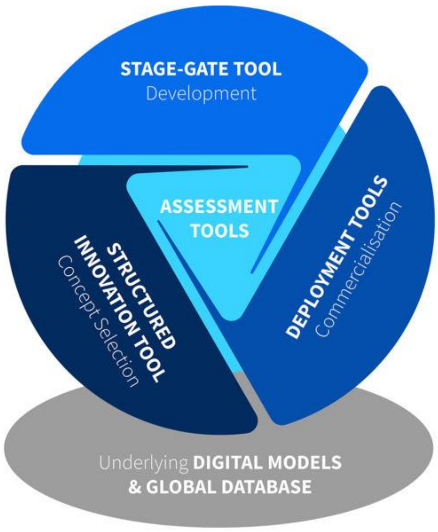


FIGURE 1.1: REPRESENTATION OF DTOCEANPLUS TOOLS

2. USE CASES AND FUNCTIONALITIES

The Environmental and Social Acceptance (ESA) module will:

- Identify the potential presence in the area of endangered species classified as such by the IUCN and listed in international conventions and European directives, namely: Barcelona Convention; Berne Convention; Bonn Convention; Helcom Convention; Ospar Convention Washington Convention; Habitat Directive; Birds Directive; and Marine Strategy Framework Directive.[1]
- Assess the environmental impacts generated by the various technology choices and array configurations of wave or tidal devices, in terms of pressure existence (e.g. chemical pollution or collision risk with marine fauna) and associated receptor sensitivity (e.g. marine mammals or sensitive seafloor habitats);
- Estimate the carbon footprint of the project at the different phases of the project (i.e. production, installation, maintenance, decommissioning, and treatment) in terms of two mid-point indicators, namely the Global Warming Potential (GWP) and the Cumulative Energy Demand (CED);
- Provide insight on social acceptance of the project in terms of cost of consenting and jobs creation during the farm lifetime;
- Show results in terms of recommendations to reduce the potential environmental impacts and to increase social acceptance during the total lifecycle of a project.

[1] IUCN (www.iucn.org),
Barcelona Convention (http://web.unep.org/unepmap/);
Berne Convention (https://www.coe.int/en/web/bern-convention/presentation);
Bonn Convention (https://www.cms.int/en/legalinstrument/cms);
Helcom Convention (https://helcom.fi/about-us/convention/);
Ospar Convention (https://www.ospar.org/convention);
Washington Convention (https://www.cites.org/eng/disc/text.php);
Habitat Directive (Council Directive 92/43/EEC);
Birds Directive (Directive 2009/147/EC);
Marine Strategy Framework Directive (Directive 2008/56/EC)

2.1 THE USE CASES

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

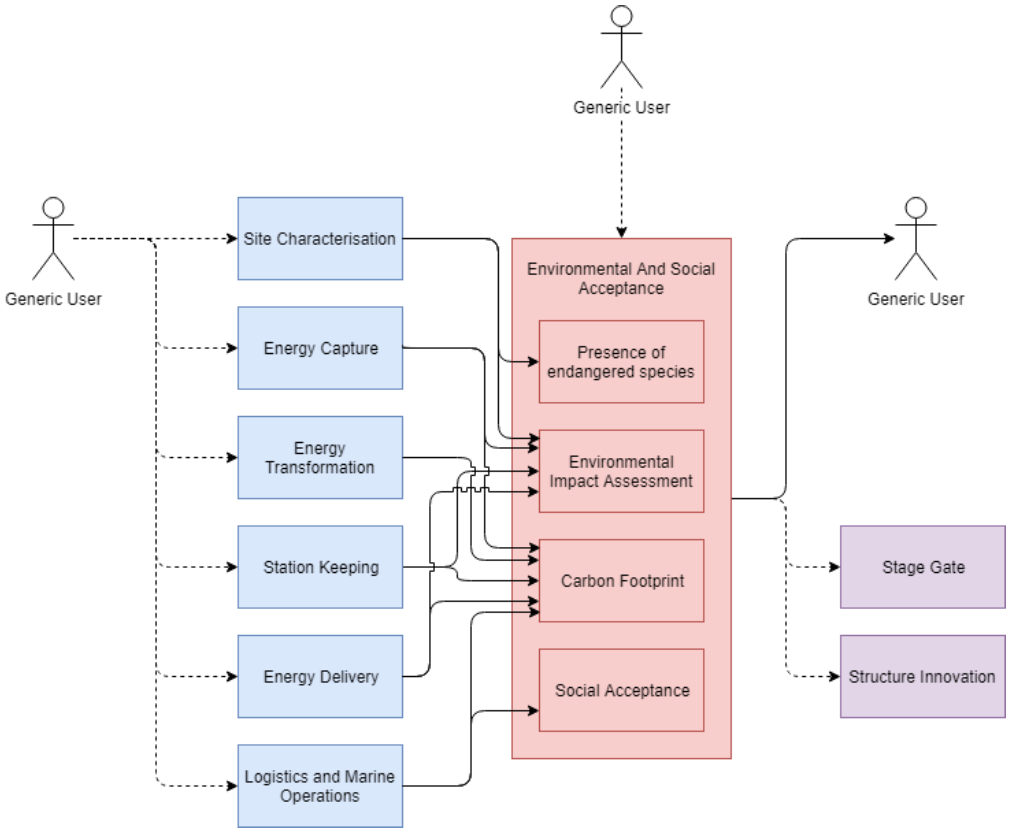


FIGURE 2.1: GENERIC USE CASE FOR USING THE ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS

The User can:

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

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

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

Modules that provide services that ESA consumes	Modules that are consuming services from ESA
Site Characterisation (SC), Energy Capture (EC), Energy Transformation (ET), Station Keeping (SK), 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 ESA 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 ESA module
3) The ESA 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 complete the information by running the Deployment Design Tools
5) ESA will run afterwards and perform the assessments
6) ESA will provide the assessments to SI/SG Tools to complete their framework
7) The outcome will be shown to the User.

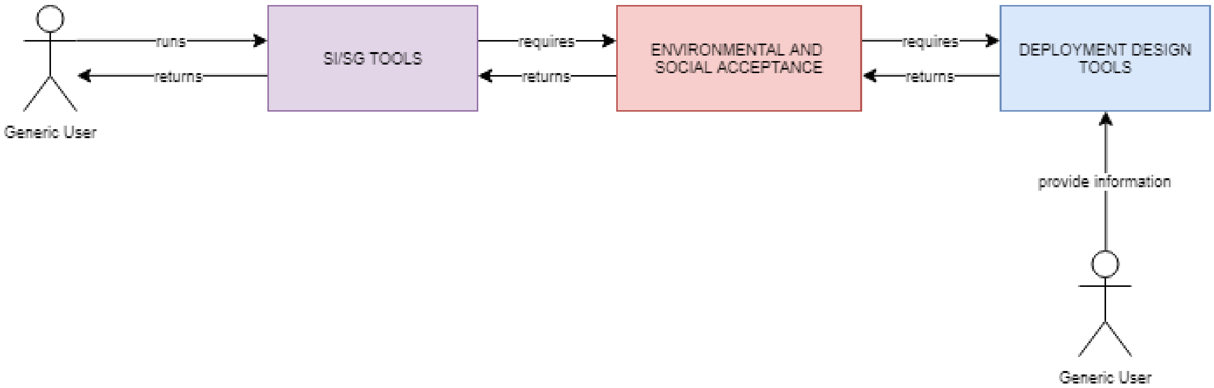


FIGURE 2.2: USE CASE FOR USING THE ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS WITHIN THE FRAMEWORK OF SG/SI DESIGN TOOLS.

2.1.2 USE CASE AFTER DEPLOYMENT DESIGN TOOLS

In this case, the User will run one or more Deployment Design Tools and then they will run the ESA module to carry out the assessments in terms of environmental impacts and social acceptance. The numerical results as well as the graphs/diagrams will be exposed to the user.

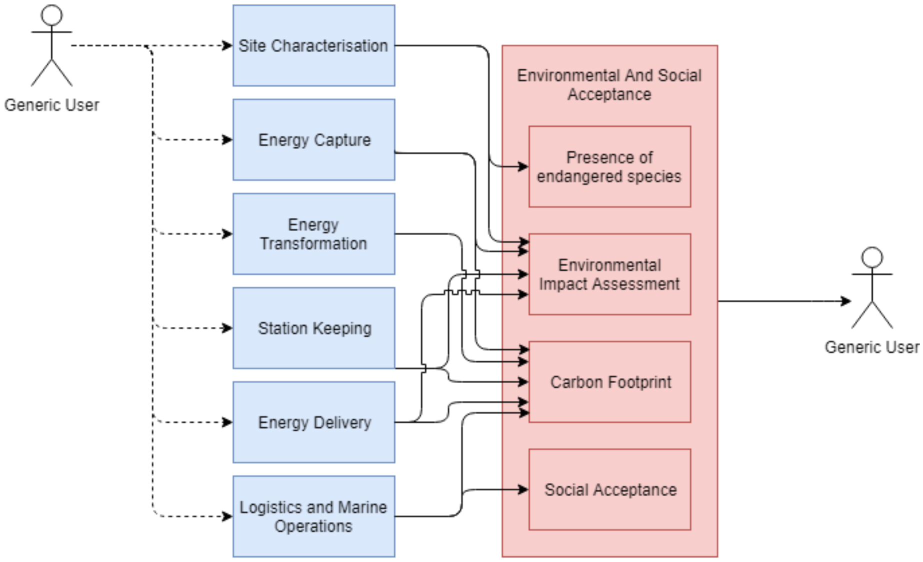


FIGURE 2.3: USE CASE FOR USING THE ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS AFTER RUNNING THE DEPLOYMENT DESIGN TOOLS.

2.1.3 STANDALONE MODE

In this Case, the User wants only to run the ESA module, to get some assessments in terms of environmental impacts and social acceptance. The user, in this case, will provide all the required inputs and they will be exposed to the overall results of the assessment.

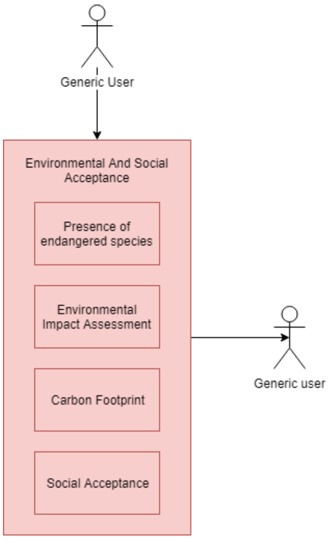


FIGURE 2.4: USE CASE FOR USING THE ENVIRONMENTAL AND SOCIAL ACCEPTANCE TOOLS IN STANDALONE MODE.

2.2 THE FUNCTIONALITIES

The ESA Module produces assessments in four main areas:

1) **Endangered species**: a set of global maps of probability of presence are integrated into Site Characterisation module and will provide insight on the presence of potentially endangered species in the farm and its corridor extent (see Section 0);
2) **Environmental impacts**: a set of 13 functions which link the identified pressures (e.g. collision risk) related to the farm's design choices with the potential receptors in the marine environment (e.g. marine mammals) (see Section 2.2.2);
3) **Carbon Footprint:** an estimation of two mid-point indicators, namely Global Warming Potential (GWP) in terms of greenhouse gas emissions CO2 per unit of energy produced and Cumulative Energy Demand (CED) in terms of total primary energy consumption per unit of energy at the different phases of the lifecycle of the project (see Section 2.2.3);
4) **Social Acceptance**: an estimation of the cost of consenting of the project and the number of people mobilized for operations at sea during the lifecycle of the project (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 (i.e. early[1], mid[2] and late[3] levels of complexity).

The ESA assessments evolves according to the level of complexity in relation to the level of information that is available from other modules or the user as shown in Table 2.2.

TABLE 2.2: ESA MODULE OUTPUTS AVAILABILITY ACCORDING TO THE LEVEL OF COMPLEXITY OF A GIVEN PROJECT

	Complexity level		Early[1]	Mid[2]	Late[3]
	Inputs availability for ESA module		low	intermediate	complete
Outputs availability for ESA module according to the level of complexity (**Green**: available, **Orange**: partially available, **Red**: not available)	Endangered species				
	Environmental impact assessment	Footprint			
		Collision risk			
		Energy modification			
		Reef effect			
		Reserve effect			
		Resting place			
		Chemical pollution			
		Turbidity			
		Temperature modification			
		Electromagnetic field			
		Underwater noise			

	Complexity level		Early[1]	Mid[2]	Late[3]
	Inputs availability for ESA module		low	intermediate	complete
	Carbon footprint	Global Warming Potential (GWP)			
		Cumulative Energy Demand (CED)			
	Social acceptance	Number of Jobs			
		Cost of consenting			

[1] Early complexity level: refers to early stages of conception of an ocean energy project. This level includes the concept creation and concept development stages, i.e. the project is still in the early immature concept phase.

[2] Mid complexity level: refers to stages where the ocean energy project is at the design optimisation and feasibility stage or even at the manufacturing and operability demonstration in representative environment stage, i.e. the project is at mid-mature testing phase.

[3] Late complexity level: refers to commercial array demonstration scale. The project is considered completely mature at this stage.

2.2.1 ENDANGERED SPECIES

2.2.1.1 PRINCIPLES AND OBJECTIVES

The first assessment of the ESA module aims to provide insight on Endangered Species (ES) potentially present in the project area.

ES will inform on the potential presence of 26 endangered species. The selection was based on their IUCN red list status and presence in European directives and international conventions. Five Class of animals were included: seven mammals, three Actinopterygii (bony fishes), six Chondrichthyes (cartilaginous fishes), five Aves (birds) and five Reptilia.

A local database of maps of large-scale probability of presence for each species has been integrated to DTOceanPlus Site Characterisation module. This NetCDF file including the global geographical information of all species has been built from AquaMaps[2]. This collaborative project aims at producing computer-generated (and ultimately, expert reviewed) predicted global distribution maps for marine species on a 0.5 x 0.5 degree grid of the oceans.

Models are constructed from estimates of the environmental tolerance of a given species with respect to depth, salinity, temperature, primary productivity, and its association with sea ice or coastal areas. Maps represent mean annual distributions of species and do not account for changes in species occurrence due to migration or unusual environmental events such as El Niño. They are based on data available through online species databases such as FishBase and SeaLifeBase and species occurrence

[2] Kaschner, K., K. Kesner-Reyes, C. Garilao, J. Rius-Barile, T. Rees, and R. Froese. 2016. AquaMaps: Predicted range maps for aquatic species. World wide web electronic publication, www.aquamaps.org, Version 10/2019.

records from OBIS or GBIF and using an environmental envelope model in conjunction with expert input.

Given the chosen location of implementation, ES will inform on the potential presence of 26 endangered species, notify on associated risks and give recommendations to have a better consideration to these species in the design processes and during the life cycle of the project. Considering that all marine birds and mammals are protected, a global warning advising to set up surveys and monitoring to improve general marine life knowledge in the area is systematically displayed.

2.2.1.2 INPUTS AND OUTPUTS

Inputs

The inputs needed to identify endangered species in the area are in Table 2.3.

TABLE 2.3: INPUTS FOR THE IDENTIFICATION OF ENDANGERED SPECIES

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
*PPP	Coordinates of the farm	SC, User	Coordinates	UTM

Outputs

From the farm's coordinates, the 'Endangered Species' class in ESA will look for the nearest coordinates to retrieve probability of presence of the 26 species at this point into the local database netCDF file. ES will provide information:

1) On the probability of presence of 26 endangered species listed in international and European conventions
2) About taxonomic classification of the identified endangered species:
    a. Class
    b. Order
    c. Family
    d. Latin name
    e. Common name
    f. IUCN status
3) Recommendations for design processes based on the main risks associated with the identified species: recommendations to mitigate identified impacts and to improve knowledge on the particular species on site (see Table 4.3 for example of ES recommendations, It is worth noticing that at this stage of writing recommendations for all endangered species are still under development)
4) Global recommendations for marine birds and mammals.

[3] 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)

2.2.1.3 IMPACT

The Endangered Species assessments can be used to:

- Identify very sensitive species potentially present in the lease area
- Identify aspects of the design that can be considered as a risk for the present endangered species
- Identify possible improvements to work on to minimise the impacts on the endangered species
- Provide recommendations for design processes based on the main risks associated and also provide global recommendations including monitoring survey protocols that are relevant to monitor the species in the array area

2.2.2 ENVIRONMENTAL IMPACTS

2.2.2.1 PRINCIPLES AND OBJECTIVES

Environmental Impact Assessment (EIA) consists of a set of functions that are able to qualify and quantify the potential pressures generated by the array of wave or tidal devices on the marine environment (Table 2.4). The aim of this assessment is to evaluate the overall impact of the different pressures of the project on the environment. In the following sections, the term "**Stressor**" will refer to the pressure that is created by the array or the logistics related to the array (Table 2.4) and the "**Receptor**" will refer to the marine animals and algal species that are impacted by the stressors.

TABLE 2.4: THE POTENTIAL PRESSURES GENERATED BY A WAVE OR TIDAL ARRAY

Pressure		Pressure		Pressure	
Energy modification		Turbidity		Reserve effect	
Footprint		Noise (underwater)		Reef effect	
Collision risk		Electromagnetic fields		Resting place	
Chemical pollution		Temperature modification			

The EIA is based on several scoring principles that are applied to each identified pressure. In summary, the use of the environmental functions allows the EIA to generate numerical values that will be converted into environmental scores (EIS - Environmental Impact Score). The conversion from the function' scores to the environmental scores are made through calibration matrices. Each function is associated with one calibration matrix (or several depending on the complexity of the function) in order to qualify the initial pressure score. Calibration matrices are based on literature data or empirical data together with a weighting protocol which is implemented in the EIA logic to better qualify the environmental impacts.

The scoring allocation system is generic for all environmental functions and based on three consecutive main steps (Figure 2.5):

Step 1. Qualification and quantification of the 'pressure' related to the farm's design choices. Each pressure is evaluated by an equation (Each pressure's equation is detailed in section2.2.2.2). The result of this equation is then converted into a Pressure Score (PS $\in [0:5]$). The PS is then adjusted to a new numerical value called the Pressure Score adjusted (PSa) through a 'weighting protocol' by multiplying the PS with a coefficient: the Weighting Score (WS) ranging from 0 to 1 (Equation 2.1). If no weighting is selected, a default value of 1 is used.

$$PS_a = PS * WS$$ **EQUATION 2.1**

Step 2. Definition of occurrence of 'receptors' or not in the area that is potentially affected by the pressures generated in the first step. PSa is then adjust depending on the receptor's sensitivity by multiplying it with the Receptor Sensitivity coefficient (RS), which ranges from 0 to 5, unless the user has no receptor data, in which case the RS is assumed to be at its maximum value 5. This process leads to the Receptor Sensitivity Score (RSS) (Equation 2.2**¡Error! No se encuentra el origen de la referencia.**). Different receptors can be identified and have different sensitivity to the pressure. In this case, the most sensitive receptors will be considered for the Environmental Impact Score (EIS) calculations.

$$RSS = RS * PS_a$$ **EQUATION 2.2**

To ultimately obtain the EIS two types of linear mapping can be applied depending on the pressure sign being negative (Equation 2.3**¡Error! No se encuentra el origen de la referencia.**) or positive (Equation 2.4**¡Error! No se encuentra el origen de la referencia.**).

$$EIS^- = -3.2 * RSS - 10$$ **EQUATION 2.3**

$$EIS^+ = 1.6 * RSS + 10$$ **EQUATION 2.4**

Step 3. Refinement of the receptor's qualification with the definition of their seasonal distribution (occurrence or absence on site during the different seasons of the year). Step 3 is similar to step 2 for each specific receptor declared onsite but is detailed for each month depending on the seasonal appearance of each receptor (Equation 2.5

$$EIS_{month} = SA_{\in[0:1]} * EIS$$ **EQUATION 2.5**

). EIS is modulated to take into account less sensitive receptors when the highest sensitive receptors are declared absent.

$$EIS_{month} = SA_{\in[0:1]} * EIS$$ **EQUATION 2.5**

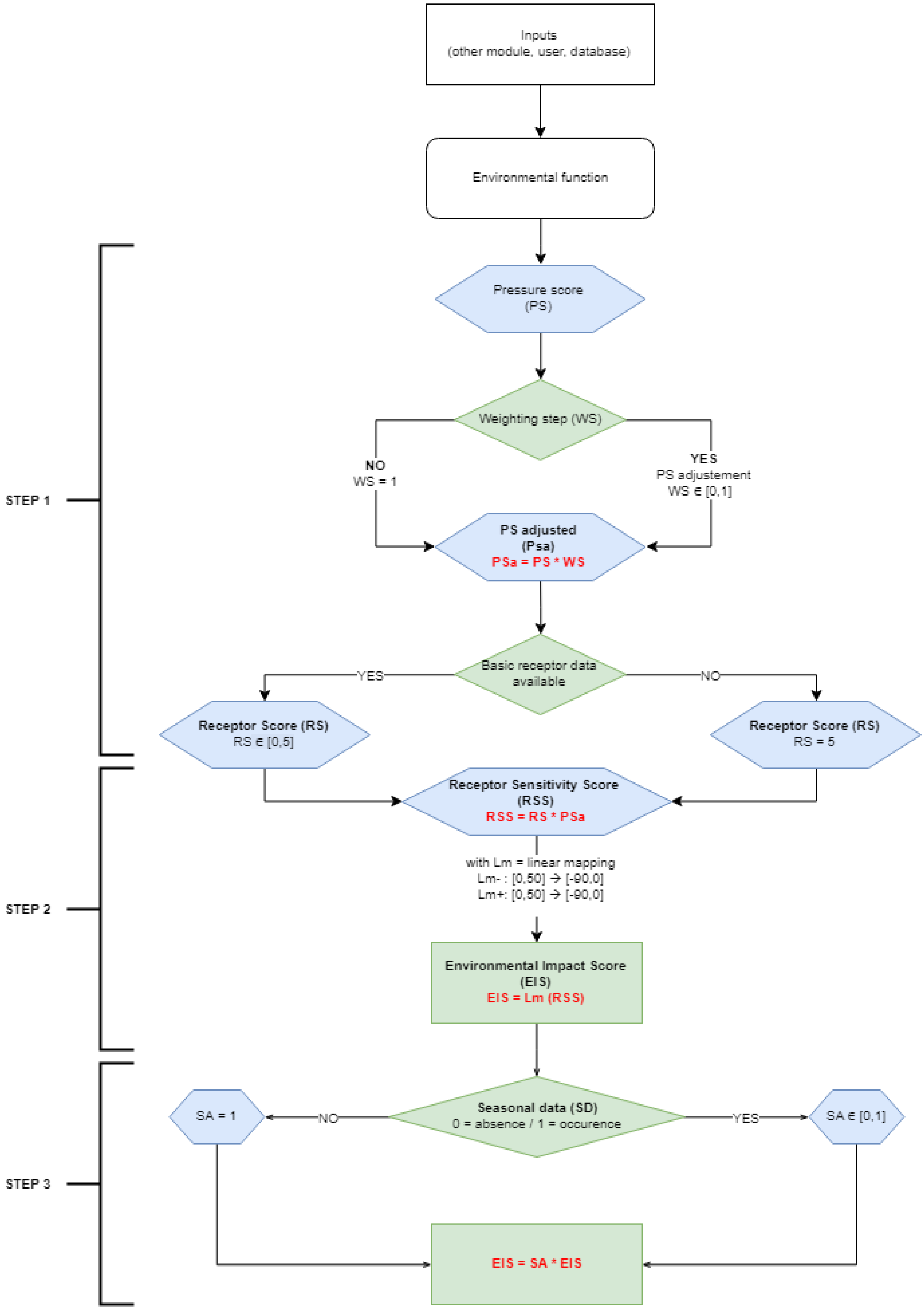


FIGURE 2.5: SCORING ALGORYTHM USED FOR EACH ENVIRONMENTAL PRESSURE

The EIA should inform the user about the 'environmental impact', including adverse (score between -100 and zero, Figure 2.6) but also potentially positive impact (zero and 50, Figure 2.6), of the technological choices and options made during each individual design module, as well as their combined effect.

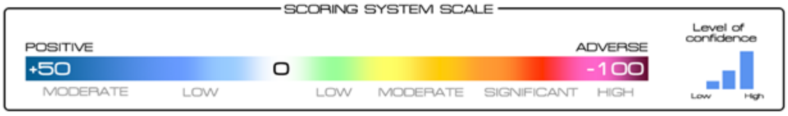
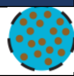
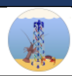
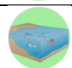
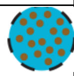


FIGURE 2.6: SCORING SYSTEM SCALE FOR ENVIRONMENTAL IMPACTS

Since each pressure can be linked to one or several technology group of the project (Table 2.5), the EIA will produce two levels of assessment (1) assessment of the impact of each technology group and (2) a global assessment which is the sum of all separate technology group assessments.

Recommendations based on the pressure and the receptor's score are provided to the user to help improve the environmental impact of the proposed array.

TABLE 2.5: LINKS BETWEEN PRESSURES AND THE FOUR TECHNOLOGY GROUPS

Pressures (see Table 2.4) / Technology groups	Energy modification	Footprint	Collision risk	Chemical pollution	Turbidity	Noise (underwater)	Electromagnetic fields	Temperature modification	Reserve effect	Reef effect	Resting place
Hydrodynamics											
Electrical Sub-system											
Moorings & Foundations											
Logistics (Installation and O&M)											

2.2.2.2 PRESSURES

The assessment of potential pressures generated by the array of wave or tidal devices on the marine environment (listed in Table 2.4 are detailed in the following subsections.

2.2.2.2.1 ENERGY MODIFICATION

The aim of this function is to assess the impact of current and wave energy modification due to arrays on biological receptors.

Stressor

The energy modification is induced by the extraction of the current and wave energy by the devices. Incoming and outgoing energy from arrays is used to calculate the percentage of energy extracted by arrays.

Receptors

Regarding energy modification, the major species that can be impacted are the benthic species (living on the hard and soft substrate).

Inputs

TABLE 2.6: INPUTS FOR THE EVALUATION OF ENERGY MODIFICATION

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
RR	Resource reduction	EC	Number, integer	%

Environmental Function

$$Energy\ modification = Resource\ reduction\ \ (\%)$$ **EQUATION 2.6**

Even if the environmental impact due to the extraction of energy is area specific, the environmental impact is usually qualified as "low" for 1% of the energy extracted and "noticeable" for an extraction around 10% [1]. The bed sediment stress is a function of the current speed, so small changes of current and waves can readily affect sediment transport.

Several ranges of extracted energy have been defined in Table 2.7:

TABLE 2.7: ENERGY MODIFICATION RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
[0 - 10 %]	0
[10 - 20 %]	1
[20 - 30 %]	3
>30 %	5

Weighting score

A flow modification can alter the dynamic sediment erosion/deposition and the size and composition of eroded particles [2]. In order to take that into account to better evaluate the impact of the extracted energy, a weighting score (WS) based on the characterization data of the sediment is used (Table 2.8).

TABLE 2.8: ENERGY MODIFICATION WEIGHTING SCORE

Soil group	Soil types	Weighting score
Cohesion less	Loose sand	1
	Medium sand	1
	Dense sand	1
Cohesive	Very soft clay	1
	Soft clay	1
	Firm clay	0.5
	Stiff clay	0.5

Soil group	Soil types	Weighting score
Other	Cemented	0.1
	Soft rock coral	0.1
	Hard glacial till	0.1
	Gravel cobble	0.1
	Hard rock	0.1

Receptor score

Benthic habitats of hard substrate are potentially more vulnerable than soft substrate because a reduction of the hydrodynamic energy could lead to a sedimentation that will change the habitats. This is the reason why we have assigned the score of 3 for species living in hard substrate and 1 for species in soft substrate. The receptor scores in Table 2.9 are based on the nature of the benthic habitats.

TABLE 2.9: ENERGY MODIFICATION RECEPTOR SCORE

Soil groups	Soil types	Receptor score
Hard substrate benthic habitats (cemented to hard rock soil types)	Rocky mesolittoral habitats Rocky infralittoral habitats Rocky circalittoral habitats (coastal and deep)	3
Soft substrate benthic habitats (cohesion less soil group)	Littoral sediment Infralittoral sediment Circalittoral sediment (coastal and deep)	1
Particular habitats	*Zostera noltii* beds, *Zostera noltii* beds, Maerl beds	4

2.2.2.2.2 FOOTPRINT

The footprint function aims at evaluating the pressure on the seabed occupied by electrical components, moorings and/or foundations, by equipment and anchors of vessels on the benthic species (living on the hard and soft substrate) and some other species as fishes classified in the ecosystem group (hard and soft substrate).

Stressors

Stressors are the physical anthropogenic elements that generates the 'footprint' pressure. The footprint is induced by electrical components, moorings and/or foundations, by equipment and anchors of vessels. The footprint is here considered as the total surface area occupied by physical anthropogenic elements.

Receptors

Receptors are all the biological (fauna and flora) species which can be impacted by the stressor. Regarding footprint the major species that can be impacted are the benthic species (living on the hard and soft substrate) and less mobile species [3] and some other species as fishes classified in the ecosystem group (hard and soft substrate).

Inputs

TABLE 2.10: INPUTS FOR THE EVALUATION OF FOOTPRINT

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
TotalElemSurf	Total surface area occupied by physical anthropogenic elements	SK, ED, LMO	Number, float	m^2
TotalLeaseSurf	Total surface of the lease area	SC	Number, float	m^2

Environmental Function

$$Footprint = \frac{\text{TotalElemSurf}}{\text{TotalLeaseSurf}}$$ **EQUATION 2.7**

An increase in the function score means an increase of the pressure. If the function's formula result is near to zero then the impact is minor. To qualify scores and calibrations for footprint, an empirical approach has been carried out. This approach is based on 5 ratio ranges of footprint areas vs. lease area (see Table 2.11)

TABLE 2.11: FOOTPRINT RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
0.01	1
[0.01 - 0.1]	2
[0.1 - 0.2]	3
[0.2 - 0.3]	4
>0.3	5

Weighting score

There is no data on the constraints so the weighting score is calibrated for the worst pressure case. It is the precaution principle. The score is one.

Receptor score

The ecosystem in hard substrata is potentiality more vulnerable because the number and the variability of species are richer than in soft substrata and that these species are less mobile. The types of benthic species are more diversified in hard substrate. This is the reason why we have assigned the score of 3 for species living in hard substrata and 2 for species in soft substrata. The receptor scores are based on the nature of the ecosystem (Table 2.12).

TABLE 2.12: FOOTPRINT RECEPTOR SCORE

Soil group	Soil types	Receptor score
Ecosystem living in hard substrate (cemented to hard rock soil types)	Firm clay	3
	Stiff clay	
	Cemented	
	Soft rock coral	
	Hard glacial till	

Soil group	Soil types	Receptor score
Ecosystem living in soft substrate (cohesion less soil group)	Loose sand	2
	Medium sand	
	Dense sand	
	Very soft clay	
	Soft clay	
Particular habitats	*Zostera noltii* beds, *Zostera noltii* beds, Maerl beds	4

2.2.2.2.3 COLLISION RISKS

The collision risks are related to the array sub-systems and to marine operations. Regarding array sub-systems, the function evaluates both the collision risk, and the entanglement between fauna (marine mammals and birds) with moorings lines, devices, and electrical components. Regarding the marine operations, the function evaluates the collision risk, between fauna (marine mammals and birds) and vessels. The two sources of pressure will be treated separately in this section because the parameters used to calculate the functions differ.

Collision risk related to array sub-systems

Stressors

Stressors are the physical anthropogenic element which causes collision and entanglement. Mooring system can contribute to a risk of entanglement while the presence of devices on seabed or in the water column can generate a collision risk for the species.

Receptors

Receptors are all the sensitive species that can be impacted by the stressor. Regarding entanglement risks, the major species that can be impacted are mainly marine mammals. Birds can be also affected with interactions with mooring lines when diving.

Inputs

TABLE 2.13: INPUTS FOR THE EVALUATION OF COLLISION RISK RELATED TO ARRAY SUBSYSTEMS

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
Coor	Coordinates of the Devices	EC	Number, float	UTM
devSize	Horizontal size of device	MC	Number, float	m
devHeight	Height of device immersed in the water	MC	Number, float	m
Bathy	Bathymetry	SC	Number, float	m
Cur_dir	Current direction	SC	Number, float	°

Environmental Function

Collision risk is the product of the probability of collision weighted by the ratio between device height and depth. The function estimates the number of intersections, between a large number of parallel lines aligned with the mean current axis. The probability of collision will be the ratio between the number of lines with at least one intersection by total number of lines (details of collision risk calculation is provided in Annexe 7.1.

$$Collision\ rate = \frac{n_{intersections}}{n_{lines}}$$ **EQUATION 2.8**

$$Depth_{factor} = \frac{devHeight}{Bathy}$$ **EQUATION 2.9**

$$Collision\ risk_{device} = Depth_{factor} * Collision\ rate$$ **EQUATION 2.10**

TABLE 2.14: COLLISION RISK RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
0.01	1
[0.01 - 0.1]	2
[0.1 - 0.2]	3
[0.2 - 0.3]	4
>0.3	5

Weighting score

Physical parameters of mooring affecting the risk of entanglement are the tension, the swept volume ratio and the mooring line curvature. According to [4], the collision risk between marine mammals and devices disposed in parallel in a channel is higher than in other areas, open ocean for example.

TABLE 2.15: COLLISION RISK WEIGHTING SCORE

Weighting parameter for mooring	Weighting score
catenary&chains	0.8
catenary&chains&nylon ropes	1.
catenary&chains&polyester ropes	0.8
taut	0.4
catenary&accessory buoy	1.
taut&accessory buoy	0.8
Weighting parameter for device	**Weighting score**
open water/ devices in parallel	0.5
sea loch entrance/ devices in parallel	1.
sounds/ devices in parallel	1.
open water/ devices in serie	0.25
sea loch entrances/ devices in serie	0.5
sounds / devices in serie	0.5

Receptor score

Regarding the collision risks between animals and devices, the major species that can be impacted are mainly marine mammals and birds. For both species the position of the devices in the water column has to be taken into account.

TABLE 2.16: COLLISION RISK RECEPTOR SCORE

Subclass or group	Receptor score
Medium diving birds	5
Shallow diving birds	5
Deep diving birds	5
Large odontocete_Mysticet	5
Odontoncete_dolphins	4
Seals	4

Collision risk related to marine operations

Stressors

Vessels used during the installation can generate a risk during the transport for marine mammals and birds.

Receptors

The major species that can be impacted are mainly marine mammals. Birds can be also affected with interactions with vessels.

Inputs

TABLE 2.17: INPUTS FOR EVALUATION OF COLLISION RISK RELATED TO MARINE OPERATIONS

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
NbVessel	Number of vessels during each phase	LMO	Number, integer	-
VesselSize	Medium size of vessels for each phase	LMO	Number, float	m
TotalLeaseSurf	Total surface of the lease area	SC	Number, float	m2

Environmental Function

$$area_{vessel} = \pi * 0.5 * VesselSize^2$$ **EQUATION 2.11**

$$Collision\ risk_{vessel} = NbVessel * \frac{area_{vessel}}{TotalLeaseSurf}$$ **EQUATION 2.12**

TABLE 2.18: COLLISION RISK VESSEL RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
0.01	1
[0.01 - 0.1]	2
[0.1 - 0.2]	3
[0.2 - 0.3]	4
>0.3	5

Weighting score

There is no data on the constraints so the weighting score is calibrated for the worst pressure case. It is the precaution principle. The score is one.

Receptor score

TABLE 2.19: COLLISION RISK WITH VESSELS RECEPTOR SCORE

Subclass or group	Receptor score
Medium diving birds	3
Shallow diving birds	3
Deep diving birds	3
Large odontocete_Mysticete	5
Odontoncete_dolphins	4
Seals	4

2.2.2.2.4 CHEMICAL POLLUTION

The goal of this function is to evaluate the impact of potential chemical pollution through leaks or spillage during the installation phase due to the presence of vessels in the area.

Stressors

The risk of pollution created during the installation phase of foundations and anchors, devices and electrical components is evaluated for the lifecycle logistics. The stressor appears in the transport of chemical pollutant during the installation phase.

Receptors

The chemical pollutants transported by vessels and equipment represent a risk (through leaks or spillage) that can affect the ecosystem living in the surrounding area [5][6].

Inputs

TABLE 2.20: INPUTS FOR THE EVALUATION OF THE RISK OF CHEMICAL POLLUTION

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
ChemPoll	Import of Chemical pollutant	User inputs	Number, float	Boolean

Environmental Function

The 'chemical pollution risk' function return score of 1 if an import of pollutant is present during the marine operations.

TABLE 2.21: CHEMICAL POLLUTION RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
0	0
1	5

Weighting score

TABLE 2.22: CHEMICAL POLLUTION WEIGHTING SCORE

Weighting parameter	Weighting score
bunker oil	0.6
highly toxic antifouling	1.
moderate toxic antifouling	0.4
natural antifouling	0.1

Receptor score

The sensitivity of species to the chemical pollution is analysed and different groups have been considered and an arbitrary Receptor Scores (RS) were attributed to these groups:

- Ecosystem living on cemented and rocky seabed (the diversity of species is higher than in the soft substrata (cohesive less seabed) so we consider the risk higher for these species)
- Ecosystem living in cohesive less seabed (the diversity of species is less than a rocky substrate, but the risk is present because the pollutant particles can be accumulated in the sediment.
- Fishes, marine mammals and birds can be impacted by the presence of oil or garbage in the sea. Toxic particles can be lethal for these species.

TABLE 2.23: CHEMICAL POLLUTION RECEPTOR SCORE

Subclass or group	Receptor score
Hard substrate benthic habitat	5
Soft substrate benthic habitat	4
Particular habitat	5
Shallow diving birds	5
Medium diving birds	5
Deep diving birds	5
Fishes	5

2.2.2.2.5 TURBIDITY

Evaluation of the intensity of the modification of the turbidity due to (1) the installation phase in the area, (2) the installation of the electrical components and (3) turbidity modification intensity in the water column due to array and the installed devices.

Stressors

The turbidity created during the installation phase of foundations and anchors, devices and electrical components is evaluated for the lifecycle logistics. Also, the hydrodynamic issue is considered a stressor for the turbidity function, the turbidity created during the operational phase of the devices.

Receptors

The turbidity created during the installation phase is a physical pressure that can affect benthos and the benthic habitats of cohesion less soils, cohesive soils or cemented and rocky soils, but also fishes [7], and sea birds [8].

Inputs

TABLE 2.24: INPUTS FOR THE EVALUATION OF TURBIDITY

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
$Turb_i$	Initial turbidity	User inputs	Number, float	NTU
$Turb_f$	Turbidity measured during operations (installation of devices and electrical components, operational phase of devices	User inputs	Number, float	NTU

Environmental Function

$$Turbidity\ modification = \frac{Turb_i}{Turb_f}$$ EQUATION 2.13

TABLE 2.25: TURBIDITY PRESSURE SCORE

Function result	PS - Pressure score
< 1	0
> 1	5

Weighting score

There is no data on the constraints so the weighting score is calibrated for the worst pressure case. It is the precaution principle. The score is one.

Receptor score

The hard substrate benthic habitats are potentiality more vulnerable by an increase of turbidity than soft substrate habitats because the number and the variability of species are richer than in a soft substrata including the presence of macroalgea. These macroalgea are indeed among the key species of the benthic habitats of hard substrate and the diminution of light induced by the increase of the turbidity directly affects them. Birds can also be impacted by the increase of the turbidity.

TABLE 2.26: TURBIDITY RECEPTOR SCORE

Subclass or group	Receptor score
Shallow diving birds	2
Medium diving birds	3
Deep diving birds	4
Fishes	4
Elasmobranchs	3
Hard substrate benthic habitat	3
Soft substrate benthic habitat	2
Particular habitat	4

2.2.2.2.6 UNDERWATER NOISE

Evaluation of the impact of underwater noise produced by the vessels and equipment during the installation phase, by the devices during the operational phase, by the underwater electrical substation and by the mooring lines on the seabed.

Stressors

Stressors are the physical anthropogenic elements that generate the environmental pressure. Underwater noise is induced by the installation phase of foundations and anchors, moorings lines through chafing and during the operational phase of the devices. The speed and power of vessels and equipment influence also the level of underwater noise.

Receptors

Receptors are all the species (fauna and flora) that can be impacted by the stressors. Underwater noise produced is a physical pressure that can affect marine mammals [9] and fishes [10]. If the noise spectra produced are more powerful than the audiogram of the species, this is considered as an impact.

Inputs

TABLE 2.27: INPUTS FOR THE EVALUATION OF UNDERWATER NOISE

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
$Noise_i$	Underwater noise before farm implantation	User inputs	Number, float	dB re 1 muPa
$Noise_f$	Underwater noise after farm implantation	User inputs	Number, float	dB re 1 muPa

Environmental Function

$$Underwater\ noise = \frac{Noise_i}{Noise_f}$$ **EQUATION 2.14**

TABLE 2.28 PRESSURE SCORE FOR THE UNDERWATER NOISE

Function result	PS - Pressure score
< 1	0
> 1	5

Weighting score

TABLE 2.29: UNDERWATER NOISE WIEGHTING SCORE

Subclass or group	Receptor score
noise vessels or tools 0 - 90 dB re 1muPa	0.4
noise vessels or tools 90 - 100 dB re 1muPa	0.6
noise vessels or tools 100 - 150 dB re 1muPa	0.8
noise vessels or tools 150 - 200 dB re 1muPa	0.9
noise vessels or tools > 200 dB re 1muPa	1.

Receptor score

TABLE 2.30: UNDERWATER NOISE RECEPTOR SCORE

Subclass or group	Receptor score
Large odontocete_Mysticete	5
Odontoncete_dolphins	5
Seals	4
Fishes	4

2.2.2.2.7 ELECTRICAL FIELD

The function evaluates of the electrical field modification induced by the electrical components.

Stressors

Electric field could interact with biological organisms and produce detectable physiological changes regarding specific functions such as reproduction, hydration, biochemical concentrations in organisms.

Receptors

Regarding electric fields, two main groups of species can react : i) marine species like elasmobranchs (sharks, rays) have specific electro-receptors that enable to detect and locate very small sources of E field, ii) electro species that haven't electro receptors but can detect voltage gradient issue to the movement of water and geomagnetic emission [11].

Inputs

TABLE 2.31: INPUTS FOR THE EVALUATION OF ELECTROMAGNETIC FIELDS

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
EFi	Electric fields before farm implantation	User inputs	Number, float	µV
EFf	Electric fields after farm implantation	User inputs	Number, float	µV

Environmental Function

$$Electric\ Field = {EF_i}/{EF_f}$$

EQUATION 2.15

TABLE 2.32: ELECTRICAL FIELDS RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
< 1	0
> 1	5

Weighting score

Cable burial helps to increase the distance between the generated fields and the marine environment [12]and therefore reduce the detectability field.

TABLE 2.33: ELECTRIC FIELDS WEIGHTING SCORE

Weighting parameter	Weighting score
Cable buried	0
Cable not buried	1

Receptor score

TABLE 2.34: ELECTRIC FIELDS RECEPTOR SCORE

Subclass or group	Receptor score
Electrosensitive species	4
Hard substrate benthic habitat	4
Soft substrate benthic habitat	4
Particular habitat	4

2.2.2.2.8 MAGNETIC FIELD

The function evaluates of the magnetic field modification induced by the electrical components.

Stressors

Magnetic fields could interact with biological organisms and produce detectable physiological changes regarding specific functions such as reproduction, hydration, biochemical concentrations in organisms.

Receptors

There are also specific species sensitive to the magnetic fields with two groups that are based on their detection capacities [11]: i) Species that can detect induced electric field: electro-sensitive species (including elasmobranchs) use induced electric field for their navigation., ii) Species that can detect magnetic field.

Inputs

TABLE 2.35: INPUTS FOR THE EVALUATION OF ELECTROMAGNETIC FIELDS

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
MFi	Magnetic fields before farm implantation	User inputs	Number, float	µT
MFf	Magnetic fields after farm implantation	User inputs	Number, float	µT

Environmental Function

$$Magnetic\ Field = {}^{MF_i}\!/_{MF_f} \quad \text{EQUATION 2.16}$$

TABLE 2.36: MAGNETIC FIELDS RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
< 1	0
> 1	5

Weighting Score

Cable burial helps to increase the distance between the generated fields and the marine environment [12] and therefore reduce the detectability field.

TABLE 2.37: MAGNETIC FIELD WEIGHTING SCORE

Weighting parameter	Weighting score
Cable buried	0
Cable not buried	1

Receptor Score

TABLE 2.38: MAGNETIC FIELD RECEPTOR SCORE

Subclass or group	Receptor score
Magnetosensitive species	2
Hard substrate benthic habitat	4
Soft substrate benthic habitat	4
Particular habitat	4

2.2.2.2.9 TEMPERATURE MODIFICATION

Evaluation of the impact of the water temperature modification around electrical components. A temperature increase can affect physiological functions and behaviour of marine organisms and especially benthic organisms.

Stressors

Cables produce heat when current flow through. Temperature can reach around 90°C within cables [13].These high temperatures can produce thermal radiation during operation of electrical components and therefore can potentially impact marine life. The impact of the increase of temperature of sediment due to the presence of a cable is difficult to evaluate [14] and only few studies have been carried out on this topic.

Receptors

A temperature increase can affect physiological functions and behaviour of marine organisms and especially benthic organisms. Species likely to be more affected by overheating cables are benthic species as they can be located at proximity of electrical components and usually less mobile than pelagic species. Most of these organisms live at the sediment water interface and up to 35 cm below this interface [15].

Inputs

TABLE 2.39: INPUTS FOR THE EVALUATION OF TEMPERATURE MODIFICATION

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
T_i	Temperature before farm implantation	User inputs	Number, float	°C
T_f	Temperature after farm implantation	User inputs	Number, float	°C

Environmental Function

$$Temperature\ modification = {}^{T_i}/_{T_f} \qquad \textbf{EQUATION 2.17}$$

TABLE 2.40: TEMPERATURE MODIFICATION RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
< 1	0
> 1	5

Weighting Score

Cable burial helps to increase the distance between the marine environment and the elevated temperature.

TABLE 2.41: TEMPERATURE MODIFICATION WEIGHTING SCORE

Weighting parameter	Weighting score
Cable buried	0
Cable not buried	1

Receptor Score

Species likely to be more affected by overheating cables are benthic species as they can be located at proximity of electrical components and usually less mobile than pelagic species.

TABLE 2.42: TEMPERATURE MODIFICATION RECEPTOR SCORE

Subclass or group	Receptor score
Hard substrate benthic habitat	3
Soft substrate benthic habitat	3
Particular habitat	4

2.2.2.2.10 RESERVE EFFECT

Evaluation of the reserve effect of the activities restriction in the array area (i.e. around the electrical components and the devices). This function is positive so if the result is close to zero the reserve effect of the array is not really pronounced. Close to one the reserve effect is maximal.

Stressors

The array can have a reserve effect depending on activities restriction in the array area (e.g. the fishery restrictions).

Receptors

Fishery restriction create a reserve effect that can positively influence all of the ecosystem [15].

Inputs

TABLE 2.43: INPUTS FOR THE EVALUATION OF RESERVE EFFECT

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
ProtectedSurf	Fishery restriction surface	User	number, float	m^2
TotalLeaseSurf	Surface of the lease area	SC	Number, float	m^2

Environmental Function

$$Reserve\ Effect = \frac{\text{ProtectedSurf}}{\text{TotalLeaseSurf}}$$

EQUATION 2.18

The highest score of 5 is assigned if the result of the function is higher than 0.5 (i.e. high reserve effect due to potential recovery higher than 50% which means more than 50% of the area is restricted for human activities and mainly fishery restriction). Pressure scores are distributed as follows:

TABLE 2.44: RESERVE EFFECT RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
[0-0.1]	0
[0.1-0.2]	0.5
[0.3-0.4]	1
[0.4-0.5]	2
[0.5-0.6]	3
[0.6-0.8]	4
[0.8-1]	5

Weighting score

The reserve effect is linked to the fishery restrictions. If fishery activities are completely prohibited in the area, the reserve effect will be potentially higher than for other restrictions. A Weighting Score WS is used to calibrate this data Table 2.45.

TABLE 2.45: RESERVE EFFECT WEIGHTING SCORE

Weighting parameter	Weighting Score
Fishery complete prohibition	1
Cast net fishing and fish traps authorized	0.5
No restriction	0

Receptor score

The reserve effect concerns each category of marine life: Benthos organism, Birds, Marine Mammals, and Fish.

Reserve effect impacts positively each category, the highest score (5) is given for each type of biological components, giving the Receptor Score Table 2.46.

TABLE 2.46 RECEPTOR SCORE FOR THE RESERVE EFFECT

Receptors	Receptor Score
Hard substrate benthic habitat	5
Soft substrate benthic habitat	5
Particular habitat	5
Shallow diving birds	5
Medium diving birds	5
Deep diving birds	5
Fishes	5
Elasmobranchs	5
Large odontocete_Mysticete	5
Odontoncete_dolphins	5
Seals	5

2.2.2.2.11 REEF EFFECT

This function evaluates the intensity of the reef effect due to the colonized surface of the underwater devices, mooring and foundations and electrical components.

Stressors

The reef effect is generated by all underwater elements of the array (i.e. underwater devices, mooring and foundations and unburied part of the electrical components).

Receptors

Receptors are all the marine species that can be impacted by the stressor. Regarding reef effect, the major species potentially impacted (positively) are benthic communities living on hard substrate [17]. Indirectly, this effect can also enhance the marine ecosystem in the vicinity of artificial reef.

Inputs

TABLE 2.47: INPUTS FOR THE EVALUATION OF REEF EFFECT

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
deviceSurf	Surface area of underwater part of device	MC	Numbers, float	m^2
elecSurf	Surface area of underwater part of electrical components	ED	Numbers, float	m^2
MoorSurf	Surface area of underwater part of moorings and foundations	SK	Numbers, float	m^2
TotalLeaseSurf	Surface of the lease area	SC	Number, float	m^2

Environmental Function

$$Reef\ Effect = \frac{\text{deviceSurf} + \text{elecSurf} + \text{MoorSurf}}{\text{TotalLeaseSurf}}$$ **EQUATION 2.19**

The reef effect is considered positive. New hard substrate can potentially create new habitats and host specific benthic communities, mainly composed of fixed and encrusting organisms. The pressure score (PS) is empirically given and presented in Table 2.48.

TABLE 2.48: REEF EFFECT RESULT AND PRESSURE SCORE

Function result	PS - Pressure score
[0-0.1]	0
[0.1-0.2]	0.5
[0.3-0.4]	1
[0.4-0.5]	2
[0.5-0.6]	3
[0.6-0.8]	4
[0.8-1]	5

Weighting score

It is useful to create a Weighting Score (WS) as a function of the design structure (vertical or horizontal) (Table 2.49).

TABLE 2.49: REEF EFFECT WEIGHTING SCORE

Types of device	Design	WS-Weighting Score
Wave	horizontal	0.5
Wave	vertical	1
Tidal	horizontal	0.5
Tidal	vertical	1

Receptor score

To discriminate the reef effect, two level of positive effects have been considered: Occurrence of benthic communities (biological ecosystem only restricted to the hard substrate), Enhanced ecosystem living in the vicinity of the reef effect.

TABLE 2.50: REEF EFFECT RECEPTOR SCORE

Receptors	RS-Receptor Score
Benthic communities	3
Enhanced ecosystem	5

2.2.2.2.12 RESTING PLACE

Evaluation of the impact of emerged parts of devices and electrical components as resting place for pinnipeds (marine mammals) and birds.

Stressors

Certain devices and electrical components have some emerged parts that can be used as a resting place for some species.

Receptors

In the case of the resting place function pinnipeds and birds are the biological receptors [17].

Inputs

TABLE 2.51: INPUTS FOR THE EVALUATION OF RESTING PLACE

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
deviceEmergSurf	surface area of the emerged part of device	EC	Numbers, float	m^2
subEmergSurf	surface area of the emerged part of substation	ED/user	Numbers, float	m^2
TotalLeaseSurf	Surface of the lease area	SC	Number, float	m^2

Environmental Function

$$Resting\ Place = \frac{\mathrm{deviceEmergSurf} + \mathrm{subEmergSurf}}{\mathrm{TotalLeaseSurf}} \qquad \textbf{EQUATION 2.20}$$

A resting place is considered as a positive effect and so the Pressure Score PS is positive Table 2.52.

TABLE 2.52: RESTING PLACE PRESSURE SCORE

Function result	PS - Pressure score
[0-0.1]	0
[0.1-0.2]	0.5
[0.3-0.4]	1
[0.4-0.5]	2
[0.5-0.6]	3
[0.6-0.8]	4
[0.8-1]	5

Weighting score

The resting place is defined in this report as a positive function, but this effect can be mitigated by the presence of dangerous parts of a device such as traps and moving parts. It was decided to add a weighting score based on this parameter Table 2.53.

TABLE 2.53: RESTING PLACE WEIGHTING SCORE

Dangerous Part of the devices	WS-Weighting Score
No dangerous part of devices	1
blades	0.1
turbine shroud	0.1
oscillating water column with cavity	0.1
oscillating bodies with translation part	0.1
oscillating bodies with rotating part	0.1
flexible sleeve between each box	0.1

Receptor score

With environmental protection status, the majority of birds and all pinnipeds are protected. A specific list of birds sensitive to resting places is expected to be available shortly. For now, RS is defined under two categories:

i. General birds
ii. Pinnipeds

TABLE 2.54: RESTING PLACE RECEPTOR SCORE

Species	RS-Receptor Score
Birds	5
Pinnipeds	5

2.2.2.3 IMPACT

The outputs of the Environmental Impact assessment tool in ESA will inform the user about:

- Qualitatively and quantitatively characterise the effects of the different stressors for tidal and wave array developments
- Quantitatively estimate exposure (and risk) to receptors
- Provide environmental impact assessment estimates (through the scoring system) to inform array design decisions
- Providing recommendations on design choices to improve the environmental impact score

2.2.3 CARBON FOOTPRINT

2.2.3.1 PRINCIPLE AND OBJECTIVES

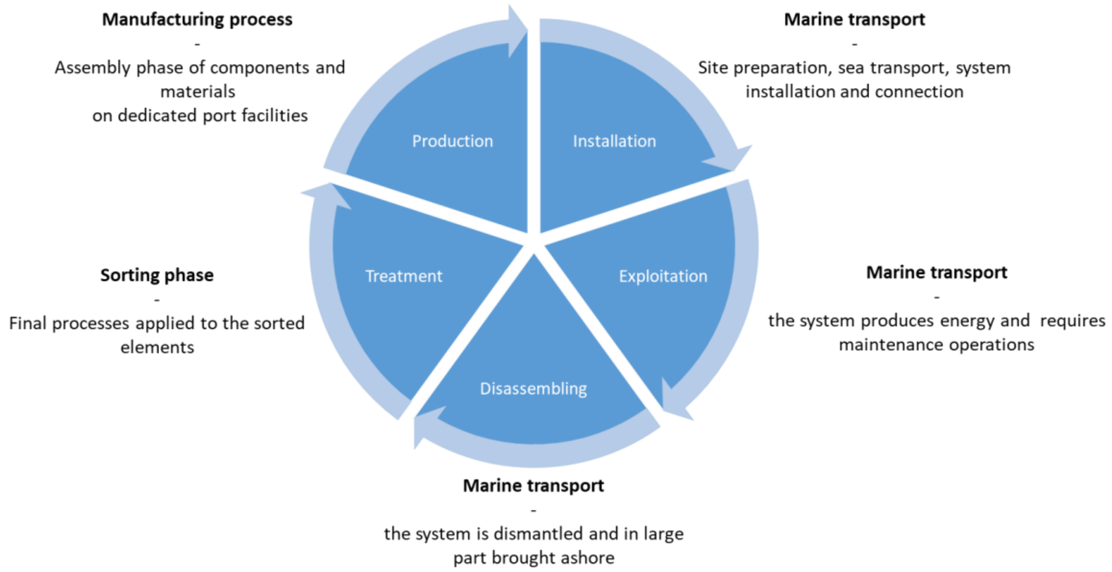


FIGURE 2.7: SCHEMATIC REPRESENTATION OF THE DIFFERENT LIFE CYCLE PHASES OF A PROJECT

Carbon footprint is a method of identifying and assessing the environmental impacts associated with the life cycle of a service or product [18]. It is a standardized method whose principles and conceptual framework are presented in "Environmental management, Life cycle assessment: Principles and framework" and "Environmental management, Life cycle assessment: Requirements and guidelines" [19]. The realization of an LCA is structured by the ISO 14040 and ISO 14044 standards.

For every phase of a project life cycle (i.e. production, installation, exploitation, disassembling and treatment phases) (Figure 2.7), there is an inventory of the components and materials weight (e.g. weight of alloyed steel) used for the device, mooring, foundations and electrical components and of the logistic information mobilized from production of materials up to their installation and maintenance (typically, the consumption of fuel).

It is worth noticing that from a qualitative point of view, the existence of recycling can reduce impacts at both ends of the life cycle: in the manufacturing phase through the use of recycled materials and at the end of the life cycle through the supply of materials to a recycling process. The objective of the model is to characterize a manufacturing process for the material in "open loop - equivalence of use" or "Open Loop - Same Primary Route" (OLSPR), which is an image of the coexistence in determined proportions of the primary and secondary manufacturing processes of this material [20].

This is why the benefits of recycling were distributed equally between the production and treatment stages. In this way, the benefits of recycling are represented in the value chain at the same stages as in reality: the use of recycled material leads to savings at the input end of the system and recovery at the output end.

Most of the processes used in the calculator have been characterized directly using the Ecoinvent[4] V3 database. The fuel combustion data are those used by the Interprofessional Technical Centre for Air Pollution Studies (Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique (CITEPA[5])).

The purpose of the impact assessment is to translate these flows into potential environmental impacts. In DTOceanPlus, two mid-point metrics are considered:

- The global warming potential (GWP, kg CO_2-eq/kWh) which is calculated in terms of CO_2 greenhouse gas emission per MW produced.
- The Cumulative Energy Demand (CED, MJ/kWh), calculated in terms of total consumption of primary energy per energy produced.

The Carbon Footprint assessments of the ESA module aim at:

- Conduct a life cycle assessment of the project
- Estimate the Global Warming Potential (GWP) at a global scale or for each phase of the project.
- Assess the Cumulative Energy Demand (CED) at a global scale or for each phase of the project.

The global scale GWP and CED are calculated by summing the GWP and CED calculated separately for each phase of the project life cycle. In the sections below, the inputs, models and outputs are presented for each life cycle phase.

2.2.3.2 INPUTS, MODELS AND OUTPUTS

Assessments of carbon footprint for each phase of the life cycle (see Figure 2.7) of the project are detailed in the following subsections.

2.2.3.2.1 PRODUCTION PHASE

Inputs

The inputs needed for carrying out the assessment of Global Warming Potential (GWP) and Cumulative Energy Demand (CED) during the production phase are represented in the Bills of Materials (BOM) listed in Table 2.55 below:

TABLE 2.55: INPUTS FOR THE EVALUATION OF THE CARBON FOOTPRINT: PRODUCTION PHASE

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
BOMmoor	BoM of moorings: Mass of materials of each component	SK, catalogue	Number, float	t
BOMmoorR	Mass of materials of each component to be recycled at the end of project lifetime	SK, user	Number, float	t

[4] https://www.ecoinvent.org/about/about.html
[5] CITEPA. Organisation et méthodes des inventaires nationaux des emissions atmosphériques en France (OMINEA). 2013.

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
BOMfound	BoM of foundations: Mass of materials of each component	SK, catalogue	Number, float	t
BOMfoundR	Mass of materials of each component to be recycled at the end of project lifetime	SK, user	Number, float	t
BOMdevice	BoM of Device: Mass of materials of each component	MC	Number, float	t
BOMdeviceR	Mass of materials of each component to be recycled at the end of project lifetime	MC, User	Number, float	t
BOMpto	BOM of PTOs: Mass of materials of each component	ET, catalogue	Number, float	t
BOMptoR	Mass of materials of each component to be recycled at the end of project lifetime	ET, User	Number, float	t
BOMelec	BOM of electrical infrastructure: Mass of materials of each component	ED, catalogue	Number, float	t
BOMelecR	Mass of materials of each component to be recycled at the end of project lifetime	ED, User	Number, float	t
TotProd	Total energy production	ED	Number, float	GWh
GWPmat	GWP of each material production	Local database[6]	Number, float	kgCO2-eq /t
GWPrecycl	GWP related to recycling process of each material	Local database	Number, float	kgCO2-eq /t
GWPBeneFactor	Half-life benefit factor from recycling	Local database	Number, float	kgCO2-eq /t
CEDmat	CED used to produce each material	Local database	Number, float	MJ/t
CEDrecycl	CED related to recycling process of each material	Local database	Number, float	MJ/t
CEDBeneFactor	Half-life benefit factor from recycling	Local database	Number, float	MJ/t

Methods and Outputs

During the production phase, the carbon footprint that is generated is mainly related to the production of materials (e.g. alloyed steel) that are used to build the devices, the electrical sub-systems and the moorings and foundations. The following formulas are applied to estimate:

- GWP during production phase (GWPprod):

The first step is to calculate the GWP related to each technology group (i.e. Equation 2.21, Equation 2.22, Equation 2.24, Equation 2.25, Equation 2.25) before summing the obtained values in order to

[6] Inputs from "local database" listed in the table below will be detailed in the technical note of ESA module.

calculate the GWP of the production phase (i.e. Equation 2.26). In the following equations, GWP_{mat} corresponds to the Global Warming Potential of the first fabrication of the material, if this material can be recycle, it is considered that $GWP_{recycle}$ is the GWP of the manufacturing processes of the secondary fabrication and $GWP_{benefactor}$ is the half of the benefits of recycling (the other half being assigned to the treatment phase).

EQUATION 2.21

$$GWPmoor = \frac{\sum_1^n[\mathrm{BOMmoor} \times \mathrm{GWPmat} + \mathrm{BOMmoorR} \times (\mathrm{GWPrecycl} - \mathrm{GWPBeneFactor})]}{TotProd}$$

EQUATION 2.22

$$GWPfound = \frac{\sum_1^n[\mathrm{BOMfound} \times \mathrm{GWPmat} + \mathrm{BOMfoundR} \times (\mathrm{GWPrecycl} - \mathrm{GWPBeneFactor})]}{TotProd}$$

EQUATION 2.23

$$GWPdevice = \frac{\sum_1^n[\mathrm{BOMdevice} \times \mathrm{GWPmat} + \mathrm{BOMdeviceR}\ \mathrm{x}\ (\mathrm{GWPrecycl} - \mathrm{GWPBeneFactor})]}{TotProd}$$

EQUATION 2.24

$$GWPpto = \frac{\sum_1^n[\mathrm{BOMpto} \times \mathrm{GWPmat} + \mathrm{BOMptoR} \times (\mathrm{GWPrecycl} - \mathrm{GWPBeneFactor})]}{TotProd}$$

EQUATION 2.25

$$GWPelec = \frac{\sum_1^n[\mathrm{BOMelec} \times \mathrm{GWPmat} + \mathrm{BOMelecR} \times (\mathrm{GWPrecycl} - \mathrm{GWPBeneFactor})]}{TotProd}$$

EQUATION 2.26

$$GWP_{prod} = GWPmoor + GWPfound + GWPdevice + GWPpto + GWPelec$$

- CED during production phase (CEDprod):

The first step is to calculate the CED related to each technology group (i.e., Equation 2.28, Equation 2.30, Equation 2.31, Equation 2.30, Equation 2.31) before summing the obtained values in order to calculate the CED of the production phase (i.e.Equation 2.32*)*.

EQUATION 2.27

$$CEDmoor = \frac{\sum_1^n[\mathrm{BOMmoor_n} \times CED\mathrm{mat_n} + \mathrm{BOMmoorR_n} \times (CED\mathrm{recycl_n} - \mathrm{CEDBeneFactor_n})]}{TotProd}$$

EQUATION 2.28

$$CEDfound = \frac{\sum_1^n[\mathrm{BOMfound_n} \times CED\mathrm{mat_n} + \mathrm{BOMfoundR_n} \times (CED\mathrm{recycl_n} - \mathrm{CEDBeneFactor_n})]}{TotProd}$$

EQUATION 2.29

$$CEDdevice = \frac{\sum_1^n[\mathrm{BOMdevice_n} \times CED\mathrm{mat_n} + \mathrm{BOMdeviceR_n} \times (CED\mathrm{recycl_n} - \mathrm{CEDBeneFactor_n})]}{TotProd}$$

EQUATION 2.30

$$CEDpto = \frac{\sum_1^n[\mathrm{BOMpto_n} \times CED\mathrm{mat_n} + \mathrm{BOMptoR_n} \times (CED\mathrm{recycl_n} - \mathrm{CEDBeneFactor_n})]}{TotProd}$$

EQUATION 2.31

$$CEDelec = \frac{\sum_1^n[\mathrm{BOMelec_n} \times CED\mathrm{mat_n} + \mathrm{BOMelecR_n} \times (CED\mathrm{recycl_n} - \mathrm{CEDBeneFactor_n})]}{TotProd}$$

EQUATION 2.32

$$CED_{prod} = CEDmoor + CEDfound + CEDpto + CEDelec$$

2.2.3.2.2 MARINE OPERATIONS (INSTALLATION, EXPLOITATION AND DISMANTLING PHASES)

Inputs

The inputs needed for carrying out the assessment of Global Warming Potential (GWP) and Cumulative Energy Demand (CED) during marine operations are listed in Table 2.56 below:

TABLE 2.56: INPUTS FOR THE EVALUATION OF THE CARBON FOOTPRINT: INSTALLATION, EXPLOITATION AND DISMANTLING PHASES

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
Totalfuelconso	Total fuel consumption during installation phase	LMO	Number, float	t
TotProd	Total energy production	ED	Number, float	GWh
LCVfuel	Lower calorific value of diesel fuel	Local database	Number, float	MJ/t
GWPfuel	100-year global warming potential of diesel fuel	Local database	Number, float	kgCO2-eq.t-1
CEDfuel	CED related to fuel consumption	Local database	Number, float	MJ/t
FactorCO2emis	CO2 emission factor of diesel fuel combustion	Local database	Number, float	kgCO2/GJ
FactorCH4emis	CH4 emission factor of diesel fuel combustion	Local database	Number, float	kgCO2/GJ
FactorN2Oemis	N2O emission factor of diesel fuel combustion	Local database	Number, float	kgCO2/GJ
ImpactFactorCO2	Impact factor of CO2 on global warming	Local database	Number, float	kgCO2-eq/kg
ImpactFactorCH4	Impact factor of CH4 on global warming	Local database	Number, float	kgCO2-eq/kg

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
ImpactFactorN2O	Impact factor of N2O on global warming	Local database	Number, float	kgCO2-eq/kg

Methods and Outputs

During the marine operation phases (i.e. installation, exploitation and disassembling phases), the carbon footprint will mainly be due to operations and maintenance at sea. These operations use different types of vessel and the main input to estimate GWP (kgCO2-eq/ kWh) and CED (MJ/kWh) is thus the total fuel consumption during marine operations. The following formulas are applied to estimate:

- GWP during marine operations (GWPmarOp):

A first equation allows to calculate the gas emissions (in kgCO2-eq) related to fuel consumption (i.e. Equation 2.33). A second equation is used to calculate the GWPmarOp (i.e. Equation 2.34) which include gas emissions plus the global warming potential of diesel fuel (i.e. 100-year global warming potential of diesel fuel).

EQUATION 2.33

$$GasEmission = (\text{Totalfuelconso} \times \frac{\text{LCVfuel}}{1000})(\text{FactorCO2emis} \times \text{ImpactFactorCO2} + \text{FactorCH4emis} \times \text{ImpactFactorCH4} + \text{FactorN2Oemis} \times \text{ImpactFactorN2O})$$

EQUATION 2.34

$$\text{GWPmarOp} = \frac{GasEmission + (\text{Totalfuelconso} \times \text{GWPfuel})}{TotProd}$$

- CED during marine operations (CEDmarOp):

EQUATION 2.35

$$\text{CEDmarOp} = \frac{\text{Totalfuelconso} \times \text{CEDfuel}}{TotProd}$$

2.2.3.2.3 TREATMENT PHASE

Inputs

The inputs needed for carrying out the assessment of Global Warming Potential (GWP) and Cumulative Energy Demand (CED) during treatment phase are listed in Table 2.57 below:

TABLE 2.57: INPUTS FOR THE EVALUATION OF THE CARBON FOOTPRINT: TREATMENT PHASE

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
BOMmoorR	Mass of materials to be recycled at the end of project lifetime	SK	Number, float	t
BOMfoundR	Mass of materials to be recycled at the end of project lifetime	SK	Number, float	t
BOMdeviceR	Mass of materials to be recycled at the end of project lifetime	EC	Number, float	t
BOMptoR	Mass of materials to be recycled at the end of project lifetime	ET	Number, float	t
BOMelecR	Mass of materials to be recycled at the end of project lifetime	ED	Number, float	t
TotProd	Total energy production	ED	Number, float	GWh
GWPBeneFactor	Half-life benefit factor from recycling for each material	Local database	Number, float	kgCO2-eq /t

Methods and Outputs

Recycling of materials at the end of the project life cycle is considered as a positive action which reduces the global carbon footprint of the project. GWPtreatment and CEDtreatment calculated here are subtracted from the global GWP and CED of the project life cycle. The following formulas are applied to estimate:

- GWP during treatment phase (GWPtreatment):

EQUATION 2.36

$$\mathrm{GWPtreatment} = \frac{\sum_1^n \begin{pmatrix} \mathrm{BOMmoorR_n} \times \mathrm{GWPBeneFactor_n} + \mathrm{BOMfoundR_n} \times \mathrm{GWPBeneFactor_n} \\ + \mathrm{BOMdeviceR_n} \times \mathrm{GWPBeneFactor_n} + \mathrm{BOMptoR_n} \times \mathrm{GWPBeneFactor_n} \\ + \mathrm{BOMelecR_n} \times \mathrm{GWPBeneFactor_n} \end{pmatrix}}{TotProd}$$

- CED during treatment phase (CEDtreatment):

EQUATION 2.37

$$\mathrm{CEDtreatment} = \frac{\sum_1^n \begin{pmatrix} \mathrm{BOMmoorR_n} \times \mathrm{CEDBeneFactor_n} + \mathrm{BOMfoundR_n} \times \mathrm{CEDBeneFactor_n} \\ + \mathrm{BOMdeviceR_n} \times \mathrm{CEDBeneFactor_n} + \mathrm{BOMptoR_n} \times \mathrm{CEDBeneFactor_n} \\ + \mathrm{BOMelecR_n} \times \mathrm{CEDBeneFactor_n} \end{pmatrix}}{TotProd}$$

2.2.3.3 IMPACT

The outputs of the carbon footprint metrics in ESA module will inform the user about the project potential impact in terms of gas emissions and use of primary energy during its life cycle. GWP and CED metrics are thus used to understand potential global impact of every phase of the life cycle of a project in terms of CO_2 emissions and non-renewable energy consumption. The two metrics proposed here are useful indicators to quickly compare different projects and scenarios.

2.2.4 SOCIAL ACCEPTANCE

2.2.4.1 PRINCIPLES AND OBJECTIVES

The social acceptance assessment of the ESA module aims at providing the user with an estimation of the number of created jobs (Njobs/MW) during MRE life cycle and the cost of consenting (€/MW) of the MRE. These metrics are important for social acceptance of MRE projects as the employment question is key in the acceptance of any new activity in a given region and the cost of consenting informs about the final cost of the energy produced.

At this point of the module development, the social acceptance functionality only takes in consideration employments on vessels during marine operations. Further research needs to be carried out to complete other phases of the project such as manufacturing processes.

2.2.4.2 INPUTS, MODELS AND OUTPUTS

Inputs

TABLE 2.58: INPUTS FOR THE EVALUATION OF THE POWER QUALITY

ID	Brief Description of the Input Quantity	Origin of the Data[3]	Data Model in ESA	Units
LCOE	Levelized Cost Of Energy	SPEY	Number, float	€/MW
NbPassengers	Number of passengers working on vessels mobilized for marine operations	LMO	Number, integer	-
TotProd	Total energy production	ED	Number, float	GWh

Methods and Outputs

The social acceptance functions are dependant from the outputs of the LMO, SPEY and ED modules. The cost of consenting (€/MW) corresponds to the Levelized Cost of Energy that is calculated in the SPEY module. Regarding the number of Jobs function, the following formula is used to generate the output of this function:

$$Nb\ of\ Jobs = \frac{\text{NBPASSENGERS}}{\text{TOTPROD}} \quad \textbf{EQUATION 2.38}$$

2.2.4.3 IMPACT

The social acceptance part of the ESA module evaluates and proposes recommendations to increase social acceptance through the number of jobs (Njobs/MW) during MRE life cycle (i.e. increasing the number of jobs) and the cost of consenting (€/MW) of the MRE (i.e. reducing the cost of energy).

3. THE IMPLEMENTATION

3.1 THE ARCHITECTURE OF THE TOOL

Each module of the DTOceanPlus suite of tools have been implemented using a similar structure which comprises 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 ESA or whose services are consumed by ESA.
- 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 ESA reflects, also in its architecture, the functionalities that were described in Section 2.

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

3.1.1.1 ENDANGERED SPECIES

Class SpeciesList

SpeciesList corresponds to the endangered species functionality (see section 0)). This class contains 5 properties corresponding to four taxonomic groups, each containing list of entities of class **Species** (see Figure 3.1). This class has two methods:

- *_init_from_files*, process the inputs list of species provided by the Site Characterisation module and/or the user
- *compute_all_species*, instantiate the four properties with data gathered from the database, each property is a list of entities of class **Species** of the same taxonomic group

Class Species

This subclass contains 9 properties including taxonomic information, main associated risks and recommendations on surveys and protocols.

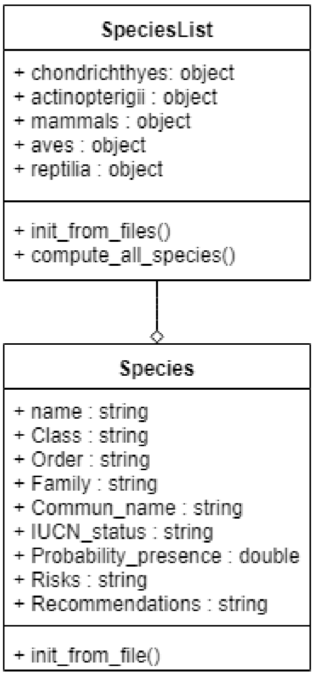


FIGURE 3.1: THE SPECIESLIST AND SPECIES CLASSES

3.1.1.2 ENVIRONMENTAL IMPACT ASSESSMENT

Class EIAList

The main **EIAList class** corresponds to the Environmental Impacts Assessment overall results. This class will process the required inputs and triggers subclasses to evaluate 13 pressures. This Class will regroup the results at project level, for each technology group and detailed for each pressure.

- *_init_from_files*, process all the inputs for EIA provided by the other modules and/or the user
- *compute_eia_tech*, call and provides inputs to the abstract class **EIA_tech_results** to evaluate each technology group impact
- *compute_eia_pressure*, process and provide detailed results for each pressure at the project scale
- *compute_eia_global*, summarise environmental impacts of all identified pressures and provides results at project scale.

Class EIA_tech_results

This Class contains properties listing the results for each of the technology group, each property is an entities of class **EIA_tech**, the methods of the Class **EIA_tech_results** allow to choose which technology group to assess and provide corresponding inputs to the different abstract classes **Stage**, **Logigram**, **Score:**

- *compute_impact_hydrodynamics*: instantiate assessment of technology group hydrodynamics
- *compute_impact_electrical*: instantiate assessment of technology group electrical
- *compute_impact_station_keeping*: instantiate assessment of technology group station keeping
- *compute_impact_logistics*: instantiate assessment of logistics group

Class **EIA_tech**

This subclass regroups the different results for each technology group and contains 5 properties:

- eis_dict, list the detailed results of all pressures generated by a technology
- global_eis, provide the global impact of a technology, is an entities of Class EIAglobal
- confidence_dict, details the level of confidence of each calculation of pressure's score
- recommendation_dict, details all recommendations for each pressure
- seasons, provide the detailed seasonal results of each pressure

Class **EIAglobal**

This subclass regroups the global results and contains 6 properties:

- negative_impact, global negative impact, summary of all pressures negative score
- min_negative_impact, minimum negative score of the different pressures
- max_negative_impact, maximum negative score of the different pressures
- positive_impact, global positive impact, summary of all pressures positive score
- min_positive_impact, minimum positive score of the different pressures
- max_positive_impact, minimum positive score of the different pressures

Abstract Class **Stage**

For each technology group, Abstract class **Stage** will instantiate the processes to evaluate impact for each technology group.

- *_init_logigram*: provide the list of pressures to assess depending on the relevant technology group, and check for constraints for each of this pressure,
- *get_inputs*: get the required inputs for each technology group (*get_inputs*),
- *can_assess* : check if all required inputs are provided
- *get_assessments*: call for the classes **Logigram** and **Assessment** to assess the impact of each technology group with negative and positive impacts

Abstract Class **Logigram**

This abstract class will instantiate the methodology described in Figure 2.5 for each pressure:

- *init_pressure_score* : will request the pressure_score from the Abstract Class **Score**
- *init_weighting_score:* will request the weighting score from the Abstract Class **Score**
- *init_receptor_score:* will request the receptor score from the Abstract Class **Score**
- *init_receptor_table*: will check if the user provides information on the potential presence of receptors to this pressure
- *get_pressure_score*: The result of the environmental function is converted into a Pressure Score by interpolation of the result between the pressure scores, this function provides the PS
- *get_adjusted_pressure_score*, if constrain are provided, this function calculates the PSa in Equation 2.1**¡Error! No se encuentra el origen de la referencia.**
- *get_receptor_sensitivity_scores :* estimates RSS procedure corresponding to Equation 2.2**¡Error! No se encuentra el origen de la referencia.**
- *get_recommendations :* call the Score class to get all recommendations

- *normalise_score:* function that normalise the RSS, corresponds to Equation 2.3**¡Error! No se encuentra el origen de la referencia.** and Equation 2.4**¡Error! No se encuentra el origen de la referencia.**.
- *get_seasonal_score:* if seasonal information is provided, the function processes Equation 2.6

$$EIS_{month} = SA_{\in[0:1]} * EIS \quad \textbf{EQUATION 2.5}$$

- .
- *calculate_score:* processes all previous functions, and call for **Assessment** class.

Abstract Class **Score**

For each pressure results, This Class provide the pressure score (PS), will look for the weighting score (WS) and receptor score (RS) used in the logogram and provide associated generic explanation, associated general recommendation and detailed recommendation to improve the results:

- *init_table*: will look for the relevant csv table that corresponds to the pressure assessed
- *get_score*: will look for the relevant score in the csv table (pressure, weighting or receptor)
- *get_genericexplanation*: will look for the corresponding generic explanation
- *get_generalrecommendation:* will look for the corresponding general recommendation
- *get_detailedrecommendation*: will look for the corresponding detailed recommendation

Class **Assessment**

This Class will store history of the results and define the level of confidence assigned to the results of the pressures.

- *init_score_history*: this function records the scoring steps: PS, the constraint, EIS and pressure recommendations
- *init_receptor_history*: this function records the steps for receptors: the list of species, list of RSS and list of EIS
- *get_EIS*: return the EIS of a pressure
- *get_recommendations*: returns recommendations for a pressure

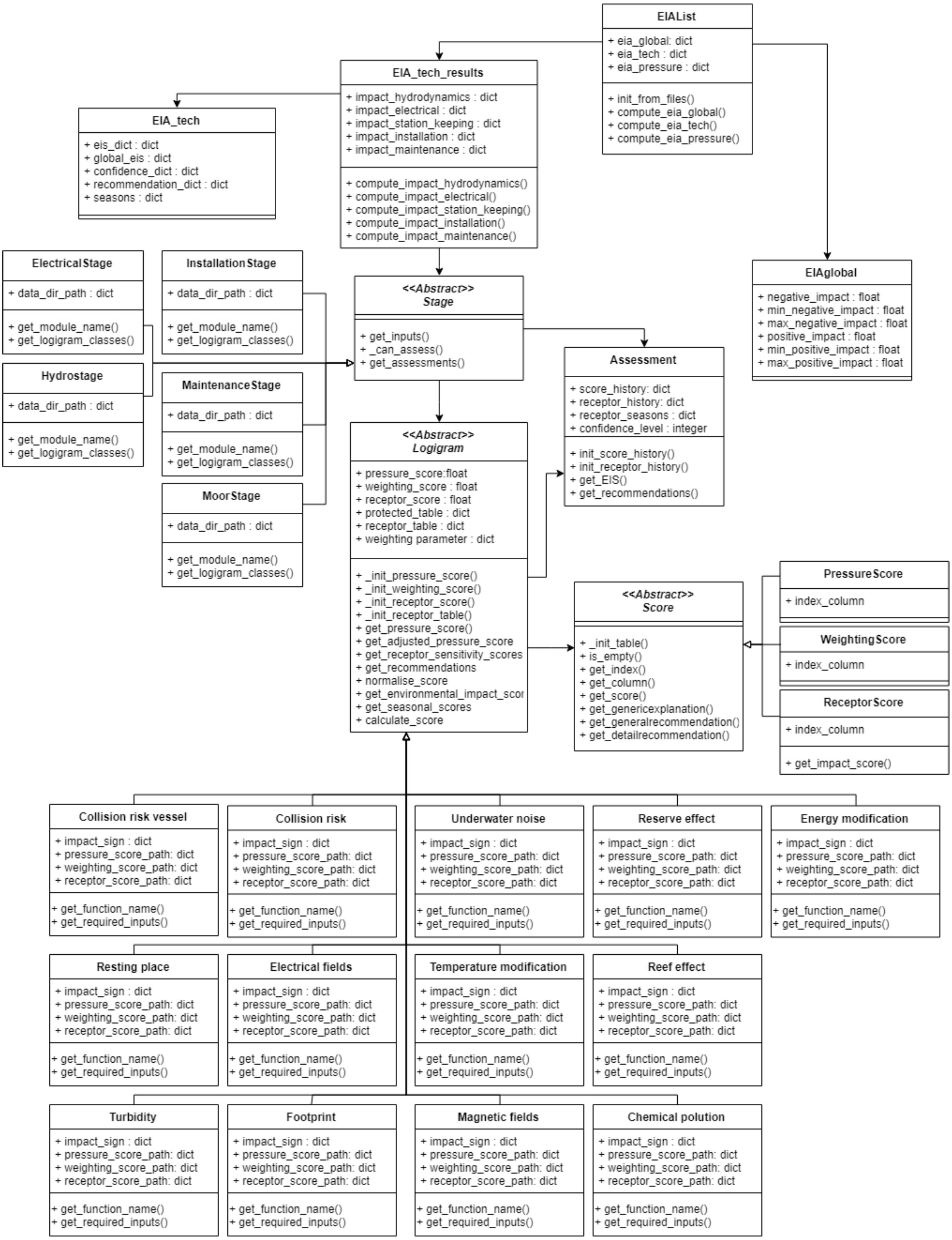


FIGURE 3.2: CLASS DIAGRAM FOR THE ENVIRONMENTAL IMPACT ASSESSMENT BUSINESS LOGIC

3.1.1.3 CARBON FOOTPRINT

Class **CFPList**

This class will process the required inputs and triggers subclasses to evaluate the carbon footprint of the project. This Class will regroup the results at project level, for each phase of the project.

- *_init_from_files*, process all the inputs for CFP provided by the other modules and/or the user
- *compute_cfp_phase*, provide inputs and instantiate assessment for each phase of the life cycle of the project
- *compute_cfp_global*, process all assessment and return global results of the project

Class **CFP_phase**

This Class has 5 properties for the different phases of the life cycle of the project and are entities of class CFP_results. This Class method instantiate assessment for one phase of the life cycle of the project:

- *get_cfp_phase*: determine which phase to assess and call for Class **CFP_results** to process the relevant assessment

Class **CFP_results**

This Class has 2 properties corresponding to the two mid-points indicators: GWP and CED. The methods of the Class process calculation for the GWP and CED:

- *get_GWP:* calculation of the Global Warming Potential, corresponding to Equation 2.21 to Equation 2.26 for production phase, corresponding to Equation 2.33 for marine operations and to Equation 2.36 for Treatment phase.
- *get_CED:* calculation of the Cumulative Energy Demand, corresponding to Equation 2.27Equation 2.32 for production phase, corresponding to Equation 2.34 for marine operations and to Equation 2.37 for Treatment phase.

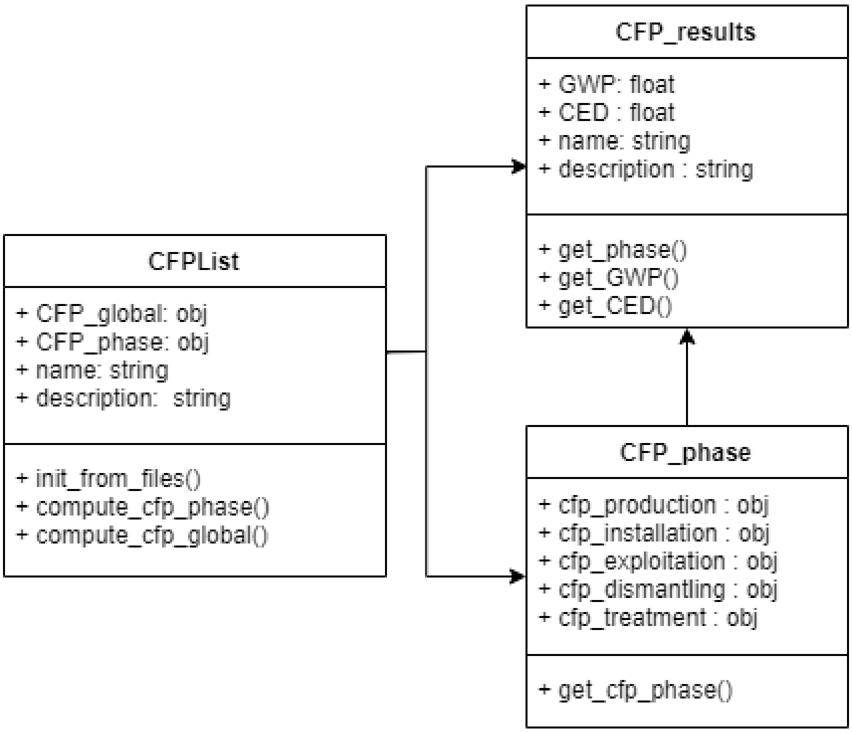


FIGURE 3.3: CLASS DIAGRAM FOR CARBON FOOTPRINT BUSINESS LOGIC

3.1.1.4 SOCIAL ACCEPTANCE

Class **SocialList**

This Class processes inputs from other modules and/or the user to provide recommendations to improve social acceptance. At this stage of development, this Class considers the number of crew member on vessels during marine operations as proxy for job creation and LCOE as proxy of cost of consenting. The only method:

- *Init_from_files*: process inputs from other modules and/or user

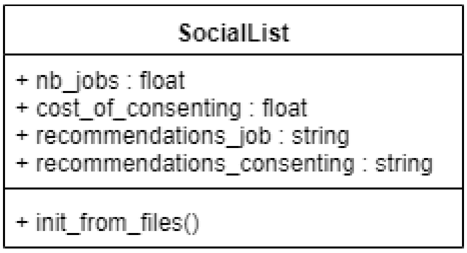


FIGURE 3.4: CLASS DIAGRAM FOR SOCIAL ACCEPTANCE BUSINESS LOGIC

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.

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

3.1.3 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 ESA module will be included into the main module. On the home page of the ESA module, the user will have the choice to either create a new assessment or to access the list of previous project's assessment (Figure 3.5).

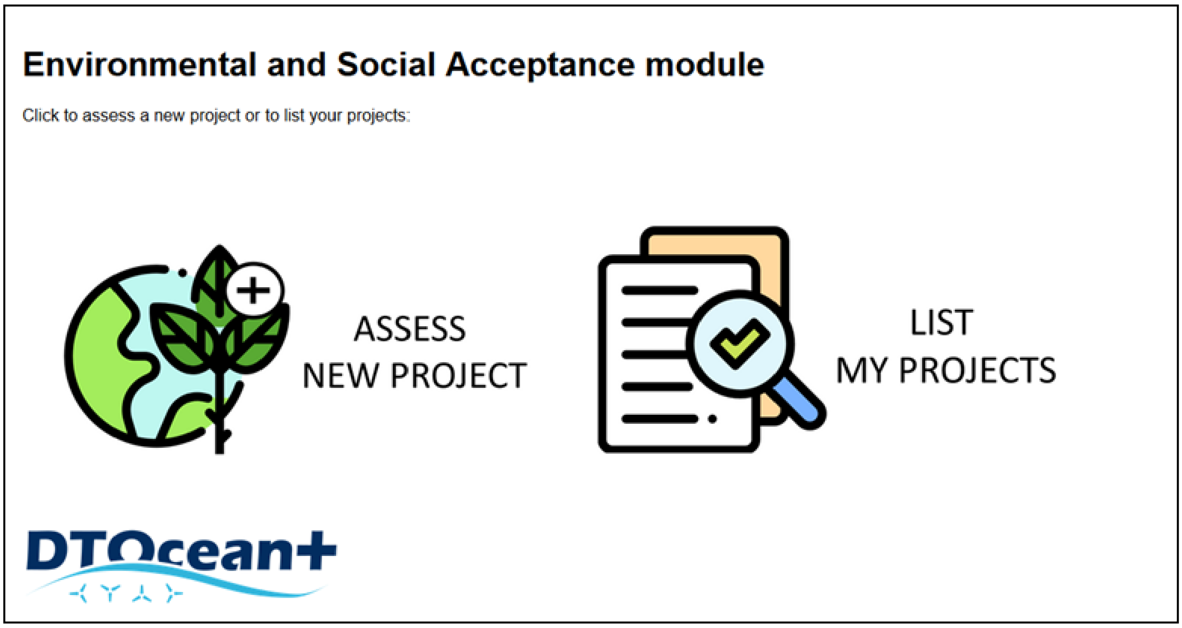


FIGURE 3.5: WIREFRAME OF THE GUI OF THE ESA MODULE: HOME PAGE

On the left of the new project page there will be a tree, with the four main functionalities: Endangered Species, Environmental Impact Assessment, Carbon FootPrint and Social Acceptance. Each assessment could be furtherly expanded into Inputs and Outputs.

The present example is based on the Endangered Species assessment, the main concepts will be extended to the other assessments.

In the case of the ES assessment, inputs are provided by the Site Characterisation module, the user can complete the list by adding Latin name of species he may have identified in the area (Figure 3.6). Once the run is finished, the user can access the Output page (Figure 3.7).

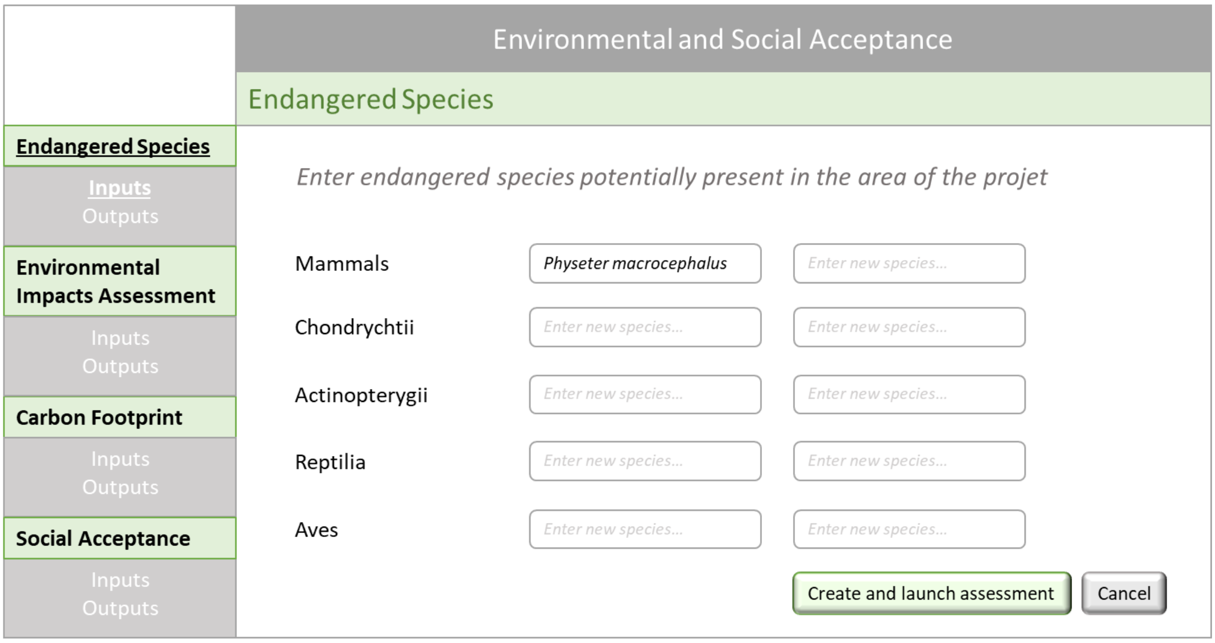


FIGURE 3.6: WIREFRAME OF THE GUI OF THE ESA MODULE: INPUTS (ES).

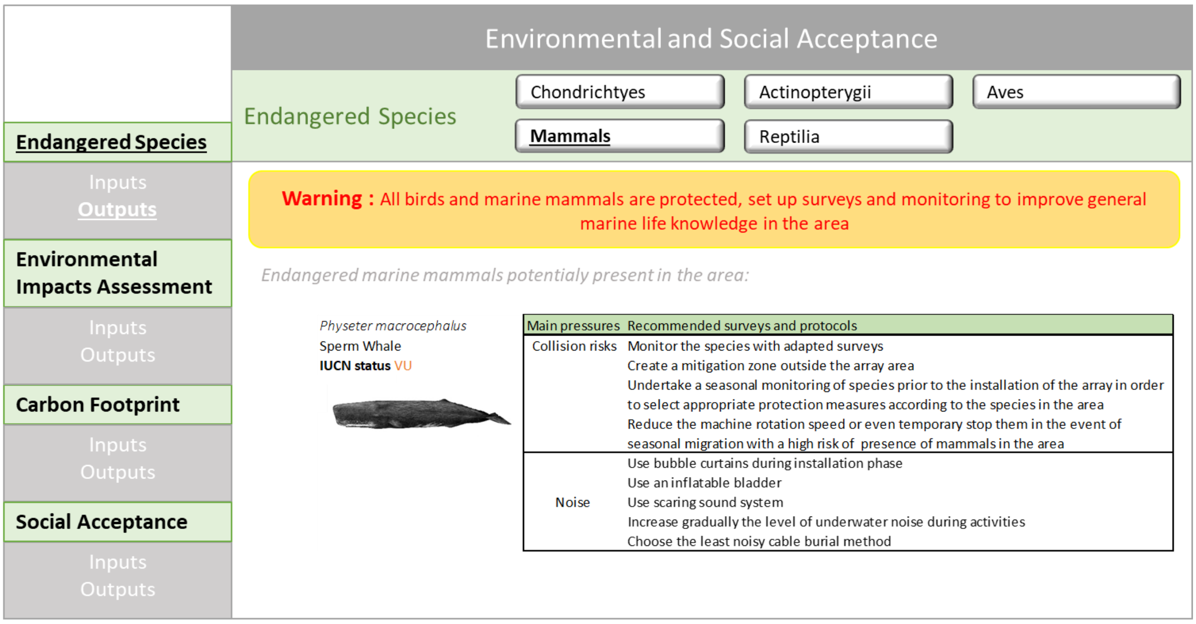


FIGURE 3.7: WIREFRAME OF THE GUI OF THE ESA MODULE: OUTPUTS (ES)

All outputs of each project are available in json format in the "Storage" file. In case that figures are available, a "Figures" file will contain all graphic outputs of the projects.

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 ESA should have, but the exact implementation is subject to change.

3.1.4 THE TECHNOLOGIES

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

- numPy
- collections
- os
- abc
- scipy
- shapely
- Matplotlib
- json
- 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

In total, a set of 4224 statements are present in the Business logic. A comprehensive set of "unit test" 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 85% of the Business Logic (Figure 3.8).

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

Coverage report: 85%

Module ↓	statements	missing	excluded	branches	partial	coverage
src\dtop_esa\Business\Carbon_Footprint\CFPList.py	134	12	0	42	13	82%
src\dtop_esa\Business\Carbon_Footprint\CFP_global.py	109	10	0	34	9	83%
src\dtop_esa\Business\Carbon_Footprint\CFP_phase.py	192	15	0	70	23	83%
src\dtop_esa\Business\Carbon_Footprint\CFP_results.py	163	10	0	64	9	89%
src\dtop_esa\Business\Endangered_Species\Species.py	193	10	0	48	15	87%
src\dtop_esa\Business\Endangered_Species\SpeciesList.py	210	17	0	92	17	88%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIAList.py	158	14	0	48	16	83%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_confidence_dict.py	113	11	0	34	10	82%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_global.py	157	11	0	42	14	84%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_pressure.py	278	23	0	102	44	81%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_recommendation_dict.py	139	11	0	38	12	84%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_results.py	113	11	0	34	10	82%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_results_tech.py	353	33	0	100	25	85%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_season.py	129	12	0	38	12	82%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_season_score.py	229	11	0	54	20	87%
src\dtop_esa\Business\Environmental_Impact_Assessment\EIA_tech.py	190	17	0	76	18	86%
src\dtop_esa\Business\Environmental_Impact_Assessment\dtocean_environment__init__.py	0	0	0	0	0	100%
src\dtop_esa\Business\Environmental_Impact_Assessment\dtocean_environment\functions.py	125	11	0	42	9	88%
src\dtop_esa\Business\Environmental_Impact_Assessment\dtocean_environment\impacts.py	224	0	0	0	0	100%
src\dtop_esa\Business\Environmental_Impact_Assessment\dtocean_environment\logigram.py	237	33	0	44	12	82%
src\dtop_esa\Business\Environmental_Impact_Assessment\dtocean_environment\main.py	152	17	0	30	6	87%
src\dtop_esa\Business\Social_Acceptance\SocialList.py	114	10	0	34	9	83%
src\dtop_esa\Business__init__.py	0	0	0	0	0	100%
src\dtop_esa\Business\outputs\Project.py	185	28	0	56	20	78%
src\dtop_esa__init__.py	0	0	0	0	0	100%
Total	**3897**	**327**	**0**	**1122**	**323**	**85%**

coverage.py v5.0.2, created at 2020-02-10 12:02

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

4. EXAMPLES

In this section, an example for each functionality implemented in ESA 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 ESA module.

4.1 ENDANGERED SPECIES

Let us consider inputs of endangered species identified as potentially present in the area of the project. The Input data are collected in the following Table 4.1. If probability of presence is not provided, species probability of presence is considered as 1.

TABLE 4.1: INPUTS FOR EXAMPLE OF USE OF THE ENDANGERED SPECIES FUNCTIONALITY

Latin name	Probability of presence (Optional)
Balaenoptera musculus	0.2
Balaenoptera borealis	0.7

The taxonomic information of the two species are given (Table 4.2) and a table providing information on the main risks associated with this taxonomic group and associated recommendations of changes in the design to reduce this risks and about surveys to carry for a better insight on the biology of the species in the area (Table 4.3).

TABLE 4.2: OUTPUTS FOR EXAMPLE OF USE OF THE ENDANGERED SPECIES TAXONOMIC FUNCTIONALITY

Class	Order	Family	Latin Name	Common name	IUCN status
Mammals	Cetacean	Balaenopteridae	*Balaenoptera musculus*	Blue whale	EN
Mammals	Cetacean	Balaenopteridae	*Balaenoptera borealis*	Sei whale	EN

TABLE 4.3: OUTPUTS FOR EXAMPLE OF USE OF THE ENDANGERED SPECIES RECOMMENDATIONS FUNCTIONALITY

Class	Risks	Project Recommendations	Survey Recommendations
Mammals	▫ Collision risk ▫ Underwater noise	▫ Create a mitigation zone outside the array area ▫ Reduce the machine rotation speed or even temporary stop them in the event of seasonal migration	▫ vessel based survey ▫ aerial survey ▫ passive acoustic monitoring ▫ visual survey, SCUBA survey

4.2 ENVIRONMENTAL IMPACTS ASSESSMENT

To demonstrate demonstrating the capabilities of Environmental Impacts Assessment functionality, let us consider a set of inputs provided for each technology group (Table 4.4).

TABLE 4.4: INPUTS FOR EXAMPLE OF USE OF THE ENVIRONMENTAL IMPACTS ASSESSMENT FUNCTIONALITY

Quantity	Sub-Quantity	Value	Units
Surface of the lease area	-	94501467	m^2
Minimum bathymetry		15	m
Resource reduction	-	0,3	%
Coordinates of the Devices	-	[x,y]	UTM
Dimensions of the Devices	Height	10	m
	Maximum horizontal size	10	m
Number of devices	-	50	-
Surface area of underwater part	device	60	m^2
	electrical	60	m^2
	foundation	60	m^2
Surface area of the emerged part	device	0	m^2
	substation	20	m^2
Theta - Current direction	-	45	°
Seabed type	-	Medium sand	-
Fishery restriction surface	-	1000	m^2
Number of vessels	Installation phase	3	-
	Exploitation phase	3	-
Medium size of vessels	Installation phase	3	m
	Exploitation phase	3	m
Footprint of mooring and foundations	-	150	m^2
Footprint of electric components	-	150	m^2
Temperature	before farm implantation	0	°C
	after farm implantation	0	°C
Turbidity	before farm implantation	50	NTU
	after farm implantation	70	NTU
Electrical fields	before farm implantation	0	µV
	after farm implantation	0	µV
Magnetic fields	before farm implantation	0	µT
	after farm implantation	0	µT
Chemical pollution	-	0	Boolean
Underwater noise	before farm implantation	60	dB re 1 muPa
	after farm implantation	150	dB re 1 muPa

Produced outputs are reported in Table 4.5. The EIA provides Global outputs at project level informing on global negative and positive impact of the overall project, or at technology group level detailing results for each pressure.

TABLE 4.5: OUTPUTS FOR EXAMPLE OF USE OF THE ENVIRONMENTAL IMPACTS ASSESSMENT FUNCTIONALITY

Level		Sub-Quantity	Value
eia_global project	-	*Negative_impact*	-42.09
		Max_negative_impact	-90
		Min_negative_impact	-20.03
		Positive_impact	10
		Max_positive_impact	10
		Min_positive_impact	10
eia_tech_group	*Impact hydrodynamics*	*Energy modification*	-74.0
		Collision risk	-20.03
		Turbidity	-74.0
		Underwater noise	-90.0
		Reserve effect	10
		Reef effect	10
		Resting place	10
		Global Negative impact	-64.51
		Global positive impact	10
	Impact electrical	*Footprint*	-10.00
		Collision risk	-39.96
		Underwater noise	-90.0
		Electric Fields	-10.0
		Magnetic fields	-10.0
		Temperature Modification	-10.0
		Reserve effect	10
		Reef effect	10
		Resting place	10
		Global Negative impact	-28.32
		Global positive impact	10
	Impact station keeping	*Footprint*	-10.00
		Collision risk	-20.03
		Underwater noise	-90.0
		Reef effect	10
		Global Negative impact	-40.01
		Global positive impact	10
	Impact logistics	*Footprint*	-10.00
		Collision risk	-10.00
		Chemical pollution	-10.00
		Turbidity	-74.00
		Underwater noise	-90.0
		Global Negative impact	-38.80
		Global positive impact	-

Different graphic representations will be provided to the user: at global project scale (Figure 4.1) and for each technology group (Figure 4.2).

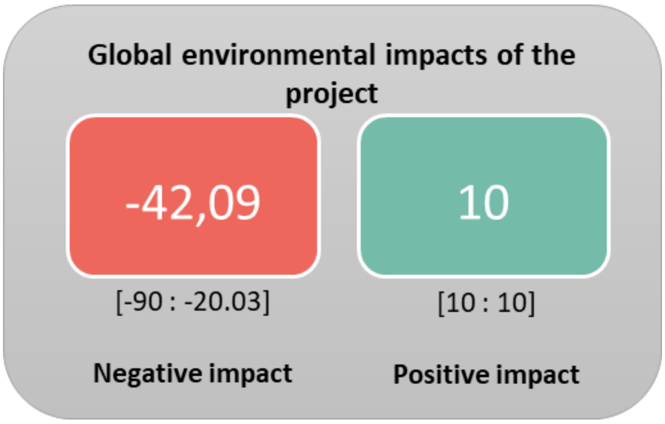


FIGURE 4.1: EXAMPLE OF GRAPHICAL VISUALISATION OF ENVIRONMENTAL IMPACT ASSESSMENT FUNCTIONALITY: GLOBAL RESULTS

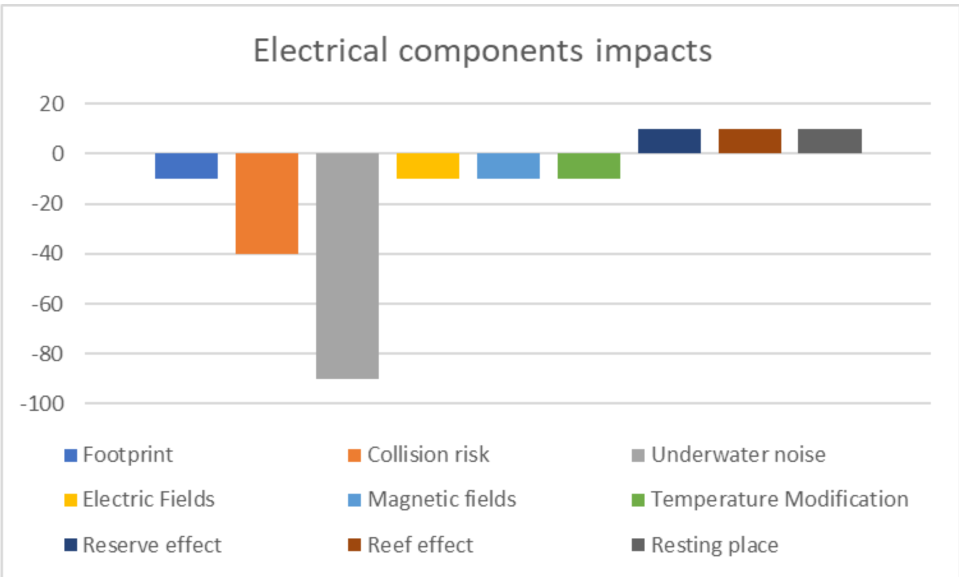


FIGURE 4.2: EXAMPLE OF GRAPHICAL VISUALISATION OF ENVIRONMENTAL IMPACT ASSESSMENT FUNCTIONALITY: ELECTRICAL COMPONENTS IMPACTS

4.3 CARBON FOOTPRINT

To evaluate the carbon footprint of a project, let us consider basic inputs of materials and vessels consumption at each phase of the project.

TABLE 4.6: INPUTS FOR EXAMPLE OF USE OF THE CARBON FOOTPRINT FUNCTIONALITY

Quantity	Sub Quantity	Value	Unit
Materials	Unalloyed_steel	171360	t
	Copper	1020	t
	Polyethylene	612	t
Materials to recycle	Unalloyed_steel	171360	t
	Copper	0	t
	Polyethylene	0	t
Vessel consumption	Installation phase	6.3E+3	t
	Exploitation phase	18E+3	t
	Dismantling phase	4.9E+3	t
Total Energy production	-	30660	GWh

The outputs produced are reported in Table 4.7. Simple result of Cumulative energy demand and global warming potential are provided and by functional unit of energy produced (kWh) for each phase.

TABLE 4.7: OUPUTS FOR EXAMPLE OF USE OF THE CARBON FOOTPRINT FUNCTIONALITY

Quantity	Sub Quantity	Value	Unit
Cumulative Energy Demand	Total life cycle	10,81E+9	MJ
		0,32	MJ/kWh
	Fabrication	6,57E+09	MJ
		0,214	MJ/kWh
	Installation	9,13E+08	MJ
		0,0298	MJ/kWh
	Exploitation	2,99E+09	MJ
		0,0976	MJ/kWh
	Dismantling	3,37E+08	MJ
		0,0110	MJ/kWh
	Treatment	-1,12E+09	MJ
		-0,037	MJ/kWh
Global Warming Potential	Total life cycle	6,57E+8	kg CO2
		22,0	g CO2/kWh
	Fabrication	5,72E+08	kg CO2
		18,7	g CO2/kWh
	Installation	5,97E+07	kg CO2
		1,95	g CO2/kWh
	Exploitation	1,96E+08	kg CO2
		6,39	g CO2/kWh
	Dismantling	2,20E+07	kg CO2
		0,72	g CO2/kWh
	Treatment	-1,74E+08	kg CO2
		-5,7	g CO2/kWh

The outputs will be available also for graphical visualisation to the user including global results of Global Warming Potential and Cumulative Energy Demand of the total life cycle (Figure 4.3). Detailed results of each indicators for every phase of the project (Figure 4.4 and Figure 4.5)

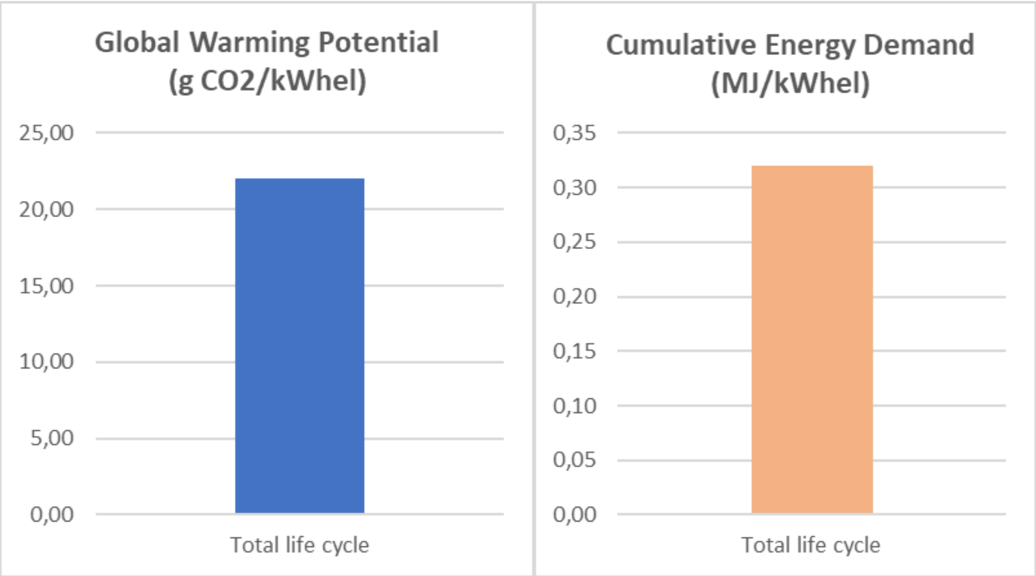


FIGURE 4.3: EXAMPLE OF GRAPHICAL VISUALISATION OF CARBON FOOTPRINT FUNCTIONALITY: GLOBAL RESULTS

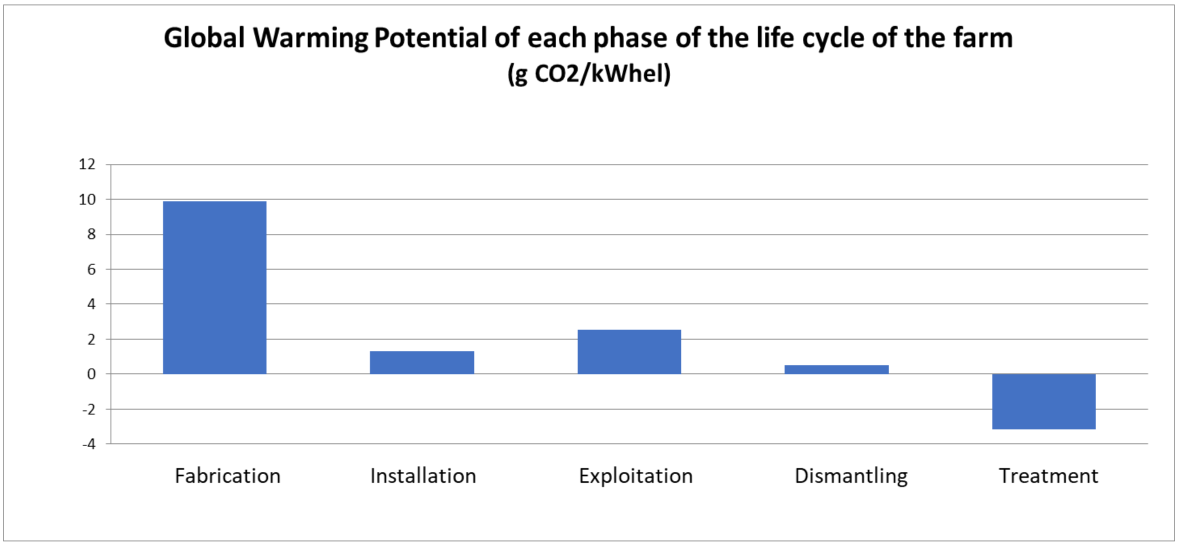


FIGURE 4.4: EXAMPLE OF GRAPHICAL VISUALISATION OF CARBON FOOTPRINT FUNCTIONALITY: GWP FOR EACH PHASE OF THE LIFE CYCLE OF THE FARM

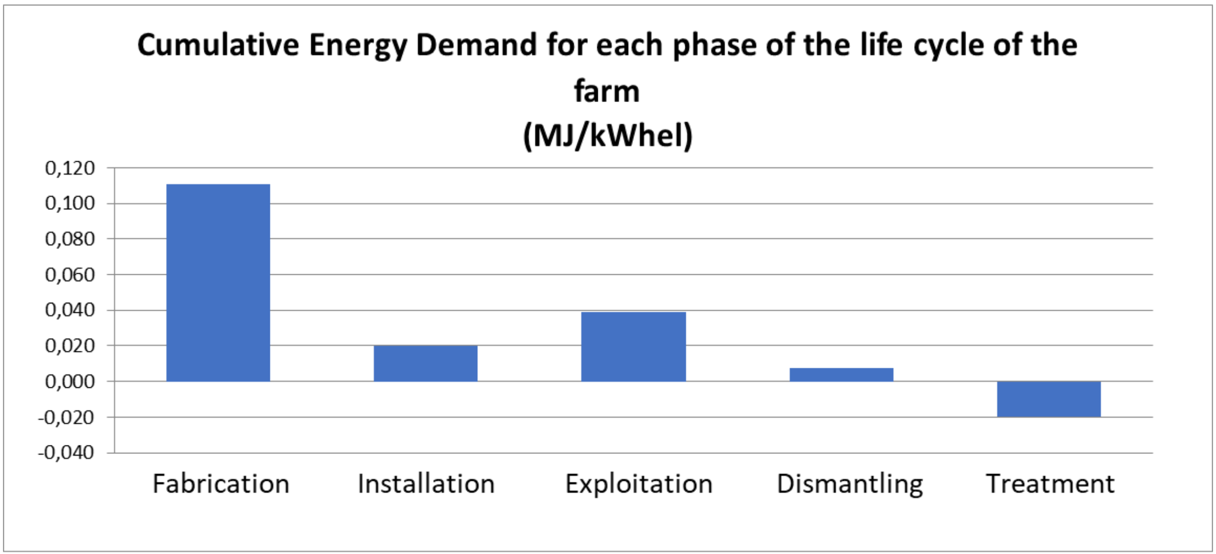


FIGURE 4.5: EXAMPLE OF GRAPHICAL VISUALISATION OF CARBON FOOTPRINT FUNCTIONALITY: CED FOR EACH PHASE OF THE LIFE CYCLE OF THE FARM

4.4 SOCIAL ACCEPTANCE

In terms of social acceptance, the module gathers information related to social acceptance, the total cost of the project and number of people on boat necessary for all marine operations during the life cycle of the farm (see example of inputs in Table 4.8 and ouputs in Table 4.9).

TABLE 4.8: INPUTS FOR EXAMPLE OF USE OF THE SOCIAL ACCEPTANCE FUNCTIONALITY

Quantity	Sub Quantity	Value	Unit
LCOE	-	0.150	€/kWh
Total energy production	-	30660	MWh
Number of crew members	Installation	469	-
	Exploitation	680	-
	Dismantling	265	-

TABLE 4.9: OUTPUTS FOR EXAMPLE OF USE OF THE SOCIAL ACCEPTANCE FUNCTIONALITY

Quantity	Value	Unit
Cost of consenting	150	€/MWh
Nb of jobs	0.05	/MWh

5. FUTURE WORK

This deliverable collects the main functional and technical aspects of the Environmental and Social Acceptance module (ESA), implemented during the tasks T6.6 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.

These activities will be developed within T6.6 (ongoing) and T6.9 of the tool (running once that all the other modules have been developed) in order to extend the functionality of the ESA module from standalone to fully integrated in the DTOceanPlus toolset.

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7. ANNEXES

7.1 COLLISION RISK DETAILED FUNCTION

```
def coll_risk(dev_pos, dev_dim, dev_height, water_dep, cur_dir):
    '''Collision risk

    the function estimates the number of intersections, between
    a large number of parallel lines aligned with the mean current
    axis. The probability of collision will be: P=nb of lines with
    at least one intersection/total nb of lines

    Args:
        dev_pos: Coordinates of the devices
        dev_dim: Maximum horizontal size of the device
        dev_height: Height of device immersed in the water
        water_dep: Minimum water depth
        cur_dir: direction of the current [in degrees]

    Returns:
        collision_risk: collision risk factor

    '''
    if not dev_pos:
        return 0.

    # x,y positions
    [x_pos, y_pos] = dev_pos

    # number of devices
    if len(x_pos) <= 1:
        return 0.
    else:
        ndev=len(x_pos)

    # area limits
    x_min = np.min(x_pos)
    x_max = np.max(x_pos)
    y_min = np.min(y_pos)
    y_max = np.max(y_pos)

    # initialize the nb of intersection points
    n_lines = 0
    n_intersections = 0

    #convert current direction to (0,360) degrees and to radians
```

```
    cur_dir = cur_dir % 360
    angle = np.deg2rad(cur_dir)

    # cartesian distance between the lines
    if np.sin(angle) != 0.:  # avoid division by zero (try except fails???)
        lx = np.abs(dev_dim / np.sin(angle))
    else:
        lx = x_max - x_min

    if np.cos(angle) != 0.:
        ly = np.abs(dev_dim / np.cos(angle))
    else:
        ly = y_max - y_min

    # detect the quadrant
    if cur_dir > 90. and cur_dir <= 270.:
        x_start = x_max
        x_end   = x_min
    else:
        x_start = x_min
        x_end   = x_max

    if cur_dir > 180. and cur_dir <= 360.:
        y_start = y_max
        y_end   = y_min
    else:
        y_start = y_min
        y_end   = y_max

    # along x
    il = 0
    xi = x_min

    while xi <= x_max:
        if np.tan(angle) == 0.: # division by zero
            break
        # this is where we define the equations for the parallel lines
        yi = y_start # origin of the line (ordinate)
        xf = (y_end-yi) / np.tan(angle) + xi # end of the line (absciss)
        yf = y_end
        trajectory = LineString([(xi, yi), (xf, yf)])

        # this is where we define the machines, considered as circles
        ni=0
        for id in range (0,ndev):
            device = Point(x_pos[id],y_pos[id]).buffer(dev_dim)
```

```
            # calculate nb of intersections ni
            if device.intersects(trajectory):
                ni=ni+1

        il += 1
        xi = x_min + 2. * lx * il
        n_lines += 1
        if ni > 0:
            n_intersections += 1

    # along y
    il=0
    yi = y_min

    while yi <= y_max:
        # this is where we define the equations for the parallel lines
        xi = x_start # origin of the line (ordinate)
        xf = x_end
        yf = (x_end - xi) * np.tan(angle) + yi # end of the line (absciss)
        trajectory = LineString([(xi, yi), (xf, yf)])

        # this is where we define the machines, considered as circles
        ni=0
        for id in range (0,ndev):
            device = Point(x_pos[id],y_pos[id]).buffer(dev_dim)
            # calculate nb of intersections ni
            if device.intersects(trajectory):
                ni=ni+1

        il += 1
        yi = y_min + 2. * ly * il
        n_lines += 1
        if ni > 0:
            n_intersections += 1
    collision_rate = n_intersections / float(n_lines)
    depth_factor = dev_height / float(water_dep)
    collision_risk = depth_factor * collision_rate

    return collision_risk
```

CONTACT DETAILS

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Naval Energies terminated its participation on 31st August 2018 and
EDF terminated its participation on 31st January 2019.

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