

D1.1 – Requirements and KPIs

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List of abbreviations

DOF	Degree of Freedom
KPI	Key Performance Indicator
LCOE	Levelized Cost Of Energy
O&M	Operation and Maintenance
PV	Photovoltaic
UHPC	Ultra High Performance Concrete



1 Executive Summary

In this report the minimum requirements are described for the different NATURSEA-PV project results to be developed in the following project activities, namely, the floating substructure concept and design, the structure components, the new eco-UHPC material and bio-Coatings, and the set of modelling tools predicting critical material and coating properties and components durability.

Also, the main Key Performance Indicators are described for all these project results in order to assess its performance and benefits from the technical, environmental and socioeconomic perspectives, describing the approach supporting decision making during the design process and final assessment.

2 Introduction

The strategic objective of NATURSEA-PV is to improve the overall lifetime, reliability and maintainability of marine substructures for offshore floating PV, to reduce degradation and failure rates, and thus investment risk and Levelized Cost Of Electricity (LCOE). This implies the redesign of the **substructure** considering the harsh conditions of the open sea, and the need to ensure durability with the minimum construction and maintenance costs. Such designs will also pursue to facilitate decommissioning, reuse and recycling of the facility at the end of the service life. Instead of using the HDPE as in the calmer inland waters, **new eco-UHPC** will be used, as alternative to the ubiquitous HDPE, due to their potential benefits in terms of environmental impact, durability and cost. More environmentally friendly surface **coatings** will also be developed to protect the whole PV facility from corrosion and fouling, and **predictive computational tools** will be developed/improved considering the particularities of the marine environment and the new materials. Such materials, components and tools will be validated in relevant environments. Finally, the potential impacts of offshore infrastructures on environment and human activities will be assessed and mitigation measures will be proposed in order to maximize impact of the proposed solution and contribute to the Mission Healthy Oceans.

To design the NATURSEA-PV new concept, inspiration is sought from Nature. Plants need to capture solar radiation for photosynthesis, in particular fast growing plants like waterlilies benefit from creating large leaves with the least amount of material. The secret of the waterlily's efficient material use lies underneath the leaves. A web of radial and tangential flexible veins/girders provides support to the thin leaf lamina. The radial ribs merge at the centre of the leaves, from which the stem goes down to the bottom of the lake. NATURSEA-PV will develop a lily-inspired PV solution to meet the specific needs for Offshore Floating PV. The lily's concept of radial and tangential girders will be researched and engineered using lightweight, flexible eco-UHPC elements. The concrete girders will provide support to a lightweight sheet, which spans the construction like an umbrella. This sheet will have openings to ensure sufficient sunlight reaches the water surface, and it will provide sufficient carrying capacity for the PV panels as well as maintenance technicians. These openings will also serve to minimize the risk of uplift and buckling by wind. To reduce the



effect of the waves, the concrete web will be raised well above the water by small diameter floating columns. Elevating the construction above the water surface will prevent wave overtopping and reduces the overall wave excitation and formation of fouling in the PV panels.

Substructure design starts by defining the requirements and key performance indicators. One of the key aspects is the LCOE, which is strongly affected by the amount of material used and the ease of installation, transportation, and maintenance. Next to cost, indicators for recyclability, emissions during construction and impact on marine life are established as well. The substructure will be modular and will use connections that facilitate disassembly and reuse of the components at the end of the service life. Conceptual parametric design will be used to allow for multi-objective optimization of parameters like length and bending stiffness of the radial and tangential girders, the diameter and amount of the vertical floaters, the number and weight of the mooring lines, and the amount and sizing of the openings in the mesh. In this way a Pareto front of all Pareto efficient solutions will be made to make tradeoffs within this set. The connectivity between substructures will be considered (Figure 1) to assure the scalability of this proposal, being necessary to avoid stress concentrations in large farms, maintaining simple inspection procedures, avoiding large areas without sunlight underneath, maximizing the use of the marine space and assuring a robust and affordable mooring network.

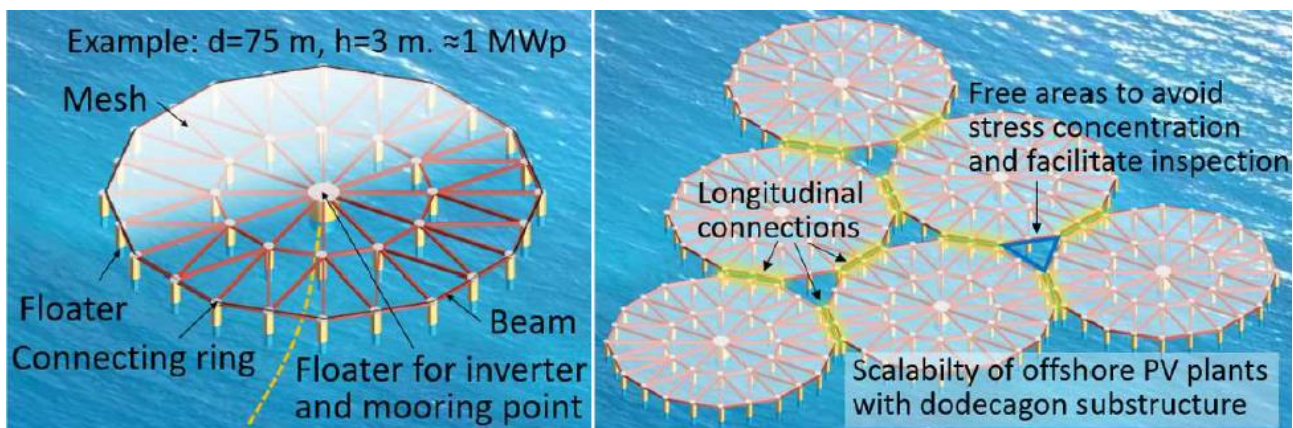


Figure 1. Conceptual Offshore Floating PV sideview (left) and scalability of the NATURSEA-PV solution (right).

NATURSEA-PV will develop this structural concept and the new eco-UHPC material and environmentally friendly surface coatings to protect material from corrosion and fouling, as well as predictive computational tools for these new materials. The first step was to define the main requirements for all these project results, together with main Key Performance Indicators (KPI) for the solutions assessment and decision making.

This report summarises these main Requirements and KPIs identified for each project result above described, including technical, environmental and socioeconomic aspects. Section 3 describes the Requirements identified for each result separately, and section 4 describes the KPIs, again separately for each project result, including a discussion on KPI weighing criteria for later assessment and decision making in further project stages.



3 Minimum requirements for NATURSEA-PV solution

Minimum requirements have been identified for each main project result, namely, for the new structure concept, new UHPC material, bio-Coating and predictive computational tools. Also, more generic socioeconomic requirements have been included, which affect the overall NATURSEA-PV solution. The following tables summarise and briefly describe all these requirements for each project results, specifying requirement type for each case, having been considered technical, economic, social and environmental requirements.

3.1 Requirements for Substructure/Components

Table 1. Requirements for substructure/components

Id	Requirement	Description	Type
R1.1	Withstand given environmental extreme conditions	Substructure and mooring/cable survival. Platform motion limits to be defined (e.g. maximum offset given by acceptable cable tension/curvature). Extreme environmental conditions considered: simultaneous and aligned wind speed 25 m/s, current 1.2 m/s and wave significant height 14 m	Technical
R1.2	Avoid PV panel immersion in operational conditions	PV panels could suffer damage and loss of energy production if immersed in normal operational sea states. This can be achieved through long beams with high flexibility or flexible joints between shorter beams so that the platform can ‘follow the wave’	Technical
R1.3	Substructure/components durability 50 years	Components durability for expected service life. This leads to mechanical fatigue requirements, corrosion protection requirements (coatings), etc...	Technical
R1.4	Limit PV panels bending	Conventional PV panels will be considered, for which maximum allowed bending is very limited. This can be achieved by limiting the beams bending (as much as allowed by R1.2) or fixing PV panels on substructure beams in a suitable way.	Technical
R1.5	Reduce cost of eco-UHPC components assembled to 78 €/m ²	Estimated cost of the required eco-UHPC components assembled (without moorings) of 78 €/m ² (currently, the floating offshore UHPC farms of PREF have a cost of 259 €/m ²)	Economic
R1.6	Reduce offshore PV LCOE	Reduce current offshore PV LCOE estimated at around 354 €/MWh	Economic



R1.7	Reduce Carbon footprint	This can be estimated as a quantification of the UHPC that will be consumed per m ² of structure, since carbon footprint per m ³ is well known	Environmental
R1.8	Reduce Energy consumption	Reduce the components/substructure energy consumption throughout the whole lifecycle	Environmental
R1.9	Platform accessibility	In order to minimise O&M activities in the sea, platform accessibility has to be addressed in a suitable way	Technical
R1.10	Modular design	Lily platform has to be easily assembled / disassembled (e.g. bolted joints) and linked to others in an array	Technical
R1.11	Ease of deployment	Ease of platform deployment in the sea as well as decommissioning, in order to reduce operational costs	Technical
R1.12	Minimise components stress/deformation	Keeping the platform stability and survival requirements, components will be designed so that stress and deformations are minimised	Technical

3.2 Requirements for eco-UHPC material

Table 2. Requirements for eco-UHPC material

Id	Requirement	Description	Type
R2.1	Self-compacting eco-UHPC	The eco-UHPC should be self-compacting, i.e. slump flow test EN-12350-8 (or mini slump) 18-21 cm at 30s	Technical
R2.2	UHPC's 24h compressive strength	24 hours compressive strength >65MPa	Technical
R2.3	UHPC's 28d compressive strength	28 days compressive strength >130MPa	Technical
R2.4	UHPC's open time	Rheology maintained for >20 minutes to allow filling the moulds	Technical
R2.5	Maximise 'eco properties' while keeping mechanical performance	Higher 'eco' properties are expected to lead to lower mechanical properties	Environmental
R2.6	Minimise material cost keeping 'eco' and mechanical properties	Ratios to be considered: cost per m ³ / bending strength and cost per m ³ / compressive strength. Reference	Economic



		values for Formex® is 600 €/m ³ and 150 Mpa. This ratio to be reduced while keeping at least around 100 MPa under compression, because below this value the durability is significantly reduced	
R2.7	Reduce material carbon footprint > 30%	Eco-UHPC with >30% reduction in carbon footprint. Reference value for Formex® is ~930 kg CO ₂ /m ³ . Transportation costs not included.	Environmental
R2.8	Include >35% recycled or second life material	Recycled material >35% (in weight) of recycled or second life (e.g. fibers) materials	Environmental
R2.9	Eco-UHPC and bio-coatings tested in offshore conditions for >6 months	Performance and durability of eco-UHPC and bio-coatings tested and validated in the lab and offshore (Tecnalia HarshLab) for >6 months, using Formex® and commercial coatings as reference materials. Biofouling on samples to be measured and its effects estimated (hydrodynamic drag)	Technical
R2.10	Durability	Chloride resistance and porosity for >50 years service life in marine environment	Technical

3.3 Requirements for bio-Coatings

Table 3. Requirements for bio-Coatings

Id	Requirement	Description	Type
R3.1	Water based coating with a biocontent > 80%	Synthesize a film forming latex with good mechanical properties using only monomers derived from the biomass and with a final biocontent > 80%	Environmental
R3.2	Synthesize latexes with a solid content > 50 %	In order to produce industrially competitive coatings the solid content of the latexes should be improved to at least 50 % (industrial requirement)	Technical
R3.3	Synthesize latexes that are durable in marine environment	Latexes with a high water resistance (low water absorption) and high durability in water (no degradation). The water resistance and durability of the biobased latexes should be equal	Technical



		or better than the ones of conventional latexes	
R3.4	Latexes with anticorrosion properties	Synthesized latexes with equal or better anticorrosion properties than the ones from conventional latexes	Technical
R3.5	Synthesize latexes with antifouling properties	Latex with better antifouling properties than the ones shown by conventional latexes	Technical

3.4 Requirements for Modelling Tools

Table 4. Requirements for Modelling Tools

Id	Requirement	Description	Type
R4.1	Prediction of components durability	Model for durability assessment, considering service life and a neutral environmental impact	Technical
R4.2	Modelling chloride diffusion phenomena	Atomistic model for bio-based surface treatments and diffusion phenomena for nature-based design of eco-UHPC surfaces with neutral environmental impact	Technical
R4.3	Estimation of effective diffusion coefficients	Numerical/analytical homogenization models to predict diffusion coefficient at the different scales (micro, meso), considering mechanical and transport phenomena. Determination of ageing coefficient.	Technical
R4.4	Low computational cost	Lowering computational costs for faster parameter studies using simplified and calibrated analytical models, accuracy and user-friendliness compared with advanced numerical models.	Technical
R4.5	User-friendly interface	Design of a simple graphical user interface for running probabilistic modelling tool (e.g. in Matlab).	Technical



3.5 Environmental, Social and Economic requirements

Table 5. Environmental and socioeconomic requirements

Id	Requirement	Description	Type
R5.1	Environmental and regulatory compliance	Consider potential environmental impacts (<i>e.g.</i> , water quality, seabed, flora, fauna, currents & waves, <i>etc.</i>) and how potential effects could be mitigated in consenting process. Compliance with, and adherence to, all applicable environmental legislative, regulatory, and other requirements	Environmental and Legal
R5.2	Social acceptability	Design of novel substructure concept to take account of, and be aligned with, key design concerns expressed by stakeholders in prospective host communities (including but not limited to socioeconomic activities such as fishing, aquaculture, sea sports, <i>etc.</i>)	Social
R5.3	Economic contribution	Potential economic contribution arising from the deployment of NATURSEA-PV solution in a particular local area.	Economic



4 Key Performance Indicators

The main Key Performance Indicators have been identified for each project result and are summarised and described in the following tables in the same way as described for Requirements. Some above described requirements are based on these KPIs, in terms of KPI threshold values defined as project objective. KPIs are expected to be used for decision making in the design process of all project results as well as final assessment.

4.1 KPIs for Substructure/Components assessment

Table 6. KPIs defined for substructure

ID	KPI	Description	Type
KPI 1.1	Platform kinematics (6 DOFs)	6 DOFs of the different platform components in order to measure the platform behaviour in operational (energy production) and extreme conditions (survival)	Technical
KPI 1.2	Mechanical stress/deformation	Platform components mechanical stress/deformation	Technical
KPI 1.3	Mooring lines forces	Lines tension values for different sea states	Technical
KPI 1.4	PV production	Energy yield kWh/kWp, Performance Ratio %, Degradation rate %/year, LCOE, etc	Technical
KPI 1.5	Component/PV panel deformation	Components mechanical deformation to be measured to be kept below limits	Technical
KPI 1.6	Carbon footprint	Carbon footprint throughout the structure's life cycle estimated and minimised	Environmental
KPI 1.7	Energy consumption	Energy consumption footprint throughout the structure's life cycle estimated and minimised	Environmental / Economic
KPI 1.8	Recyclability	The percentage of recycled materials used in the materials and biocoating	Environmental
KPI 1.9	O&M indicators	Time-based availability, Mean time between failures (MTBF), Mean time to repair (MTTR), Mean down time (MDT), etc.	Economic



4.2 KPIs for eco-UHPC material assessment

Table 7. KPIs defined for eco-UHPC material

ID	KPI	Description	Type
KPI 2.1	UHPC material Slump	Measured by slump flow test EN-12350-8 (or mini slump)	Technical
KPI 2.2	24 hour compressive strength	UHPC compressive strength after 24 hours	Technical
KPI 2.3	28 days compressive strength	UHPC compressive strength after 28 days	Technical
KPI 2.4	Open time	Determined by slump test 20 minutes after mixing	Technical
KPI 2.5	Chloride penetration at 90 days	Determined by the UNE-EN 12390-11 unidirectional chloride test	Technical
KPI 2.6	Porosity at 90 days	Measured by mercury intrusion porosimeter	Technical
KPI 2.7	Percentage recycled	Recycled or second life material used in the new UHPC material	Environmental
KPI 2.8	Carbon footprint	Carbon footprint associated to UHPC material manufacturing	Environmental
KPI 2.9	Material consumption Energy	Energy consumption associated to UHPC material manufacturing	Environmental/ Economic

4.3 KPIs for bio-Coatings assessment

Table 8. KPIs defined for bio-Coatings

ID	KPI	Description	Type
KPI 3.1	Biocontent	Calculation of the percentage of carbon atoms that that come from the biomass in the final polymer	Environmental
KPI 3.2	Solid content	Gravimetric calculation of the final solid content of the synthesized latexes	Technical
KPI 3.3	Hydrophobicity	Water resistance will be measured by water uptake and water contact angle measurements.	Technical
KPI 3.4	Adhesion to the substrate	Adhesion of the coatings to the substrate will be measured by using ASTM D3359 test.	Technical



KPI 3.5	Degradation of the coating in marine environment	Degradation of the coatings will be analysed by immersing the polymer films in DI water and marine water over long periods of time (4-6 months) and measuring the weight loss.	Technical
KPI 3.6	Mechanical properties	Mechanical properties of the latexes will also be measured by tensile test and scrub resistance experiments.	Technical
KPI 3.7	Anticorrosion properties	Anticorrosion properties of the coatings will be measured by electrochemical impedance spectroscopy (EIS) and using the anticorrosion salt spray chamber.	Technical
KPI 3.8	Antifouling properties	Antifouling properties will be evaluated in laboratory scale by measuring the protein adhesion into the coating surface. Antifouling properties will also be measured offshore, using Tecnalía's HarshLab.	Technical

4.4 KPIs for Modelling Tools assessment

Table 9. KPIs defined for Modelling Tools

ID	KPI	Description	Type
KPI 4.1	Improved reliability of modeling tools	Perform benchmark tests using literature data and/or ad-hoc experiments. Prediction accuracy of high fidelity, low fidelity numerical models compared with conventional and improved analytical engineering models.	Technical
KPI 4.2	Computational costs	Optimise computational cost versus prediction accuracy using various mesh discretisation approaches as inputs for virtual input meso-scale structures. High and low fidelity numerical models, that do rely or do not need high computational resources, respectively are comparatively employed and finally compared to a simple analytical models currently used in engineering practice.	Technical



4.5 Environmental, Social and Economic KPIs

Table 10. Environmental and socioeconomic KPIs

ID	KPI	Description	Type
KPI 5.1	Minimization of environmental impacts and regulatory compliance	Observance of, and adherence to, applicable environmental legislative, regulatory, and other requirements (% compliance). Propose appropriate mitigation measures from most significant potential impacts (if any) (# impacts identified from literature/tests).	Environment and Legal
KPI 5.2	Social acceptability	Design of novel substructure concept to take account of, and be aligned with, key design concerns expressed by prospective host communities (# concerns reflected in design).	Social
KPI 5.3	Local economic impact	Economic contribution to locality of NATURSEA-PV deployment (€ spend per €m CAPEX; € spend per €m OPEX).	Economic

4.6 Methodology to quantify and weigh KPIs

Different approaches can be followed as methodology to weigh KPIs, supporting the decision making process among several alternatives in design. Two possible KPI weighing criteria are based on environmental and economic approaches:

- Best 'eco' design approach**
 This approach is based on the objective of minimising environmental impact throughout the life cycle of NATURSEA-PV solution. Environmental KPIs are weighed highest.
- Best LCOE design approach**
 This approach is based on the objective of minimising LCOE throughout the life cycle of NATURSEA-PV solution. Economic KPIs are weighed highest.

Some threshold values, mostly related to environmental and technical aspects, have been set as NATURSEA-PV project objectives. Assuming these objectives, a minimum LCOE approach will be considered, selecting minimum LCOE designs while keeping these environmental and technical threshold values. The threshold values considered as project objectives are summarised below:



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Table 11. Project objective threshold values

ID	Description	Threshold (unit)	Min/Max	Type
1	Environmental conditions the platform shall withstand (assumed collinear and simultaneous) <ul style="list-style-type: none"> Wave significant height Current speed Wind speed 	<ul style="list-style-type: none"> 14 (m) 1.2 (m/s) 25 (m/s) 	Minimum	Technical
2	Cost of eco-UHPC components assembled	78 (€)	Maximum	Economic
3	Self-compacting eco-UHPC at 30 s	18-21 (cm)		Technical
4	UHPC 24-hour compressive strength	65 (MPa)	Minimum	Technical
5	UHPC 28-days compressive strength	130 (MPa)	Minimum	Technical
6	Material carbon footprint reduction	30 (%)	Minimum	Environmental
7	Recycled or second life material	35 (%)	Minimum	Environmental
8	Water based coating with a biocontent	80 (%)	Minimum	Environmental
9	Synthesize latexes with a solid content	50 (%)	Minimum	Technical

