[1]s

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 727689

Document Title:
Reduction of environmental impacts due to increased reliability

Document No:
RLT-WP1-7-PDL-001-00

Status Code	Description
A	Accepted
B	Issued for Acceptance
C	Issued for Review
D	Information Only Approval not required
E	Cancelled

01					
00	C		Marcos Navarro, Jaime Fº Robles (ISSA) Collaborators: Vincent Le Diagon (BV), Ana I. Mayorga (EO), Mael Arhant and Peter Davies (IFREMER) Julie Marcille (SAB)	All partners	Stéphane Paboeuf
Rev No	Status	Revision Description	Prepared By / Date	Reviewed By / Date	Approved By / Date

European Commission
H2020 Programme for Research & Innovation

Advanced monitoring, simulation and control of tidal devices in unsteady, highly turbulent realistic tide environments

REALTIDE

Grant Agreement number: 727689

Project Acronym: RealTide

Project Title: Advanced monitoring, simulation and control of tidal devices in unsteady, highly turbulent realistic tide environments

(D1.7)
Reduction of environmental impacts due to increased reliability

WP 1
Increased reliability of tidal rotors

WP Leader:
Bureau Veritas
Dissemination level:
Public
Summary:
One of the main environmental impacts of tidal energy is due to the operations related to the installation, the maintenance throughout the life cycle of the turbine and, finally, during dismantling. These operations will involve associated ships and human intervention in the turbine and may also generate some waste. These operations are considered and included in a comparative study to assess the improvement achieved through the increased level of reliability and the consequent reduction in maintenance visits. This deliverable establishes a baseline for assessing the reduction in environmental impact resulting from increased reliability, over the entire life cycle of the turbine. This document includes an assessment of the environmental impact linked to the reduction in the number of parts replaced, the reduction in the size of vessels required, the number of vessel operations and human interventions. Taking as an example the data relating to the D10 tidal turbine of Sabella, a final comparative table concludes that the reduction of the environmental impact (measured in Carbon Footprint) is more than 50% over the life of the turbine and after its dismantling, after applying the studies carried out in the different WPs of the RealTide project.
Objectives:
The main objective is, from the environmental point of view, to perform a comparative study to assess the environmental benefit achieved thanks to the higher reliability level and the associated reduction of maintenance visits.

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

In recent decades, and due to the great energy potential of the seas and oceans, projects and studies are being developed worldwide to enhance the possibility of converting this potential into electrical energy in a clean and sustainable manner. Various technological alternatives have been proposed depending on the type of use of this potential, from current energy to tidal energy, including tidal wave and osmotic potential or blue energy [2], see Figure 1. Within the Real Tide project, four different types of electrical energy production devices are being studied, Concepts 1-4 (Figure 2), included in the different technological alternatives mentioned [3].

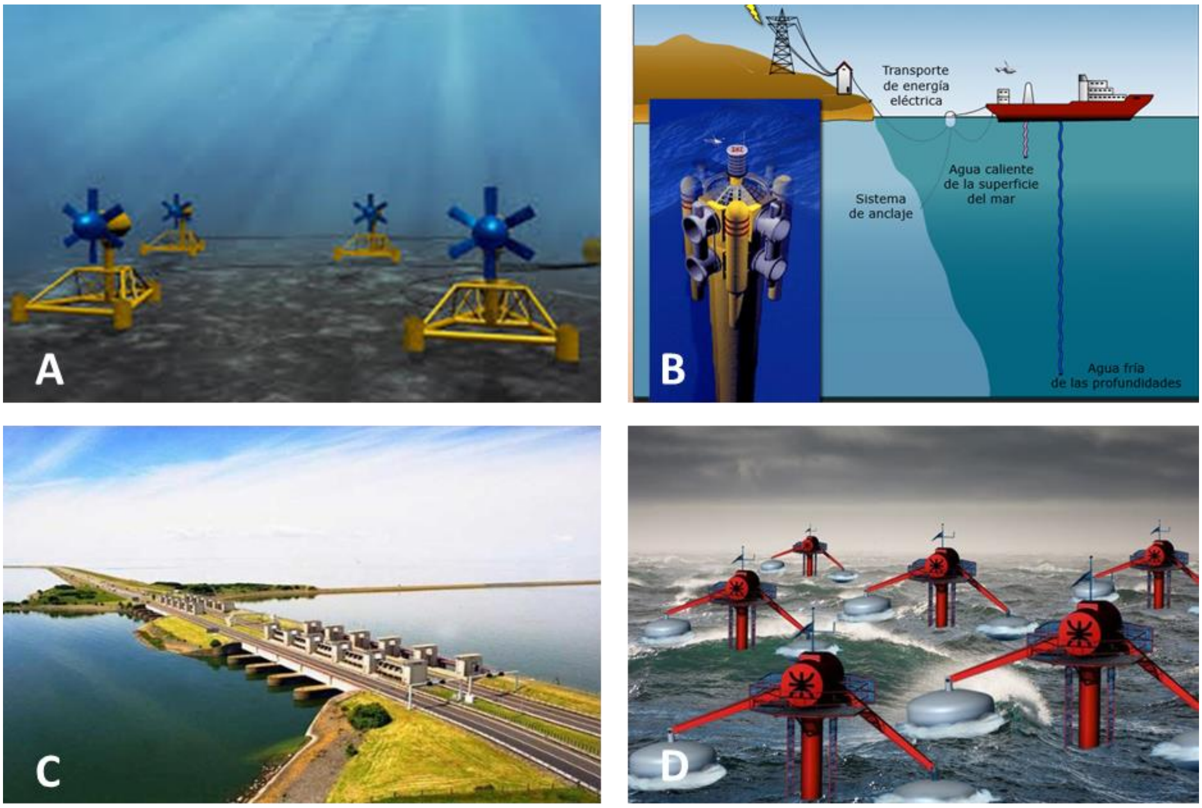

Figure 1 - Different types of technologies. Tidal energy (A), Ocean thermal energy conversion (B), Potential osmotic or Blue energy (C) y Wave energy (D)

The construction, operation and maintenance (O&M) of this type of installations and their devices require a significant mobilization of resources and, in certain cases, a modification of the environment in the possible locations for the performance of tasks such as assembly, disassembly and maintenance. In general, for the concepts 1-4 (Figure 2), objects of study in this project, resources such as crane barges, jack-up vessels, cable-laying vessels, workboat, remote operated vehicle (ROV), among others, will be used. On the other hand, it will also be necessary to build dikes, concrete footings and other fastening elements for the different types of electrical energy production devices. All this interaction with the environment implies an environmental impact.

Tidal energy is considered to be one of the most environmentally friendly forms of electricity generation. However, depending on the regulatory regime, projects may be subject to an environmental impact assessment as part of project development activity in order to minimize and mitigate the potential impacts of a project.

Throughout this document, in its different sections, an attempt will be made to define all the types of assembly and O&M tasks that can influence the environment, to catalogue the severity of the different types of environmental impact in this type of installation and to establish, based on all the studies and work carried out in this project, the levels of reduction of environmental impact that O&M tasks cause in the environment, through the use of new maintenance and monitoring strategies for tidal turbines.

1.1 Abbreviations & Definitions

BV	Bureau Veritas
BV M&O	Bureau Veritas Marine & Offshore
HO	HydrOcean
UEDIN	The University of Edinburgh
EO	EnerOcean
SAB	Sabella
1-T	1-Tech
IFR	Ifremer (Institut Français pour la Recherche et l'Exploitation de la Mer
ISSA	Ingeteam Power Technology
GA	Grant Agreement
PMP	Project Management Plan
O&M	Operation & Maintenance
ROV	Remote Operated Vehicle
SGWTE	Study Group on Environmental Impacts of Wave and Tidal Energy
EIA	Environmental Impact Assessment
AA	Appropriate Assessment
SEA	Strategic Environmental Assessment
IA	Impact Assessment
SAC	Special Areas of Conservation
SPAs	Special Protection Areas
RIAM	Rapid Impact Assessment Matrix
GIS	Geographic Information System
CTV	Crew Transport Vessels
OSV	Offshore Supply Vessel
IMO	International Maritime Organization
CF	Carbon Footprint
PP	Polypropylene
PE	Polyethylene
PVC	Polyvinylchloride
PS	Polystyrene
PA	Polyamide

1.2 References

[1] M. A. E.-E.-0. Ashish Dewan, "Reference O&M Concepts for Near and Far Offshore Wind Farms," December 2016.

[2] L. E. Q. G. Julián Rodrigo Quintero González, "Tidal energy: potential energy and environment," 2015.

[3] RealTide Consortium, "RLT-WP1-1-DEL-000-01 -D1.1 - FMEA Report," 2020.

[4] SGWTE, "Report of the Study Group on Environmental Impacts of Wave and Tidal Energy (SGWTE)," 2013.

[5] CE, *EIA Directive 85/337/CEE,* 1985.

[6] E. project, "D6.2.2 Scientific guidelines on Environmental Assessment," 2010.

[7] Proyecto CENIT-OCEAN LIDER, "GUÍA PARA LA ELABORACIÓN DE LOS ESTUDIOS DE IMPACTO AMBIENTAL DE PROYECTOS DE ENERGÍAS RENOVABLES MARINAS," 2010.

[8] The Scottish Government, "Marine Scotland Consenting and Licensing Guidance For Offshore Wind, Wave and Tidal Energy Applications," 2010.

[9] U.S. Department of Energy, "Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies," 2009.

[10] H. D. C. B. E. H. W. E. J. M. D. A. M. a. J. H. Jacqueline Michel, "Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf," 2007.

[11] G. R. M. a. C. E. T. George W. Boehlert, "Ecological Effects of Wave Energy Development in the Pacific Northwest," 2007.

[12] C. MK, "CONSIGMAR," 15 junio 2018. [Online]. Available: http://consigmar.com/reducir-el-consumo-de-combustible-en-buques/. [Accessed 11 11 2020].

[13] M. L. T. Pintos, "UNIVERSIDAD PONTIFICIA COMILLAS," JUNIO 2018. [Online]. Available: https://repositorio.comillas.edu/xmlui/bitstream/handle/11531/29942/TFM000893.pdf?sequence=1&isAllowed=y.

[14] RealTide Consortium, "RLT-WP4-1-DEL-000-01 -D4.1 - Initial monitoring plan," 2018.

[15] RealTide Consortium, "RLT-WP5-2-DEL-000-01 -D5.2 - Novel Materials for Blade Design," 2020.

[16] A. Gholampou and T. Ozbakkaloglu, "A review of natural fiber composites: properties, modification and processing techniques, characterization, applications," *Journal of Material Science,* pp. 829-892, 2020.

[17] A. Rekondo and G. Vara, "Novel thermoset composites for more competitive and sustainable industries," *JEC Composites Magazine,* pp. 48-49, October 2020.

[18] M. project, "Interreg Mediterranean- Maestrale," [Online]. Available: https://maestrale.interreg-med.eu/.

[19] M. S. a. L. C. K. Abid, "Fault Prognostics for the Predictive Maintenance of Wind Turbines: State of the Art," 2019.

1.3 Distribution List

This Document is a RealTide Internal Document and is classified as a public Report. It is for distribution. It will also be distributed to all Beneficiaries of the RealTide project and published online.

2 ENVIRONMENTAL IMPACT OF WAVE & TIDAL ENERGY

The wave and tidal energy sectors are a newcomer to the marine environment, but is developing rapidly. There is an urgent need for new science to understand the potential environmental and socio-economic interactions of wave and tidal energy developments and for this science be applied in policy, planning, consenting and regulatory processes.
From this need to understand and identify the different environmental impacts that this new technology can have on the marine environment and in order to increase the interest of governments and industry in these new renewable energies, groups of studies and publications have been born over the last few years such as [4] where a study group composed of several participants from different countries exposes the legislative and organizational situation in several European countries.
Clearly, depending on the regulatory regime, projects may be subject to an Environmental Impact Assessment (EIA) as part of project development activity in order to minimize and mitigate the potential impacts of a project, in this case focusing on European legislation: the European Commission Report on the application and effectiveness of the EIA Directive. The focus areas for an environmental impact assessment define areas which are affected by the activities both in terms of O&M, and in terms of the assembly and dismantling of the systems.
To better understand some of the issues discussed in the following sections, some definitions are given below:

Appropriate Assessment (AA) – this is the requirement to consider the possible nature conservation implications of any plan or project on the Natura 2000 site network before any decision is made to allow that plan or project to proceed. Not only is every new plan or project captured by this requirement but each plan or project, when being considered for approval at any stage, must take into consideration the possible effects it may have in combination with other plans and projects, when going through this appropriate assessment process. AA is not a prohibition on new development or activities but involves a case-by-case examination of the implications for the Natura 2000 site and its associated conservation objectives.

Environmental assessment – this is a procedure that ensures the environmental implications of decisions are taken into account before the decisions are made. These can be undertaken for individual projects, under the European Union's Environmental Impact Assessment (EIA) Directive (Directive 85/337/EEC [5]) or for public plans or programmes under the Strategic Environmental Assessment (SEA) Directive (Directive 2001/42/EC).

Environmental Impact Assessment (EIA) – Under EU law, this is required to identify the direct and indirect effects of a project on human beings; fauna and flora; soil; water; air; climate and landscape; the interactions between these factors; material assets and the cultural heritage. The Directive applies to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment.

Impact Assessment (IA) – an impact assessment generally assesses the potential economic, social and environmental consequences a new initiative (plan, programme, development, decision etc.) may have. It is carried out by way of a set of logical steps which helps the decision-maker come to a decision on the proposed new initiative. It can also be described as a process that prepares evidence for decision-makers on the advantages and disadvantages of possible options by assessing their potential impact.

Natura 2000 – This is an EU-wide network of nature protection areas established under the EC's Habitats Directive. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. It is made up of Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive and Special Protection Areas (SPAs) designated under the Birds Directive. The establishment of this network of protected areas fulfils a Community obligation under the UN Convention on Biological Diversity. The network is comprised of both terrestrial and marine sites.

Project – within the context of the EIA Directive, project is taken to mean:

- the execution of construction works or of other installations or schemes,
- other interventions in the natural surroundings and landscape including those involving the extraction of mineral resources (Article 1(2), EIA Directive).

Strategic Environmental Assessment (SEA) – this can be defined as an environmental impact assessment process as applied to policies, plans and programmes, acknowledging the fact that the process of evaluating environmental impacts at a strategic level is not necessarily the same 7 as evaluating them at a project level. SEA is meant to be a continuous source of environmental information throughout all the stages of decision-making Under the EU's SEA Directive an SEA is required for those plans and programmes that meet a complicated set of screening requirements. [Screening is the term given to the process of deciding whether an SEA is needed or not]. The SEA Directive applies to a wide range of public plans and programmes (e.g. on land use, transport, energy, agriculture, etc). The SEA Directive does not refer to policies. Plans and programmes in the context of the SEA Directive must be prepared or adopted by an authority (at national, regional or local level) and be required by legislative, regulatory or administrative provisions.

2.1 Environmental impact based on concepts 1-4

Environmental assessments are conducted to understand and evaluate the potential environmental effects of a marine renewable energy project and to promote the sustainable development and implementation of ocean energy projects. The assessments are typically used by stakeholders and consenting or regulatory bodies to inform the consultation and decision-making process from concept to decommissioning. An environmental assessment of a marine renewable energy project is used to:

- Inform the project development process and if possible, the design phase;
- Identify, predict, evaluate and classify the potential environmental and socio-economic impacts (beneficial and harmful) from construction to decommissioning, and are most useful if initiated from the conceptual stage of the project;
- Recognize and evaluate possible cumulative impacts of the project itself and in combination with other projects – existing or planned – and / or marine activities;
- Contribute to site selection by identifying significant environmental and socio-economic features of the possible deployment areas, by estimating their sensitivity to the project characteristics (baseline survey outcomes);
- Identify appropriate mitigation measures for potentially harmful impacts;
- Establish a monitoring program for the pre-deployment, operation, decommissioning and post-decommissioning stages;
- Consult with and inform stakeholder groups and the public in general;
- Propose and implement adaptive environmental management actions.

The environmental analysis should be considered a planning instrument and thus it is desirable that it can form an integral part of the project development from the very beginning.
The environmental assessment of wave and tidal projects is a process that should be carried out by project developers to inform stakeholders and regulatory bodies in their assessment and decision-

making process from concept to decommissioning.
The environmental assessment of a project should start at site selection and project development design. The identification of environmental risks for a given site (and/or alternatives) and/or device type (Figure 2) and the incorporation of environmental criteria in the decision-making process of the development design are considered environmental best practices. These practices aim to minimize any negative impacts, maximize positive impacts and reduce development constrains at the early stage of the environmental assessment process.

Concept 1 - Complex bottom fixed
Horizontal axis
Open rotor
3 blades
Bottom fixed with pile
Pitch control
Yaw mechanism
Gearbox drive

Concept 2 - Simple bottom fixed
Horizontal axis
Open rotor
Multi blade (>3)
Bottom fixed gravity base
No Pitch control
No Yaw mechanism
Direct drive

Concept 3 - Floating multi rotor
Horizontal axis
Open rotor
2 blades
Flaoting
Pitch control
No active Yaw mechanism
Gearbox drive

Concept 4 - Cross flow turbine
Vertical axis
Close rotor
Multi blade (> 3)
Bottom fixed (gravity or pile)
No pitch
No yaw
Direct drive

Figure 2. Generic Tidal Turbine Concepts and features. Source: [3]

Based on the Scottish Guide to Marine Renewable Energy Development [6] in Table 1 examples of useful criteria to be considered for site selection and design stages of project development are presented.

Table 1. Examples of criteria that should be considered when selecting a potential development site for a given development. Source [6]

Criteria for site selection	Examples
Marine Spatial planning	Strategic Environmental Assessment
The proximity of the site to nature conservation interests	Special Areas of Conservation; fish spawn areas at certain times of the year
Cumulative or in combination impacts with other nearby developments	Noise disturbance a proximity of cetacean habitats
Regulatory context	Proximity of legal protected areas
Potential impacts on landscape and visual amenity	Beach proximity
Availability of access and necessary infrastructure	Transport routes, number and type of vessels, frequency of transport
Effects on other marine uses	Navigation, tourism and fisheries
Impacts on wildlife	Proximity of migratory routes or movement routes of birds and cetaceans
Criteria for project development plan	Examples
Device design	Marine animal physical harm due to sharp edges of the machine
Device installation and decommissioning operations	Disturbance on fisheries in the vicinity
Methods of operation	Collision of marine animals with the device rotor blades
Device maintenance activities	Antifouling methods and vessel traffic

The environmental assessment of any new wave and tidal project should be carried out using a model EIA methodology. This model should have a phased approach with continuous re-evaluation and adjustment (Figure 3).

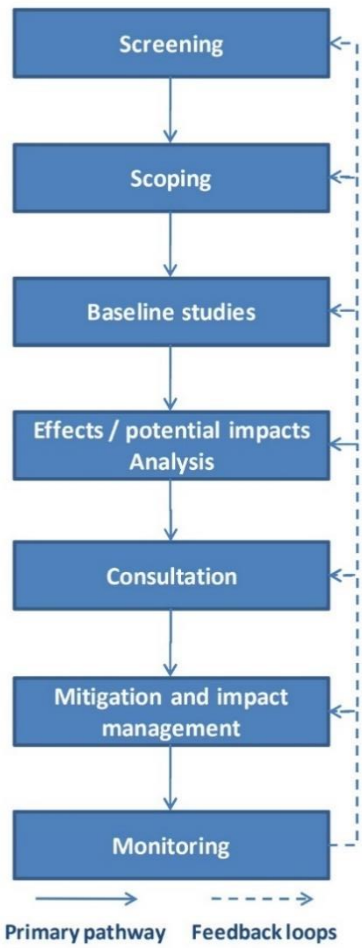

Figure 3. Schematic representation of the Environmental Impact Assessment methodology. Source: [6]

I. **Screening**: It is the previous process that defines if a project requires an EIA or not and the steps to follow in case it is not necessary. The typology of the project will be framed within Annex I or II with the support of the legal framework defined in the EIA Directive (85/337 / EEC and its amendments) [5].

II. **Scoping**: It is an essential step of the EIA to identify the key environmental problems arising from the project as significantly affected environmental receptors, potential effects or impacts on the environment, environmental issues that will require detailed study, possible mitigation measures, etc.

Table 2. Example list (non-exhaustive) of key information to be submitted in a formal scoping report. Source: [6]

Topics	Contents
Project details	• Device characteristics • Location and suggested alternatives for the development • Summary of the project activities (e.g. installation, maintenance and decommissioning methods and plans)
Potential effects	• List of receptors likely to be affected by project stages and activities • Identification of the potential environmental impacts • Knowledge and data gaps
Mitigation measures	• Possible mitigation measures • Guidance on identifying the preferred option from an environmental perspective
Methods and level of studies	• Details / plan for conducting technical studies, methodologies and resources to be used • Methodologies for baseline surveys (field work)
Consultation	• Stakeholder consultation strategies • List of consultants and interest groups
Structure of the EIS	• Suggestion on the contents and length of the EIS

III. **Baseline studies**: These are preliminary studies that will inform the baseline condition of the environmental and socio-economic systems in the impact area and are the basis for valid impact predictions and effective mitigation and monitoring programmes.

Table 3. Type of issues that might be considered under the baseline line survey. Source: [6]

Key topics for wave and tidal project EIAs
Designated sites
Coastal sedimentary processes
Geology, hydrology and hydrogeology
Benthic ecology
Fish and shellfish
Commercial fisheries
Marine mammals
Birds
Terrestrial habitats and ecology
Marine uses: navigation, fisheries, cultural heritage, recreation and access
Visual landscape and seascape
Noise and vibration
Cumulative impacts

IV. **Effects / potential impacts analysis**: This is the stage to deepen the analysis by assessing the scale of potential impacts both on land and at sea. Knowledge of the project and of the reference environmental conditions at the proposed site is required (III). This impact analysis consists of three phases: identification, evaluation (with qualitative and quantitative criteria) and significance of the impacts.

In the assessment phase, qualitative assessment will be carried out using neutral, mild, moderate or severe ratings (for both negative and positive impacts) while quantitative assessment will involve measuring or calculating numerical values.

Table 4. Example of classification criteria used in impact valuation. Source: [6]

Criteria	Qualitative grade	Quantitative grade
Nature of impact	Direct, indirect	-
Signal	Positive, neutral, negative	-
Magnitude (severity)	Maximal, moderate, minimal	Threshold levels (e.g. level of a pollutant; noise levels)
Probability of occurrence	High, medium, low	-
Duration	Temporal, permanent	Duration time of each occurrence
Frequency / Periodicity	Continuous, Discontinuous, periodic (e.g. seasonal), regular occurrence, rare	-
Temporal extension	Immediate, short term, medium term, long term	Duration time (e.g. during installation or operation)
Spatial extension	Local, adjacent, regional, national, global	Degrees and extension of impact areas of influence
Recoverability	Irrecoverable, irreversible, reversible, recoverable, fugal	-
Inter-relations between actions and effects	Simple, cumulative, synergetic	-
Need for mitigation measures	Critical, severe, moderate Total, partial, no-mitigation	-
Importance	High significance, significant, low significance, irrelevant	-

V. **Consultation**: During this phase of the EIA, it is very important to carry out levels of public consultation so that all stakeholders in the development of the project can contribute their concerns and/or opinions and thus be further integrated into the decision-making process.

VI. **Mitigation and impact management**: To avoid, minimize/reduce, remediate or compensate for adverse impacts of the project, it is necessary to establish mitigation measures. Some of these measures can be: selection of alternative locations, modification of construction methods and times or minimisation of operational impacts.

VII. **Monitoring**: After the baseline characterization, an operational monitoring plan should accompany the project installation, operation and decommissioning process taking into account that each site is unique and may benefit from more or less monitoring as regards its baseline characterization. Monitoring is the key to validate and expand the findings of the initial EIA. Its conclusions must flow into future assessments at all levels, from the baseline study to the impact evaluation and mitigation measures. The monitoring needed to understand and minimize environmental impacts has either a site-specific (conducted by the developer) and a general (addressed by collaborative groups) value; collaborative monitoring studies can help the individual developers to refine their designs and operations in order to minimize the environmental impacts.

Table 5. Environmental monitoring methodologies regarding wave and tidal energy project installation, operation and decommissioning. Source: adapted from [6]

Environmental issues	Monitoring issues / methodologies
Coastal sedimentary processes	Modelling approaches
Geology, hydrology and hydrogeology	
Benthic ecology	Monitoring soft and rocky sea beds: - Qualitative sampling (species composition) - Quantitative sampling (species abundance) Methods for data analysis (application of indices) Video transects and photos of underwater device equipment (e.g. mooring system) and adjacent area
Fish and shellfish	Video transects and photos in the device site location and in the adjacent area Fishery boat trajectories Artificial reef effect analysis
Marine mammals	Monitoring cetaceans from land sites Monitoring cetaceans from boats Monitoring cetaceans from air Acoustic surveys
Birds	Ship and aerial sampling methods
Electromagnetic fields	Electromagnetic fields measurements in situ
Noise and vibration	Marine mammals noise exposure Pile driving monitoring: Marine Mammal Observer methodologies and requirements and Passive Acoustic Monitoring

2.2 Environmental impact on operation and maintenance

Based on all of the above (section 2), the environmental impact that can occur in the operation and maintenance of a wave and tidal power project can be evaluated using different analysis tools. Some of these tools are briefly described below 2.2.1, 2.2.2, 2.2.3 y 2.2.4.

In Table 6 a brief state of the art can be seen in relation to the list of potential environmental receptors affected, potential environmental effects/impacts, environmental assessment (baseline and monitoring studies), mitigation measures and knowledge gaps.

As already stated, the requirements of the EIA study are specific to the exact location and characteristics of each wave and tidal energy project and should be defined at the scoping stage. Based on the reports listed in Table 6 and the information, available to date, regarding the identification and analysis of potential environmental impacts, it is possible to show, list and analyze by identifying stressors and receptors (Table 7) which are most discussed and of concern to developers, legislators and evaluators within the marine renewable energy sector. It is important to note that although there is already a good amount of information available on this subject, there is still a need to collect and analyze more data to reduce uncertainties of effects, prioritize impacts and improve best practice in project development and deployment.

Table 6. Examples of reports on reviews of environmental key issues of wave and tidal energy developments. Source: adapted from [6]

Title	Year	Country / entity	Description	Reference
Protocol to develop an environmental impact study of wave energy converters	May 2010	Spain, AZTI Tecnalia	Reviews the likely environmental effects of wave energy and presents a risk management framework to predict, prevent and deal with the environmental impacts of wave energy deployment of in Spain	[7]
Marine renewables licensing manual – Part IV Wave and Tidal Annex	April 2010	Scotland, Marine Scotland (MS)	A comprehensive guidance for license applications of wave and tidal energy projects. This annex provides detailed information on the potential impacts (offshore and onshore) that might need to be considered during the EIA and the methods by which the impacts should or may be assessed	[8]
Report to the congress on the potential environmental effects of marine and hydrokinetic energy technologies	December 2009	USA, U.S. Department of Energy (DOE)	Describes the technologies that are being considered for development, their potential environmental impacts and options to minimize or mitigate the impacts, and the potential role of environmental monitoring and adaptive management in guiding their deployment	[9]
Worldwide synthesis and analysis of existing information regarding environmental effects of alternative energy uses on the outer continental shelf	July 2007	U.S.A., U.S. Department of the Interior, Minerals Management Service (MMS)	Identifies, collects, evaluates and synthesizes existing information on offshore alternative energy activities for public acceptance, potential environmental impacts, mitigation measures, physical and numerical models for environmental impacts prediction and information gaps	[10]
Ecological effects of wave energy development in the Pacific Northwest	October 2007	U.S.A., U.S. Department of Commerce, (NOAA), National marine Fisheries Service	Presents the results of a workshop held in Oregon to develop an initial assessment of potential impacting agents and ecological effects of wave energy development and formulate general conceptual framework of physical and biological relationships that can be applied to wave energy	[11]

Table 7. Key environmental issues to be considered in the environmental assessment. Source: [6]

Receptors	Stressors	Effects and / or ecological issues
Physical environment Pelagic habitat Benthic habitat Fish and fisheries Marine birds Marine mammals Humans (users)	Physical presence of the devices Chemical effects Lighting Acoustics Electromagnetic fields Cumulative effects	• Alteration of currents and waves due to the energy extraction and or physical presence of the devices • Alteration of substrates and sediment transport and deposition which may alter coastline processes and morphology • Benthic habitat disturbance or destruction • Changes to factors such as nutrients, temperature, light levels, turbidity (suspended sediments) • Water contamination due to e.g. effluent or waste discharge, oil leaks • Collision, strike, entrapment and entanglement of marine invertebrates, fish, mammals and birds with the equipment e.g. device, mooring lines • Interference with animal movements and migration • Displacement of marine species • Noise disturbance • Effects of electromagnetic fields in elasmobranchs fish (sharks, rays and skates) orientation and reproduction

2.2.1 Checklists

Checklists are widely used tools to describe the project and the scope of the EIA, providing a systematized means to identify and categorize impacts, however, they do not allow for the identification of higher order impacts or their correlation.

Table 8. Possible screening checklist for an ocean energy project. Source: [6]

Project characteristics		**Yes**	**No**
	Project area above xx m2?		√
	Other	...	...
Proposed project activities		**Yes**	**No**
Installation	Dredging		√
	Pilling requirements	√	
	Foundation construction		√
	Navigational diversion		√
	Vessel requirements	√	
	Other	...	...
Deployment	Corrosion protection	√	
	Lighting arrangements	√	
	Other	...	...
Decommissioning	Generation of waste litter	√	
	Vessel requirements	√	
	Other	...	...
Affected physical and chemical components		**Yes**	**No**
	Hydrodynamic changes	√	
	Water quality		√
	Seabed (sediments) quality		√
	Noise	√	
	Waste disposal issues		
	Local air quality		√
	Other	...	...
Affected biological components		**Yes**	**No**
	Fish populations		√
	Marine mammal populations	√	
	Spawning habitat		√
	Bird habitat	√	
	Wildlife habitat changes	√	
	Contamination of wildlife		√
Affected socio-economic components		**Yes**	**No**
	Employment	√	
	Visual (seascape/landscape)	√	
	Noise		√
	Health		√

2.2.2 Matrices

The matrix is a table where the project activities are represented in one of its axes and the environmental characteristics in the other. In this way the environmental impacts can be identified and evaluated according to the interactions between the environment and the activity, and the severity of the impact or the characteristics related to its nature can be reflected in the different cells. There are several types of matrices but the two most used are the Leopold matrix and the Rapid Impact Assessment Matrix (RIAM). Below is an example of a simple matrix, based on the Leopold matrix, for the identification of impacts of a wave energy device Table 9.

Table 9. Simple matrix (based on Leopold matrix) for impacts identification of a wave energy converter. Source: [6]

Environmental factors	Actions	Installation				Operation				Decommissioning			
		Ships	Cable	Mooring	Device	Ships	Cable	Mooring	Device	Ships	Cable	Mooring	Device
Abiotic	Geology and factors affecting coastal processes		X	X			X	X	X		X	X	
	Water quality	X	X	X	X	X			X	X	X	X	X
	Air quality	X				X			X	X			
Biotic	Benthos		X	X				X			X	X	
	Fish		X	X	X		X	X			X	X	X
	Marine mammals	X		X	X	X		X		X		X	X
	Other aquatic fauna		X	X				X			X	X	
	Marine birds								X				X
	Flora		X	X				X			X	X	
	Terrestrial ecology												
Socio-economic	Conflict of uses	X	X	X	X	X	X	X	X	X	X	X	X
	Archaeology & cultural resources		X	X									
	Visual Impact	X			X	X			X	X			X
	Noise								X				

2.2.3 Geographic information systems

A Geographic Information System (GIS) can be defined as the computer hardware, software and technical expertise that inputs, stores, maintains, manipulates, analyzes and outputs geographically referenced data. A GIS combines the power of spatial database management with high resolution graphic display to effectively present information and they are widely used in the EIA process. The most significant use cases are detailed below.

Table 10. GIS and Environmental Impact Assessment steps. Source: [6]

EIA steps	Objectives of the GIS use	GIS application examples
Screening	Deciding whether a project requires EIA	- Maps of the project area can be generated automatically - Using GIS to overlay a map of the project and a map of the relevant sensitive areas (in which case an Environmental Impact Statement can be required) - In some cases, EIA is required if a project is within a certain distance from a certain type of feature (e.g. road, residence area); GIS can be used to create a buffer zone around the project and clip a map containing all the relevant features
Scoping	Identifying impact themes which require further investigation; helping to clarify the spatial scope of the study (In this step GIS can be used in ways not too different from those applicable to screening)	To inform a scoping decision regarding archaeology, creating a 500 buffer around a proposed project and then combine a map of known archaeological sites; the query can be structured to identify areas of archaeological interest falling within the buffer zone that have been submerged following sea-level rise Identification of areas or receptor locations which will require detailed consideration in the assessment of a particular impact

Baseline studies	Building on the spatial information generated as part of the scoping process GIS is ideally suited to organizing and storing multi-disciplinary monitoring data sets to be analyzed, queried and displayed interactively;	GIS can be a powerful tool for displaying and visualizing trends and patterns in spatial data sets: • Point-type data relate to specific sample location • Spatially continuous data (e.g. noise) can be used to produce a contour (isoline) map • Linear data describing features • Area data which relate to discrete spatial units
Impact prediction	Spatial identification of impact magnitude and dimensions	GIS is most suited to deal with the spatial dimension of impacts, and at the simplest level of analysis it can be used to make quantitative estimates of aspects such as: • "Land take" caused by the development • Length of zones which passes through designated land or seascape areas • The number / importance of features (e.g. archaeological finds) that would be lost to the development
Impact mitigation	Identification and evaluation of alternative locations for a development project Exploitation of visualizing and displaying impact spatial distribution to identify and target possible mitigation measures (through impact significance)	The maps produced for the baseline and impact assessment stages in an ecological assessment could be used to investigate: • The potential to minimize impacts on nature conservation sites or habitat patches by project design modifications • The potential for species translocation or habitat creation including e.g. corridor habitats between fragmented habitats • The optimum locations and dimensions of buffer zones to protect sensitive habitats
Monitoring	Integrative tool to store, analyze, and display monitoring data to identify patterns in the data and examine change over time	

2.2.4 Mathematical modelling

Mathematical models have been widely used to predict and assess the environmental impact of wave and tidal energy devices, but are aimed at predicting larger scale effects of marine protected areas on commercial species and the ecosystem. This type of model is being used mainly to investigate the interaction between fisheries and marine renewable energies.

3 DESCRIPTION AND TYPES OF OPERATIONS IN THE FIELD OF TIDAL ENERGY

Within the operation and maintenance of wave and tidal power generation devices, three main types of activity can be distinguished: installation, maintenance (preventive and corrective) and dismantling. Each of these types is described in the following sections, detailing each of the phases that make them up. This division and description have been developed on the basis of the knowledge and experience provided by the partners of the RealTide project and is oriented towards the D10 tidal energy device designed by Sabella (Figure 4), one of the partners of the consortium.

3.1 Installation

The installation comprises all the phases and processes that must be carried out from the moment the turbine is prepared on the quay until it is fixed on the seabed in the exact location chosen. The following Table 11 details the different phases of the process with a description and an estimate in hours of each phase, taking into account that this duration can vary depending on many factors such as: the port of origin of the vessel used, the type of vessel, distance to the chosen location, weather conditions, etc.

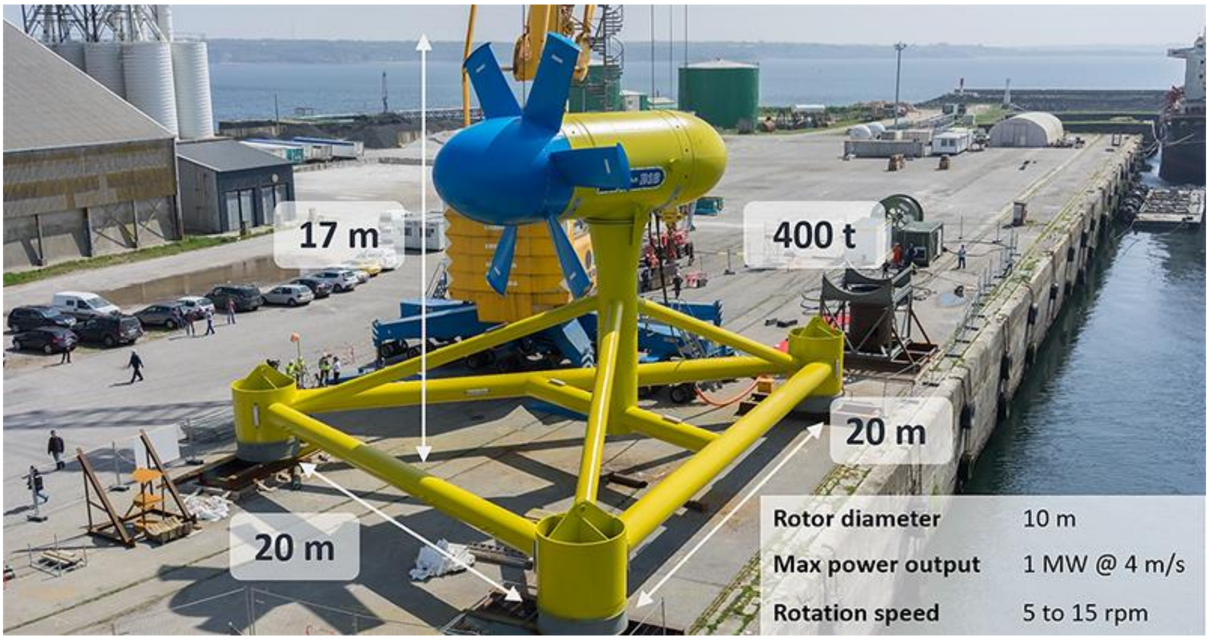

Figure 4. Sabella D10 turbine dock arrangement. Source: Sabella website

Table 11. Phases of installation of a tidal turbine. Source: RealTide consortium

Installation phases	Description	Duration (hours)
Arrival in port	It includes the time for the vessel to travel from its location to the port of collection of the turbine once contracted	Depends on vessel location before hiring Assumed 20
Equipment loading	Turbine loading time and all necessary equipment and tools	9
Sea fastening	Turbine and equipment fastening on the deck	27
Transit	Journey to the location chosen for the installation of the device	6
DP Trials	Testing of the Dynamic positioning of the vessel during mid-tide	6
As found survey	ROV video survey of the installation site before installation	3
Foundation installation	Installation of the foundation elements	9
Ballast weights installation	Installation of ballast weights	12
Turbine installation	Installation of the turbine assembly	9
Jumper cable laydown	Laying the turbine starter cable	1.5
Export cable recovery	Recovery of the export cable to the electrical network	1.5
Jumper cable recovery	Turbine starter cable recovery	1.5
Connection	Connection of the turbine starter cable and the export cable	3
Cable laydown	Laying the connected cable	6
As laid survey	ROV video survey of the turbine and cable after installation	6
Transit	Journey to the port	6
Equipment unloading	Unloading of equipment and tools in port	20
	TOTAL HOURS	146,5

3.2 Maintenance

During the maintenance of this type of device, two main types of tasks will be carried out: preventive and corrective. Due to adverse weather and access conditions, these operations and interaction with the device must be carefully programmed and will include two different actions: recovery and reinstallation of the turbine. These maintenance actions are detailed in the following tables (Table 12 and Table 13).

Table 12. Phases of maintenance (recovery) of a tidal turbine. Source: RealTide consortium

Turbine recovery phases	Description	Duration (hours)
Arrival in port	It includes the time for the vessel to travel from its location to the port of collection of the turbine once contracted	Depends on vessel location before hiring Assumed 20
Equipment loading	Turbine loading time and all necessary equipment and tools	6
Sea fastening	Turbine and equipment fastening on the vessel's deck	18
Transit	Journey to the location chosen for the installation of the device	6
DP Trials	Testing of the Dynamic positioning of the vessel during mid-tide	6
As found survey	ROV video survey of the turbine and cable	3
Cable recovery	Recovery the connected cable	6
Disconnection	Disconnection of the turbine starter cable and the export cable	3
Jumper cable laydown	Laying the turbine starter cable	1.5
Export cable laydown	Laying of the export cable to the electrical network	1.5
Jumper cable recovery	Turbine starter cable recovery	1.5
Turbine recovery	Recovery of the entire turbine	9
As laid survey	ROV video survey of the foundation after turbine recovery	3
Transit	Journey to the port	6
Equipment unloading	Unloading of equipment and tools in port	15
	TOTAL HOURS	105,5

Figure 5 shows the installation of the Sabella D10 turbine. The vessel used for this operation is the Far Superior, a DP vessel with a 250t crane capacity.

Figure 5. Installation of the Sabella D10 turbine. Source: Sabella website

Table 13. Phases of maintenance (reinstallation) of a tidal turbine. Source: RealTide consortium

Turbine reinstallation phases	Description	Duration (hours)
Arrival in port	It includes the time for the vessel to travel from its location to the port of collection of the turbine once contracted	Depends on vessel location before hiring Assumed 20
Equipment loading	Turbine loading time and all necessary equipment and tools	6
Sea fastening	Turbine and equipment fastening on the vessel's deck	18
Transit	Journey to the location chosen for the installation of the device	6
DP Trials	Testing of the Dynamic positioning of the vessel during mid-tide	6
As found survey	ROV video survey of the foundation before the turbine installation	3
Turbine installation	Installation of the turbine assembly	9
Jumper cable laydown	Laying the turbine starter cable	1.5
Export cable recovery	Recovery of the export cable to the electrical network	1.5
Jumper cable recovery	Turbine starter cable recovery	1.5
Connection	Connection of the turbine starter cable and the export cable	3
Cable laydown	Laying the connected cable	6
As laid survey	ROV video of the turbine and cable after installation	3
Transit	Journey to the port	6
Equipment unloading	Unloading of equipment and tools in port	15
	TOTAL HOURS	105,5

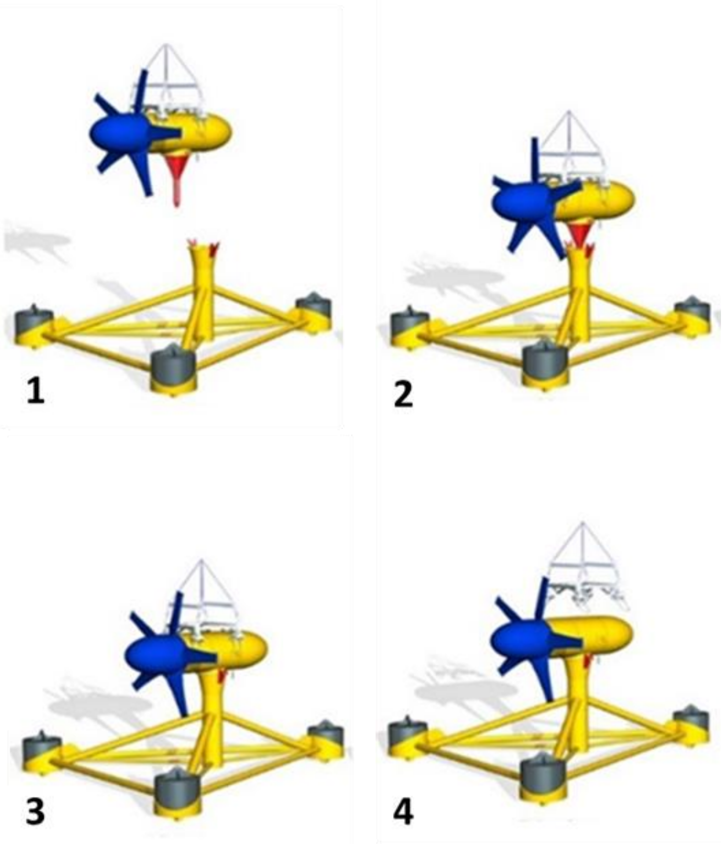

Figure 6. Steps in the installation phase of the Sabella D10 turbine Source: Sabella website

3.3 Dismantling

The dismantling comprises all the phases for the removal of the device and all the parts that form it leaving the location used in the same conditions as they were found at the beginning of the project.

Table 14. Phases of dismantling of a tidal turbine. Source: RealTide consortium

Dismantling phases	Description	Duration (hours)
Arrival in port	It includes the time for the vessel to travel from its location to the port of collection of the turbine once contracted	Depends on vessel location before hiring Assumed 20
Equipment loading	Turbine loading time and all necessary equipment and tools	9
Sea fastening	Turbine and equipment fastening on the vessel's deck	27
Transit	Journey to the location chosen for the installation of the device	6
DP Trials	Testing of the Dynamic positioning of the vessel during mid-tide	6
As found survey	ROV video of the turbine before removal	3
Cable recovery	Recovery the connected cable	6
Disconnection	Disconnection of the turbine starter cable and the export cable	3
Jumper cable laydown	Laying the turbine starter cable	1.5
Export cable laydown	Laying of the export cable to the electrical network	1.5
Jumper cable recovery	Turbine starter cable recovery	1.5
Turbine recovery	Recovery of the entire turbine	9
Ballast weights recovery	Recovery of ballast weights	12
Foundation recovery	Recovery of the foundation elements	9
As laid survey	ROV video survey of the site after turbine and foundation recovery	6
Transit	Journey to the port	6
Equipment unloading	Unloading of equipment and tools in port	20
	TOTAL HOURS	146,5

Figure 7. Recovery phase of the D10 turbine. Source: Sabella website

Figure 8. Connection and cable laying phases of the D10 turbine. Source: Sabella website

4 REDUCTION OF ENVIRONMENTAL IMPACT IN O&M

4.1 Reliability, availability, maintainability (RAM) assessment

4.1.1 Increased reliability

Base on the FMEA and RAM analysis performed in Tasks 1.1 and 1.2 of the project, a number of scenarios highlighted the impact of the Tidal Turbine failures on the environment but also the impact of the environment on the Tidal Turbine reliability. These two topics are presented in the following session.

4.1.1.1 Impact on environment due to Turbine reliability issue

a) Environment pollution due to external leakage

In a tidal turbine nacelle, lubrication oil and cooling medium could be used inside the mechanical system. In case failure occurs at nacelle body, sea water could ingress inside the nacelle body and bring potentially the lubrication oil/ cooling medium into the sea. It is noted that in FMECA, different failure causes could provoke the structure failure of nacelle body, including:

- Nacelle Joint structural deficiency
- Interface with supporting structural deficiency
- Nacelle penetration rupture
- Access into nacelle (hatches) structural deficiency
- Foundation/ interface with foundation structural deficiency

Considering these failure causes, different mitigation ways were proposed in different tidal turbine models:

1) Nacelle is fully welded, that no joint is used
2) Ensure lubrication oil and cooling medium are in a closed loop that avoid lubrication oil and/or cooling medium release into the sea in case of sea water ingress in nacelle.

It should be noted that it is not mandatory that two mitigation ways arecarried out together. Selection of only one of the mitigations would be sufficient to reduce the risk probability.

b) Environment Pollution due to explosion

Tidal turbines normally donot include explosive products. However, investigation in FMECA shows that the electronic components could be source of explosion or fire. Even if explosive electronic components may not be a credible scenario for most tidal turbines, this risk is recorded in order to fully cover the risk.

Mitigation such as short circuit protection could help to further reduce the risk of explosion from electronic components.

c) Environment Pollution due to toxic painting selection

Any toxic paint applied on Tidal turbine surfaces, could be a cause of environment pollution. Designers should investigate environment friendly painting in order to reduce pollution effects.

d) Submarine animal impact

In most tidal turbine concepts, turbine blades are designed to rotate at a given speed. It is unknown in this step if the rotating speed of blades is sufficiently important to potentially cut passing animals and put their life in danger. This investigation shall be done in the future. And blade rotation speed could be limited to an acceptable level in order to avoid this scenario.

4.1.1.2 Tidal turbine Reliability Impact due to Environmental issues

a) Bio-fouling/ Marine growth:

Bio fouling/ marine growth is one of the most important environment challenges for tidal turbine design. Additional weight could be found on blades or other external turning mechanical system (e.g. yaw, pitch). Performance of tidal turbines will be reduced annually due to bio-fouling/ marine growth on blades. Other mechanical system could even be blocked due to bio-fouling / marine growth. Sea water temperature is an important factor that impacts bio-fouling/ marine growth.
Anti-fouling painting is the main mitigation way to reduce the bio fouling risk. It shall be noted that in the RealTide project, task T1.2 – RAM analysis considered that Bio fouling will reduce performance of tidal turbines by 1% every year even taking into account the anti-fouling painting.

b) Collision with passing vessel / Dropped object

Today, most tidal turbines are submerged;, depending on the depth of installation, tidal turbines may not be noticed by passing vessels. Collision impact could be an important consequence. Different strategies could be implemented to reduce collision impact probability:

- Define dedicated tidal turbine zone that passing traffic is not allowed to enter,
- Make sure the tidal turbines installation area is far from passing traffic path,
- Install floating top lights in case other mitigation ways above are not possible.

Dropped objects such as fishing net are another possibility that could block the rotating blades. Similar mitigation ways to above could solve this problem.

4.1.2 Maintenance Strategies

In the RAM analysis performed in T1.2, the impact of the Weather condition on maintenance operations was considered, and consequently on Tidal Turbine availability. Indeed, the main external factor that can significantly impact on delaying maintenance operations is bad weather and sea conditions. Offshore Supply Vessel (OSV) operations for tidal turbine connection/disconnection, lifting/laydown and mooring/unmooring can be performed only under a certain limit of wave, wind and current conditions. Similarly, Crew Transport Vessels (CTV) maintenance crew can only operate under certain weather conditions, mainly the wave conditions.

In order to take into consideration weather conditions, current, wave, and wind data of the Turbine location was compared with the vessel’s requirement. Below is presented the main assumptions regarding the Weather Conditions in the RAM models regarding OSV and CTV operations

a) Weather conditions for OSV

Table 15 shows the typical operational constraints for OSV

Table 15. Typical operational constraints for OSV operations

Items	Marine operation limits
Current speed max (Vmax)	6 knots
Hs max	2 m
Wind speed max (Wmax)	15 m/s
Duration of a weather window	2 days

Figure 9 illustrates an example of weather windows derived from imposing the requirement in Table 15 against the current, wind, wave datasets for 1995.

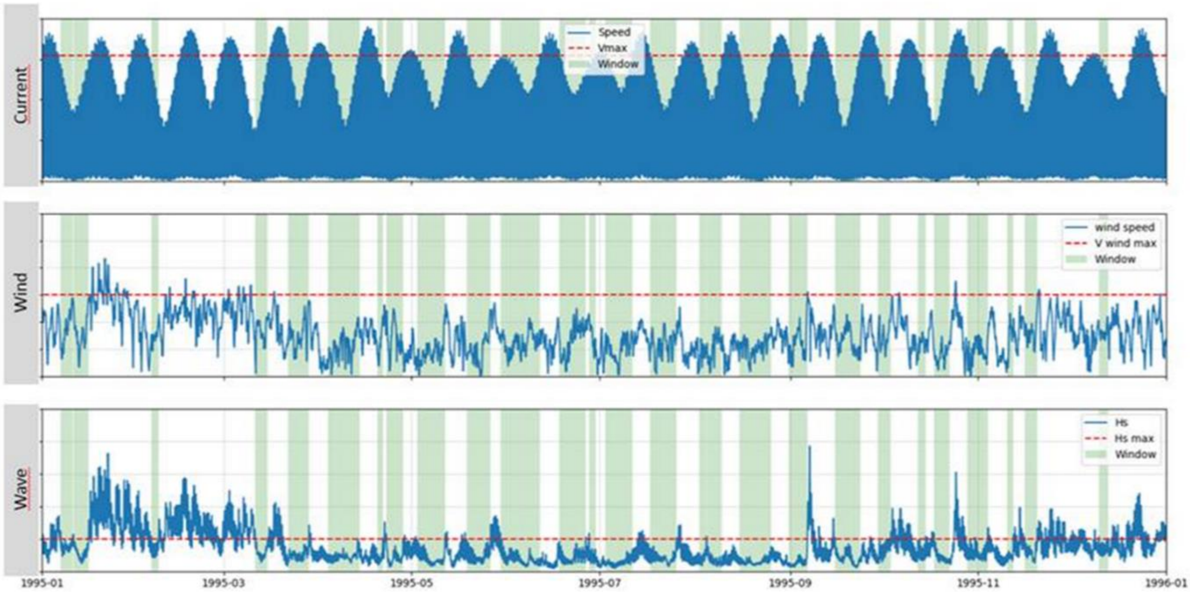

Figure 9. Weather windows historic for connection/disconnection OSV operations

The green zones represent the periods where the combination of good conditions of wave, wind and current allows the OSV to operate, whereas white zones are period where wave wind and/or current conditions are above the OSV allowable operational limit. This process is applied throughout the length of 19 years environment datasets. Figure 10 provides an example for weather windows heatmap from 1994 to 1998 where the green colour indicates suitable weather windows for OSV operation, while the red ones indicate unsuitable days.

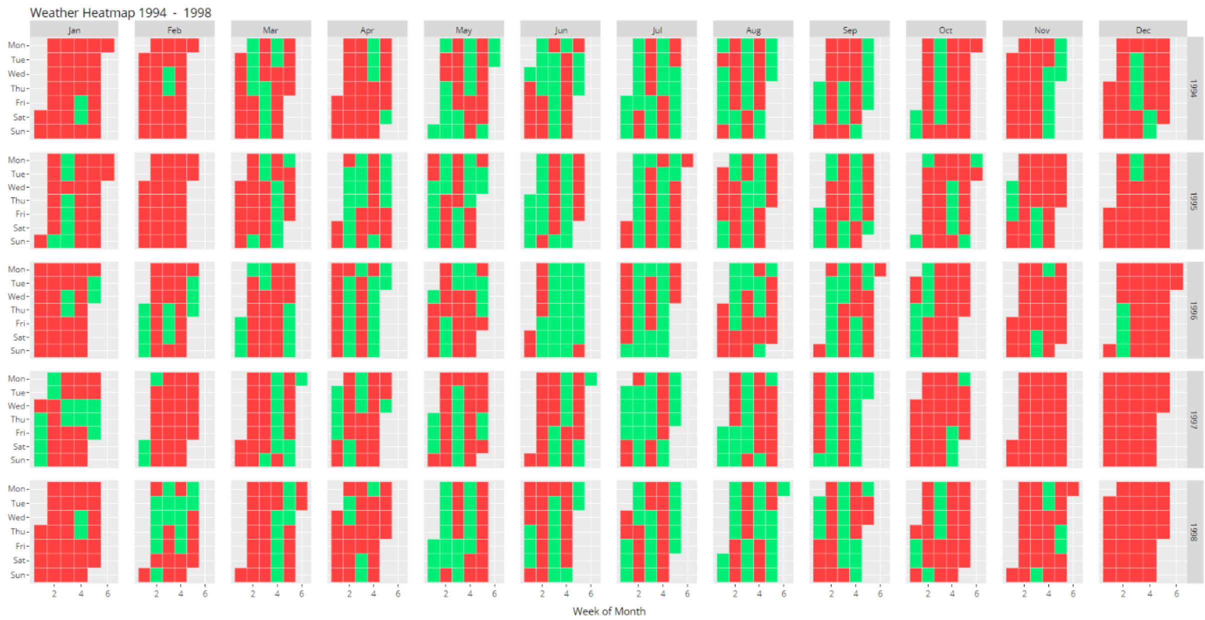

Figure 10. Suitable weather window heatmap for OSV operation in 1994-1998

Based on this approach, the probability of having suitable weather windows for the next two days can be estimated, i.e., for each day of the year, the probability of having good conditions to perform the OSV operation for removal and installation of the tidal turbine can be quantified. Figure 11 provides the daily probability of having suitable conditions for OSV operation.

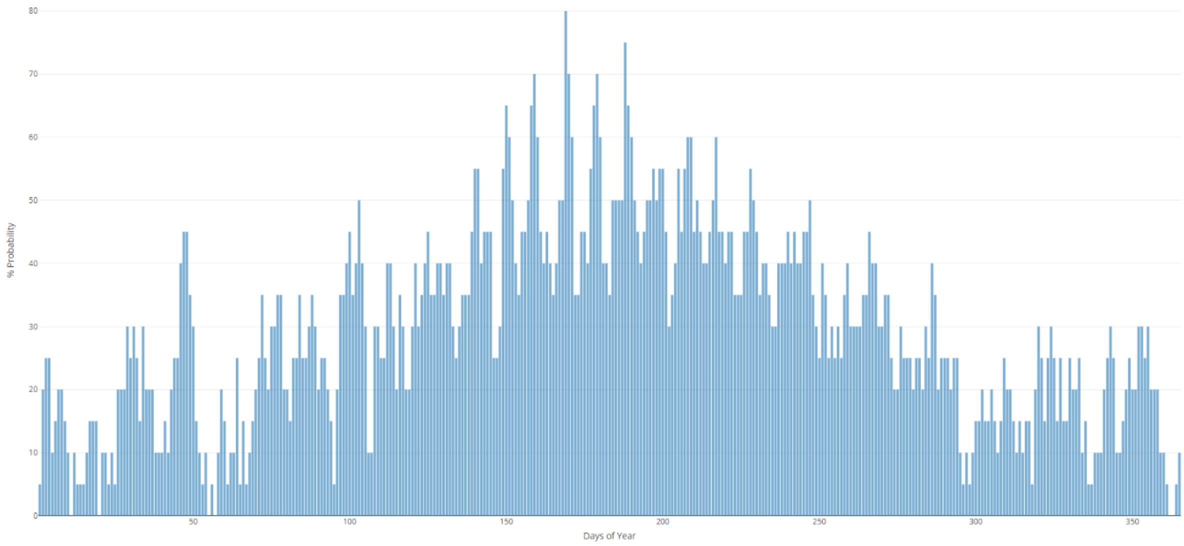

Figure 11. Daily probability of having suitable condition for OSV operation

This weather windows probability is used for all categories of maintenance for the 1st concept turbine (as it was assumed that the fixed bottom Tidal Turbines should always be removed from water in order to perform a repair), and for major failures for the 3rd concept turbine (major failures are those that required the removal of the Tidal Turbine from its location to be repaired). It is to be noted that the weather conditions do not affect the displacement of the vessel but only the operations requiring dynamic positioning for removal and installation of the tidal turbine for maintenance purposes.

b) Weather conditions for CTV

Unlike OSV operations that requires specific current, wave, and wind conditions for allowable operation, CTV operation is only limited by Significant Wave Height (Hs). The accepted wave range for CTV operation is ranging from 1-2 m, depends on the vessel type. For this study it was assumed that CTV operation can be conducted for Hs lower than 1.5 m.

Table 16. Typical operational constraints for CTV

Vessel Characteristics	Crew Transfer Vessel
Governing weather criteria	Wave
Weather criteria	1.5 m
Speed of vessel	20 knots
Duration of a weather window	10 hours
Technician capacity	12

Typical required maintenance windows for offshore wind turbines are around 10-14 hours and generally the maintenance only performed during daylight hours. Based on this, the required weather window for this study is assumed to be 10 hours during daylight (08:00 – 18:00) all year. Figure 12 shows the time series data of Hs from 1994 to 2013 where the red line indicates the maximum allowable Hs for minor and trivial maintenance of 3rd concept turbine.

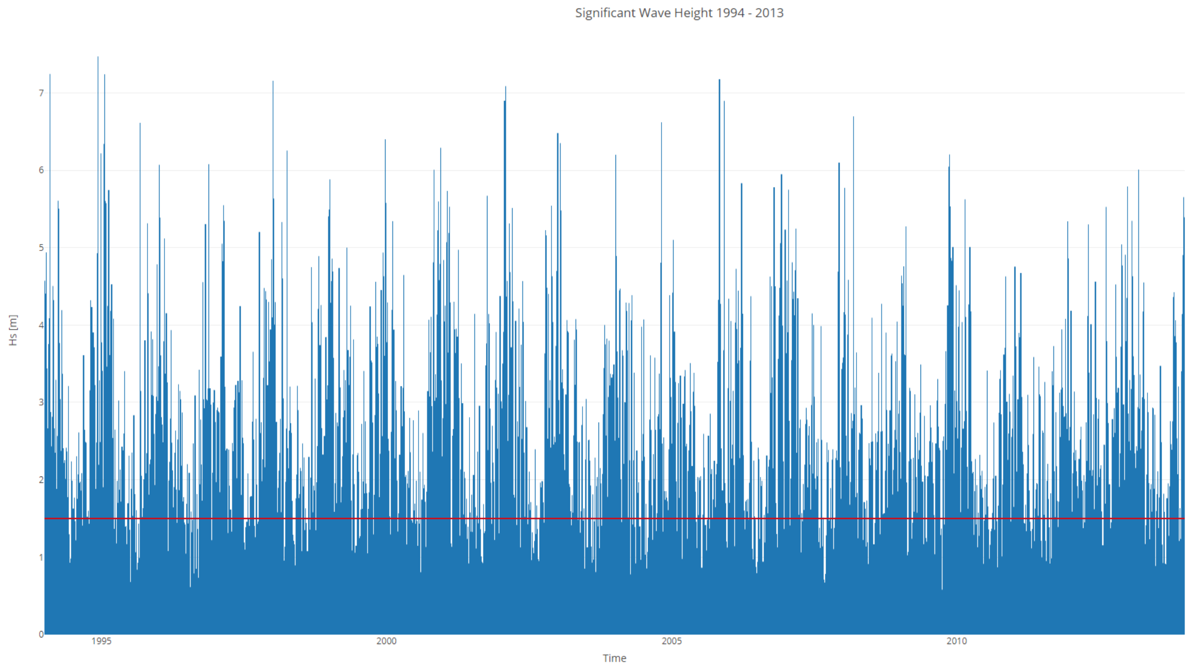

Figure 12. Significant wave height (Hs) time series

A Heat map example presented in Figure 13 takes into account the requirement of 10 hours duration during daylight hours, where the green colour indicates during daylight hours there are at least 10 hours consecutive of Hs lower than 1.5 m between 08:00 to 18:00 hour that allow crews in CTV to intervene on the turbine for 1994 to 1998. The red ones indicate unsuitable conditions for CTV operation.

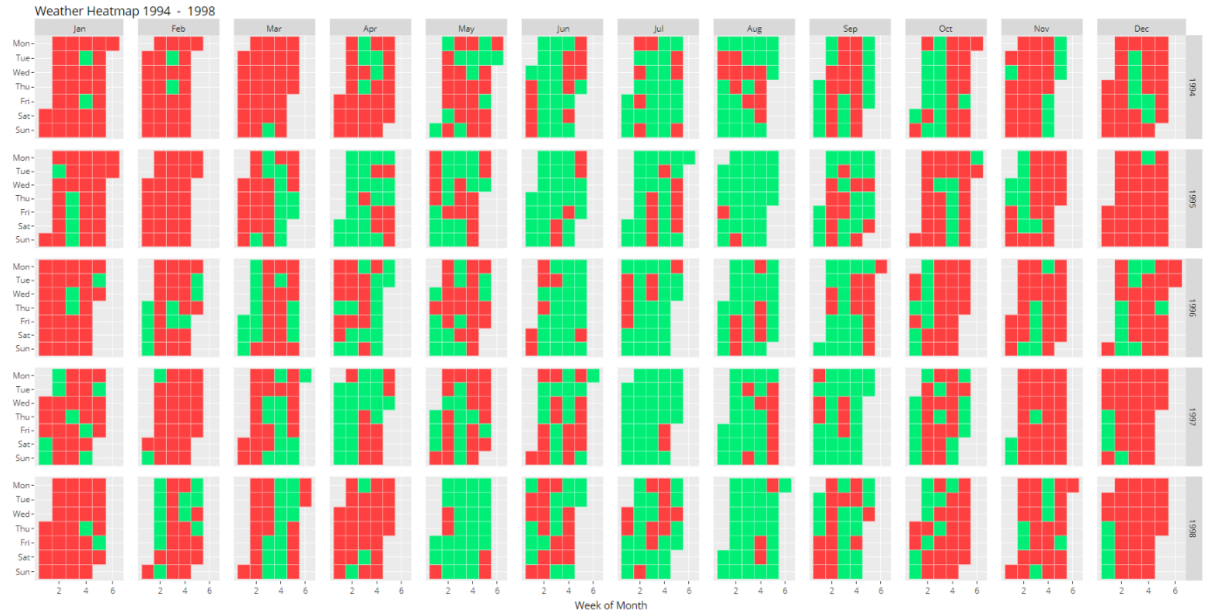

Figure 13. Suitable weather window heatmap for CTV operation in 1994-1998

Similar to the approach for OSV operation explained previously, this process is applied for 19 years of data from 1994-2013, then a daily probability of having suitable conditions for CTV operation can be extracted as shown in Figure 14.

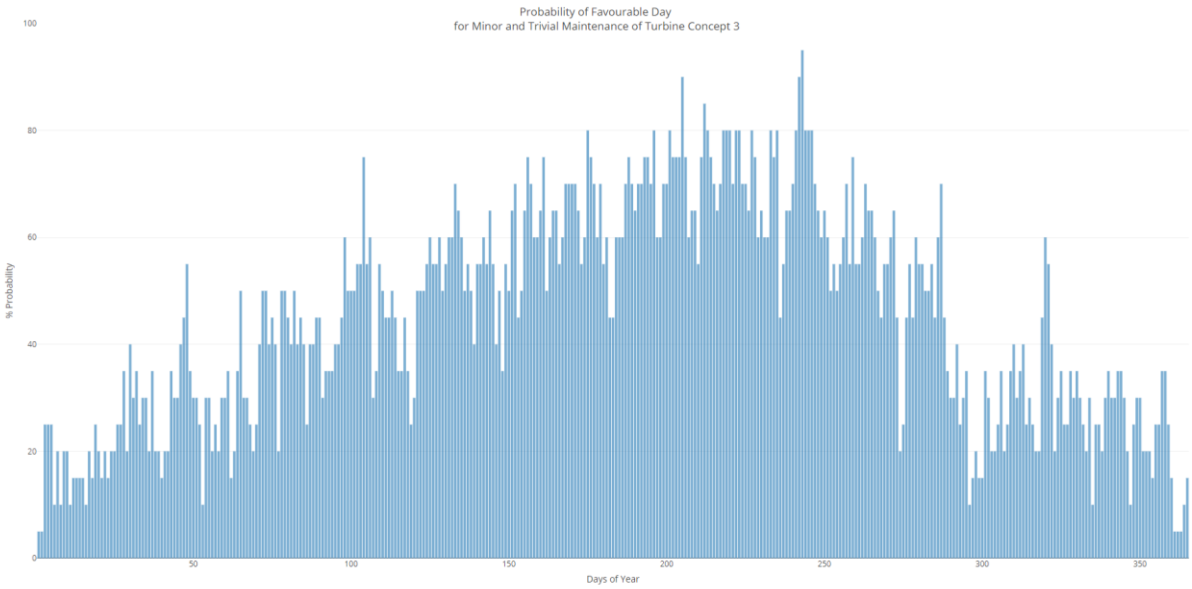

Figure 14. Daily probability of having suitable condition for CTV operation

c) Results of RAM regarding impact of weather conditions on turbine availability

Taking into account the weather conditions described above, a RAM study was performed for two generic tidal turbine concepts previously defined during Task 1.1: Concept 1 - "complex bottom fixed tidal turbine" and Concept 3 - "floating multirotor tidal turbine" (herewith called concept 1 and concept 3 respectively).

For concept 1, the RAM analysis resulted in an availability over 20 years of 71.82%. The OSV mobilisation was required 2.45 times per year for turbine components repair.

For concept 3, the RAM analysis indicated an availability for 20 years of 80.09%. The OSV mobilisation was required 1.87 times per year and the CTV mobilisation 1.43 times per year.

Then, a Sensitivity cases (SC1) study was performed in order to assess the impact of the weather condition on maintenance operations and consequently on Tidal Turbine availability.
The SC1 was performed without considering the weather condition effect on OSV and CTV operations. In other words, in that case, it was assumed that OSV and CTV operations would not be delayed due to weather conditions.

For concept 1, the availability increased from 71.82% (from base case) to 78.54%. The difference between the base case and SC1 means that the contribution of weather condition to unavailability is 6.72%. It indicates that the turbine is unavailable on average during 24.5 days/year due to weather conditions factors.

For concept 3, the availability increased from 80.09% (from base case) to 85.64%. The difference between the base case and SC1 means that the contribution of weather condition to unavailability is 5.55%, so the turbine is unavailable on average during 20.3 days/year due to weather conditions.
The Figure 15 and Figure 16 show the contribution of the weather condition to unavailability for concept 1 and concept 3 respectively.

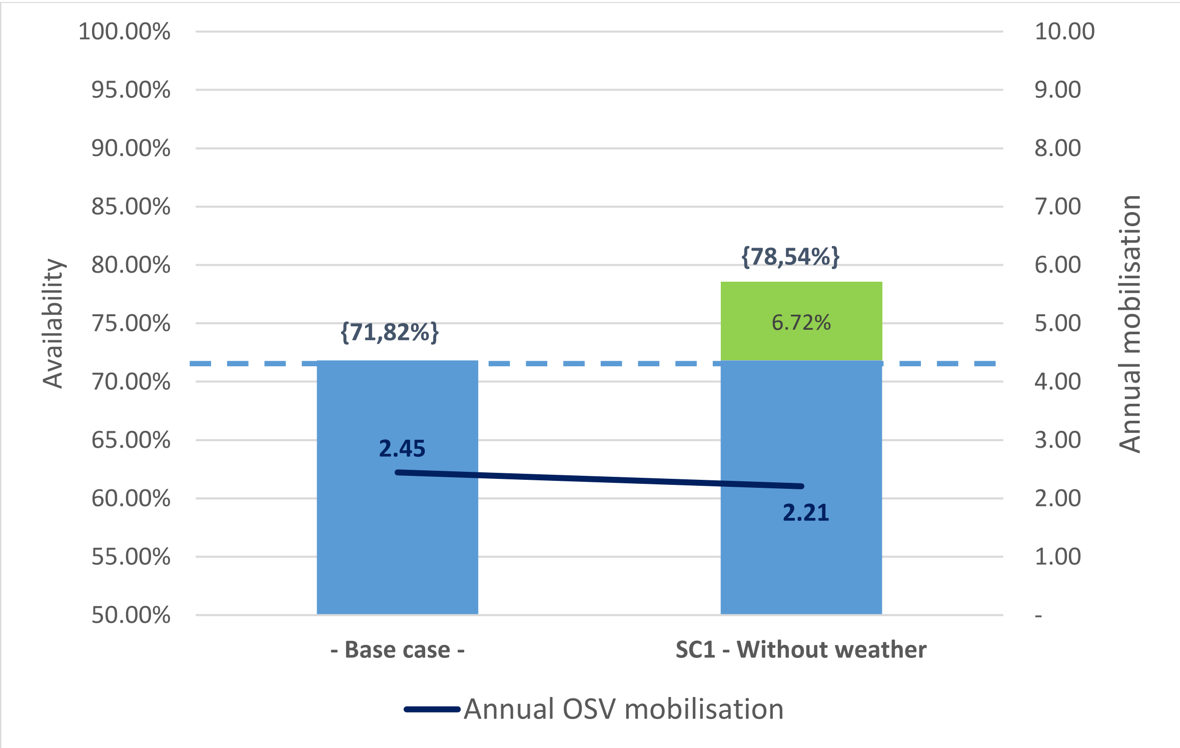

Figure 15. Sensitivity case1 – Weather condition impact – Concept 1

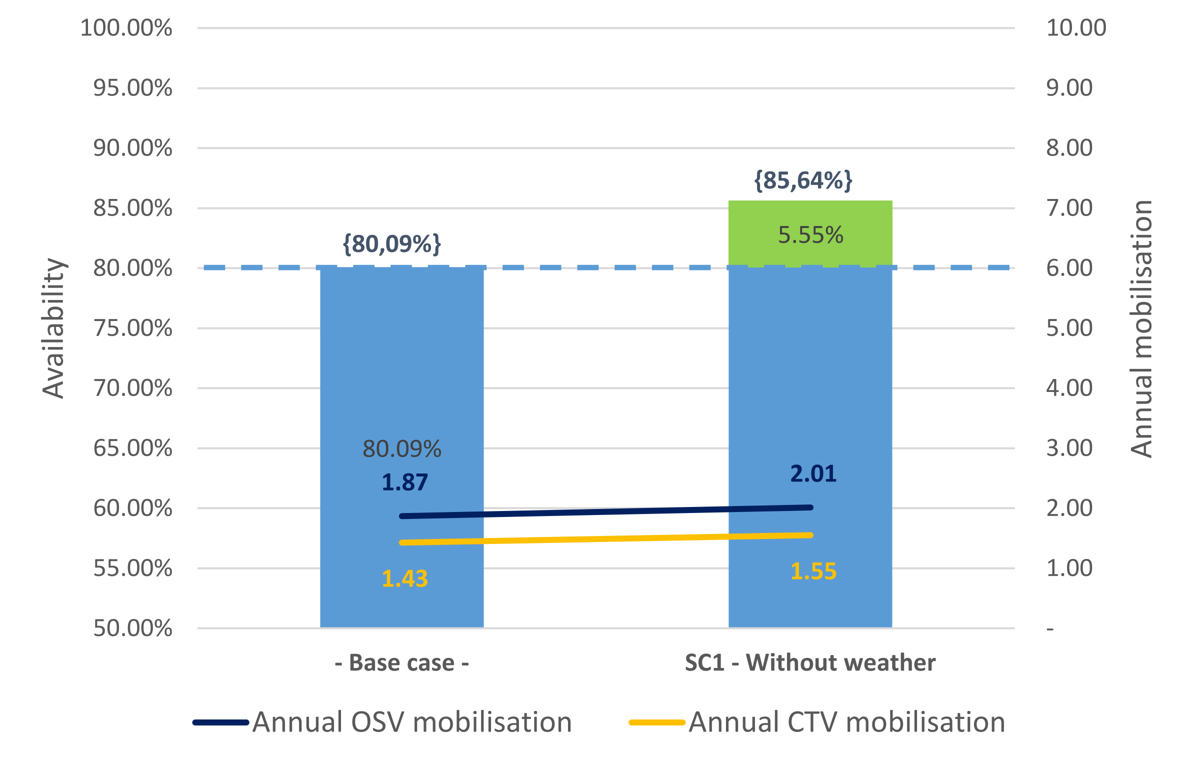

Figure 16. Sensitivity case1 – Weather condition impact – Concept 3

As a conclusion, it can be noted that the weather conditions have a significant impact on the tidal turbine availability. Therefore, careful attention must be paid to the location where the tidal turbine will be installed. The weather condition and the access to the tidal turbine should be carefully analysed prior to its installation as the turbine availability might change significantly from one location to another depending on its environmental condition constraints.

In addition, the environmental impact reduction on maintenance operations and consequently on Tidal Turbine availability, can be focused on the following maintenance strategy factors:

a. **Decrease in fuel consumption:**
   More than 90% of the international transport of goods is carried out by sea, so the maritime industry, despite using very efficient transport, is a source of emissions and waste, which includes polluting discharges into the oceans. This point reinforces the value of energy efficiency to guide the maritime sector towards a low emission and marine environment friendly future. That is why all shipping companies and ship-owners around the world are working with the IMO (International Maritime Organization), to identify technical and operational means to improve the efficiency and sustainability of their fleets.

b. **Decrease in CO2 emissions:**
   A new methodology has been created for granting carbon credits for the shipping business. This is a remarkable initiative that is the first carbon credit methodology, applicable to ships. It aims to be a measure that benefits and rewards ship-owners for having invested capital in their commitment to more sustainable technologies. Each credit represents the elimination of a ton of carbon dioxide from the atmosphere, that is, each credit means that pollution equivalent to one ton of CO_2 is avoided.

c. **Reduced use of spare parts, thereby reducing the use of raw materials.**

Advance in the reduction of the use of raw materials, reusing the materials contained in the waste as secondary raw materials as long as public health and the protection of the environment are guaranteed.

d. **Increased efficiency of facilities, increasing the use of new technologies:**
The automation of processes generated by new technologies increases productivity between 0.8% and 1.4%.

The following table shows the different levels of environmental impact that must be mitigated using maintenance strategies:

Table 17. Environmental impacts levels. [12] [13]

Environmental Impact Level	Fuel consumption	CO2 emissions	Spare parts manufacturing	Efficiency & new technologies
Major	The reduction of fuel consumption derived from the transport of equipment to the facilities is negligible.	CO2 emissions derived from the transport of equipment to the facilities is negligible.	Reducing the use of raw materials is not possible.	Low efficiency of the equipment used
Moderate	The reduction in consumption is approximately >10%.	The reduction of CO2 emissions is approximately >15%.	Reducing the use of raw materials is approximately >40%.	Medium efficiency of the equipment used
Minor	The reduction in consumption is approximately >20%.	The reduction of CO2 emissions is approximately 30%.	Reducing the use of raw materials is approximately >50%.	High efficiency of the equipment used
Positive	Fuel consumption has been avoided by avoiding displacement.	CO2 emissions has been avoided by avoiding displacement.	There is no use of new spare parts.	100% efficiency equipment used

4.1.2.1 Corrective maintenance

As defined in [14] D4.1 - Initial monitoring plan, corrective maintenance is a process that consists of locating and correcting the breakdowns or faults that are preventing the machine from performing its normal function.
According to the types of corrective maintenance, there are different ways to reduce the environmental impact:

4.1.2.2 Environmental impact reduction on corrective maintenance

The environmental impact reduction can be assessed in corrective maintenance as follows:

- **Contingent corrective maintenance**

Contingent on corrective maintenance implies that the repair is carried out as quickly as possible in order to avoid material and human damage, as well as economic losses.

Due to this, the reduction of the environmental impact in this case is minimal, since there is no possible forecast of the transport to be used or the time that the repair will take.

- **Scheduled corrective maintenance**

The programmed corrective maintenance is the one that has as objective to anticipate to the possible failures or damages that can occur from one moment to another. In addition, this type of maintenance allows the time when the overhaul is to be carried out to be set in advance, so that hours of inactivity or little activity can be taken advantage of.

The following table shows how corrective maintenance is not efficient for the reduction of environmental impact, therefore, effort has to be directed towards preventive maintenance.

Table 18. Inefficient method of environmental impact reduction

CORRECTIVE MAINTENACE	Contingent corrective	Scheduled corrective
Fuel consumption	Major	Moderate
CO2 emissions	Major	Moderate
Spare parts manufacturing	Major	Minor
Efficiency	Major	Minor

4.1.2.3 Environmental impact reduction on preventive maintenance

As we saw in [14] D4.1 - Initial monitoring plan, this type of maintenance is done before the failure occurs, where the component is replaced periodically without the prior knowledge about its state or condition.

The main characteristics of preventive maintenance are as follows:

- It is carried out periodically and routinely.
- It is a type of maintenance whose tasks and budgets are planned. It has a start and end time.
- It is carried out in conditions of total control to avoid accidents, while the equipment is stopped.
- It seeks to anticipate future failures or damage to equipment.
- The manufacturer generally recommends when to do so, through technical manuals.
- The activities that are carried out follow a previously elaborated program.
- It offers the possibility of updating the technical configuration of the equipment.

The preventive maintenance of turbines can be divided into four time periods:

- **Preventive 3 months**: This is carried out three months after the start-up of the WTG, and basically consists of checking the tightness in different parts of the WTG such as foundations, between sections, hub union with main shaft, blades, etc ... and is mainly carried out with hydraulic tools.
- **Minor preventive**: This is carried out at 6 months and then every 12 months (i.e. at 18, 30, etc...) in each WTG, tightening the most unfavourable parts of the machine, crown and bearing greases, checking of levels, temperatures, checking of the fibre, connected checks of Pitch, G.H., blades, gearbox, brakes, cardan, electrical revisions, etc. This is a very extensive overhaul.

- **Major Preventive**: This is carried out at 12 months and every 12 months thereafter (i.e. 24, 36, 48). It is a preventive maintenance with many points in common with the minor.
- **Mechanical preventive**: This is done at 18, and then every 12 months. It coincides with the minor preventive maintenance. It is an extensive revision of the machine's tightness in all the most unfavourable parts and checking of connections.

4.1.2.4 Types of preventive maintenance

Preventive maintenance is subdivided into three types:

- **Scheduled maintenance**

This type of maintenance is planned and budgeted, given that the revisions or inspections to the equipment are carried out according to time parameters, operating hours, consumption, among other factors.

- **Predictive maintenance**

Predictive maintenance determines when repair should be performed according to maintenance advice and the maximum recommended operating time before undergoing repair.

- **Maintenance of opportunity**

This is usually done when equipment is taken out of operation for this purpose, such as a turbine in a hydroelectric power plant, thus taking advantage of its resting time.

The following table shows the levels of environmental impact reduction according to the type of predictive maintenance:

Table 19. Environmental impact levels for preventive maintenance

	Scheduled maintenance	Predictive maintenance	Maintenance of opportunity
Preventive 3 months	Minor	Positive	Positive
Minor preventive	Minor	Moderate	Positive
Major Preventive	Moderate	Positive	Positive
Mechanical preventive	Moderate	Moderate	Positive

4.1.3 Monitoring strategies and techniques

Below are the monitoring techniques and strategies used to reduce the environmental impact, in order to reduce the maintenance of the turbine and consequently increase its availability.

4.1.3.1 Condition Based Maintenance (CBM) strategies.

This technique is based on the results of the [14] D4.1 - Initial monitoring plan, and the FMEA. Three different **monitoring strategies** have been defined:

1. **Spot Measurement (SM)**

Minimum monitoring system. The system is not installed permanently on the TEC and it is installed in-situ when performing maintenance tasks. This technique is highly susceptible to being integrated in the blade monitoring system since it largely reduces the complexity of the system.

2. **Basic Permanent Monitoring (BPM)**

A permanent installation of transducers in the critical components that allows readings to be made during maintenance interventions/visits on the tidal device (included in a periodic review of the machine or in the context of an additional maintenance intervention). This is the most commonly found installation. It is an intermediate solution between SM and PM.

3. **Permanent Monitoring (PM)**

A permanent installation of both transducers and interfacing electronics in the tidal device that allows an automatic periodic reading of the sensors remotely in real-time. This strategy allows performing remotely the Condition Monitoring of all the critical or more expensive composite material elements. In this configuration, the RealTide monitoring system becomes the SCADA system of the machine, including all the monitoring needed and some actuation capacity, linked to protection of the device in case of a problem appears. It will be communicated to the power electronics/electrical generator control.

4.1.3.2 Comparative

In the following table we can find the environmental impact levels for the monitoring strategies:

Table 20. Maintenance strategies environmental impact level.

Maintenance Strategy	Definition	Environmental impact level
SM	• Machines are not "over maintained" • No condition monitoring related costs	• Moderate
BPM	• Maintenance is performed in controlled manner • Fewer catastrophic failures • Unexpected machinery failure should be reduced	• Minor
PM	• Equipment life is extended • Reduced downtime • Reduced overall maintenance costs • Fewer failures, thus fewer secondary failures	• Positive

4.1.4 Reduction of environmental based on new proposed materials [15]

Environmental impact is not considered an important criterion today, as most tidal turbines are at the prototype stage, but successful commercial development and a multiplication of the number of blades will lead to the question of life cycle analysis. It is important both to examine end-of-life options and to ensure that the benefits of cleaner energy are not offset by increased environmental impact.

For this reason, alternative blade materials to carbon fibre reinforced epoxy composite have been evaluated in order to reduce the environmental impact. The use of bio-sourced materials for composite construction has been of increased interest in recent times. Composites are manufactured materials, whose properties can be tuned based on the type of resin and the type of fibres used for reinforcement. Mechanical properties of these materials have to be validated against those for the conventional materials used for tidal blade construction, such as carbon/epoxy or glass/epoxy composites, in order to consider them competitive in addition to being environmental impact friendly [15].

4.1.4.1 Alternative matrix polymers

Matrix polymers can be classified according to their ability to degrade, which provides an advantage to take in consideration to reduce the environmental impact after service. This classification is expressed in Figure 17, where the heading "fully degradable" indicates that there is potential to degrade the polymer completely but this does not necessarily occur under all conditions.

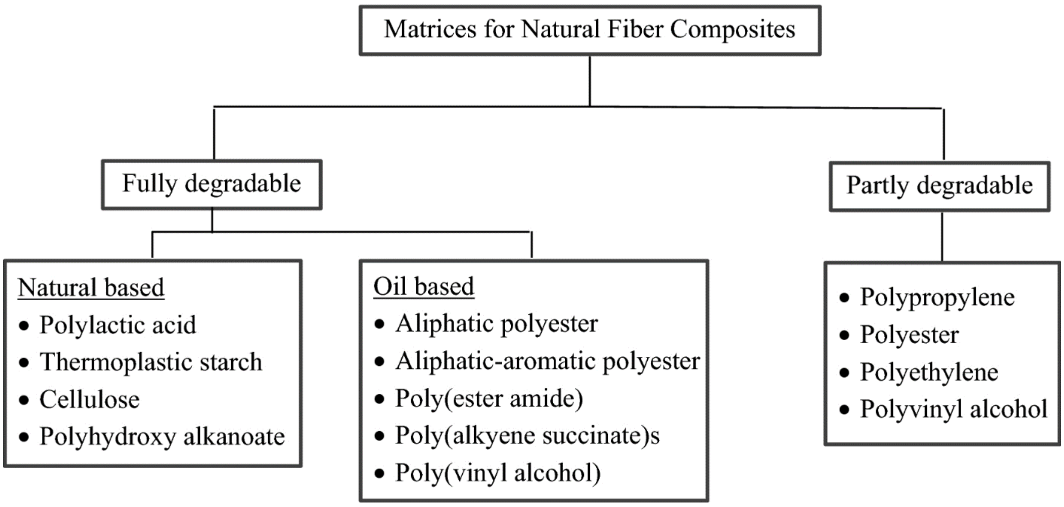

Figure 17. Classification of polymer matrices for natural fibre composites [16]

Thermoplastics such us, polypropylene (PP), polyethylene (PE), polyvinylchloride (PVC), polystyrene (PS), polyamide (PA), acrylic, polycarbonate, etc.; are alternative materials that can be remoulded by heating and they are used to replace thermoset resins that cannot be remoulded after the initial forming.
Another possibility for alternative polymers is to improve the reusability of thermoset polymers. A novel concept related to this has been presented in [17]. The approach is based on the introduction of reversible or exchangeable bonds into the polymer network. The concept is named 3R Composite – with enhanced re-processability, reparability and recyclability compared to typical thermoset polymers.

4.1.4.2 Alternative fibres

Bio-sourced fibres such as wood, cotton, flax, kenaf and hemp, are alternative fibres that replace classical fibre materials like glass and carbon. These materials are readily available, and less harmful to the environment. Other naturally occurring materials with significant mechanical properties, such as basalt, may also provide alternatives as eco-friendly reinforcements

4.1.4.3 Alternative core material

For composite blade construction, the use of eco-friendly core materials can reduce the environmental impact. One such material that has been used in the marine field for many years is balsa wood. In addition to being eco-friendly, balsa wood is an excellent core material due to its good strength and stiffness properties. Cork can also be used as a core material.

4.1.4.4 Analysis of alternative materials

The following four alternative materials to the carbon and E-glass fibre have been analysed based on their properties, the recyclable property being the most important one to take into consideration when talking about reducing environmental impact.

- Carbon fibre reinforced Green Epoxy™. This corresponds to the material combination finally selected by the blade manufacturer for the first blade manufactured and tested in WP4.4. The epoxy resin produced by Sicomin SA is partially biobased.

- Carbon fibre reinforced polyamide 6. This thermoplastic matrix composite offers the possibility for recycling, and will allow a direct comparison with the carbon/epoxy composite used today for the Sabella (and most other) tidal turbine blades, characterized in WP 1.3.

- Glass fibre reinforced polypropylene. This material is also recyclable, polypropylene is an inexpensive thermoplastic with low sensitivity to moisture. Glass fibre composites have not received much attention for tidal turbine blades compared to carbon fibre composites but they should be cheaper, and glass/PP can be directly compared to the glass/epoxy characterized in WP 1.3.

- Flax fibre reinforced acrylic. This is a radically different option, involving a new potentially recyclable polymer matrix (Elium™ from Arkema), reinforced by natural flax fibres. It will allow a further comparison with the glass/epoxy characterized in WP 1.3.

Table 21 summarizes the different material systems, together with their environmental impacts and associated costs. It provides a fairly criterion to be able to choose the material that adjust to the requirements and takes into account the environmental impact.

Table 21. Materials environmental impact and associated cost

Material	Fibre	Resin	Cost	Biobased Petro based	Recyclable Repairable
1	Carbon	Polyamide 6	Similar cost	Petro based	Yes
2	Glass	Polypropylene	Lower	Petro based	Yes
3	Flax	Elium	Lower	Partially biobased	Probably
4	Carbon	Green Epoxy	Similar cost	Partially biobased	No

However, the best candidates to replace the reference materials appear to be the C/GR33 (all properties above 60% of the associated reference property) and the C/PA6 (all above 50%). The glass/PP and F/El appear to be further away from their glass/epoxy reference. However, in design, all these materials may be used efficiently because other aspects than mechanical properties must be taken into account, such as associated cost, ease of manufacturing, weight, and environmental impact etc. The results from evaluation of these alternative materials will be discussed in WP 5.1.

5 SUMMARY

The environmental analysis should form an integral part of the project development from the very beginning. The environmental assessment of wave and tidal projects is a process that to be carried out by project developers in order to inform stakeholders and regulatory bodies in their assessment and decision-making process from concept, starting at site selection and project development design, to decommissioning.

The identification of environmental risks has to be evaluated for each particular project taking int consideration the given site (and/or alternatives) and device type, in order to minimize any negative impacts, maximize positive impacts and reduce development constrains. And this have to be considered at the early stage of the environmental assessment process.

In Task 1.7: "Reduction of environmental impacts due to increased reliability", the objective is not to perform an environmental impact analysis itself as the requirements of the EIA study are specific to the exact location and characteristics of each tidal energy project and should be defined at the scoping stage. Nevertheless, it is important to note that although there is already a good amount of information available on this subject, there is still a need to collect and analyze more data to reduce uncertainties of effects, prioritize impacts and improve best practice in project development and deployment.

Having noted this, and shown the best practices to follow for an environmental impact analysis, the work performed have been focused on a comparative study to assess the environmental benefit achieved thanks to the higher reliability level and the associated reduction of maintenance visits as the main objective of this Deliverable.

Based on the results obtained in the different studies carried out in the various work packages of the RealTide project, an estimate can be made of the potential reduction of the environmental and economic impact of a tidal turbine when the guidelines, techniques and new materials proposed by RealTide, and focused on increased reliability, are applied.

As shown Table 22 using Sabella D10 model as a reference, the estimated reduction does not impact directly on the carbon footprint or costs of the installation or dismantling phases, as que operations remains the same and reliability have no impact on them.

However, in operation phase the impact can be more than significant due to the reduction of maintenance visits from 125 to 50 in the lifecycle of a tidal turbine. This estimation totals not only a heavy reduction in the total environmental impact during the life cycle rising up to almost a 60% reduction (19.320.495,8 Kg CO_2-eq of Carbon Footprint vs. 47.565.741,7 Kg CO_2-eq of Carbon Footprint) but also a similar percentage cost reduction on the operational phase (OPEX) (2.860.108,84 € estimated cost introducing RealTide innovations vs. 7.037.773,59 € estimated using standard operation and maintenance practices).

Table 22. Estimation of the reduction of environmental and economic impact over the lifetime of a tidal turbine. Source: [1], [18] and RealTide consortium

OPERATION	INSTALLATION																
Sub-operation																	
Phases	Arrival in port	Equipment loading	Sea fastening	Transit	DP Trials	As found survey	Foundation installation	Ballast weights installation	Turbine installation	Jumper cable laydown	Export cable recovery	Jumper cable recovery	Connection	Cable laydown	As laid survey	Transit	Equipment unloading
Vessel Type	Offshore Support Vessel (OSV) wiht 250T crane capacity																
Duration (hours)	20	9	27	6	6	3	9	12	9	2	2	2	3	6	6	6	20
Fuel consumption (m3/hour)	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Fuel consumption (m3)	16	2	5	5	3	2	5	6	5	1	1	1	2	3	3	5	4

OPERATION	MAINTENANCE														
Sub-operation	Turbine recovery														
Phases	Arrival in port	Equipment loading	Sea fastening	Transit	DP Trials	As found survey	Cable recovery	Disconnection	Jumper cable laydown	Export cable laydown	Jumper cable recovery	Turbine recovery	As laid survey	Transit	Equipment unloading
Vessel Type	Offshore Support Vessel (OSV) wiht 250T crane capacity														
Duration (hours)	20	6	18	6	6	3	6	3	2	2	2	9	3	6	15
Fuel consumption (m3/hour)	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
Fuel consumption (m3)	16	1	3	5	3	2	3	2	1	1	1	5	2	5	3

OPERATION	MAINTENANCE														
Sub-operation	Turbine reinstallation														
Phases	Arrival in port	Equipment loading	Sea fastening	Transit	DP Trials	As found survey	Turbine installation	Jumper cable laydown	Export cable recovery	Jumper cable recovery	Connection	Cable laydown	As laid survey	Transit	Equipment unloading
Vessel Type	Offshore Support Vessel (OSV) wiht 250T crane capacity														
Duration (hours)	20	6	18	6	6	3	9	2	2	2	3	6	3	6	15
Fuel consumption (m3/hour)	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0
Fuel consumption (m3)	16	1	3	5	3	2	5	1	1	1	2	3	2	5	3

OPERATION	DISMANTLING																
Sub-operation																	
Phases	Arrival in port	Equipment loading	Sea fastening	Transit	DP Trials	As found survey	Cable recovery	Disconnection	Jumper cable laydown	Export cable laydown	Jumper cable recovery	Turbine recovery	Ballast weights recovery	Foundation recovery	As laid survey	Transit	Equipment unloading
Vessel Type	Offshore Support Vessel (OSV) wiht 250T crane capacity																
Duration (hours)	20	9	27	6	6	3	6	3	2	2	2	9	12	9	6	6	20
Fuel consumption (m3/hour)	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Fuel consumption (m3)	16	2	5	5	3	2	3	2	1	1	1	5	6	5	3	5	4

OPERATION	INSTALLATION	MAINTENANCE – Turbine recovery	MAINTENANCE – Turbine reinstallation	DISMANTLING
Total fuel consumption (T)	64,93	49,87	49,87	64,93
Duration (days)	6	4	4	6
Vessel trips	12	9	9	12
Vessel cost/day (€)	2250	2250	2250	2250
Vessel cost /trip (€)	500	500	500	500
Vessel cost (€)	19.838,54	14.286,46	14.286,46	19.838,54
Fuel cost (€)	17.660,96	13.564,64	13.564,64	17.660,96
Carbon Footprint CF (kg CO2-eq/T)	3775,85	3775,85	3775,85	3775,85
CF per operation (kg CO2-eq)	245.165,94	188.301,64	188.301,64	245.165,94
Operations by life cycle (25 years)	1	125	125	1
Environmental impact on the life cycle (25 years)	245.165,94 Kg CO2-eq of Carbon Footprint	23.537.704,9 Kg CO2-eq of Carbon Footprint	23.537.704,9 Kg CO2-eq of Carbon Footprint	245.165,94 Kg CO2-eq of Carbon Footprint
Economic impact on the life cycle (25 years)	37.499,50 €	3.481.387,29 €	3.481.387,29 €	37.499,50 €
Total environmental impact during the life cycle	47.565.741,7 Kg CO2-eq of Carbon Footprint			
Total economic impact during the life cycle	7.037.773,59 €			

Below is the data after applying maintenance strategies and monitoring techniques to reduce the environmental and economic impact

OPERATION	INSTALLATION	MAINTENANCE – Turbine recovery	MAINTENANCE – Turbine reinstallation	DISMANTLING
Operations by life cycle (25 years)	1	50	50	1
Environmental impact on the life cycle (25 years)	245.165,94 Kg CO2-eq of Carbon Footprint	9.415.081,98 Kg CO2-eq of Carbon Footprint	9.415.081,98 Kg CO2-eq of Carbon Footprint	245.165,94 Kg CO2-eq of Carbon Footprint
Economic impact on the life cycle (25 years)	37.499,50 €	1.392.554,92 €	1.392.554,92 €	37.499,50 €
Total environmental impact during the life cycle	19.320.495,8 Kg CO2-eq of Carbon Footprint			
Total economic impact during the life cycle	2.860.108,84 €			