TRANSEATION

BLUE IS THE NEW GREY · NATURE-BASED SOLUTIONS

Advancing Ecosystem-Based Management through Hybrid Blue-Grey Infrastructures in Marine and Coastal Areas

D3.3 Report on baseline monitoring in project demos

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1. TABLE OF CONTENTS

1. Table of Contents 4
Executive summary 7
1. Introduction 8
2. Overview of Demonstrators' Monitoring 11
3. Coastal protection infrastructure demonstrator I 13
3.1. Environmental parameters 13
3.1.1. Methodology 13
3.1.2. Results 14
3.2. Socio-economic parameters 14
3.2.1. Methodology 14
3.2.2. Results 16
4. Coastal protection infrastructure demonstrator II 20
4.1. Environmental parameters 20
4.1.1. Methodology 20
4.1.2. Results 22
4.2. Socio-economic parameters 22
4.2.1. Methodology 22
4.2.2. Results 23
5. Offshore wind farm infrastructure demonstrator 24
5.1. Environmental parameters 24
5.1.1. Methodology 24
5.1.2. Results 27
5.2. Socio-Economic parameters 28
5.2.1. Methodology 28
5.2.2. Results 30
6. Low-trophic aquaculture infrastructure demonstrator 31
6.1. Environmental parameters 31
6.1.1. Methodology 31
6.1.2. Results 36
6.2. Socio-economic parameters 39
6.2.1. Methodology 39
6.2.2. Results 43
7. Conclusion 46
ANNEX I: EU Social Challenges addressed by TRANSEATION demonstrators. Definitions are extracted from Cardinali (2021). 47
Bibliography 49

LIST OF FIGURES

Figure 1 A schematic diagram showing the hybrid NbS monitoring cycle within TRANSEATION. 9
Figure 2 Sunburst charts summarizing the categories of indicators used to monitor the four TRANSEATION demonstrators. The blue sections represent environmental indicators, while the orange sections show socio-economic indicators. 12
Figure 3 Map of showing location of cliff collapse events in 2023. Location of cliff collapse events (red) since 2010; debris accumulated at the base of the cliff (blue); areas where debris was washed out to sea (green). (data source: MCCP – Mediterranean Coastal Cliffs Preservation). 17
Figure 4 Mapping of public and private infrastructures potentially impacted by cliff collapse (direct & indirect) (Data source: various including Netanya municipality and National Bureau of Statistics (Israel)). 18
Figure 5 Photo of a diver using a photoquadrat (Scripps). 21
Figure 6 Images for measuring the visual colonization in SRU. 27
Figure 7 Results regarding the colonization measured thought e-DNA at baseline period in the SRU. 28
Figure 8 Detail of the bivalve mollusc production area (MPA) (black square), the production polygon (red square) and the area where the longlines are located (green square). 33
Figure 9 Diagram of the installation of the acoustic buoys on the longline. The orange circles represent the head buoys supporting the longline. The acoustic buoys are marked as blue circles connected to the line, one at the beginning and one near the end of the cultivation area (suspended ropes planted with mussels). Two acoustic buoys were installed at two heights of the mussel line to estimate the possible aggregation or avoidance effect of the line on the pelagic fish communities in the area. 34
Figure 10 (Left) Wet connection system between each buoy and the main line of the longline (Right) Deployment of Zunibal acoustic sensors attached to the main longline in the experimental area. 34
Figure 11 Taxonomic composition of the phytoplankton community (% of major groups) and cell abundance in spring 2024 at the offshore station. 37
Figure 12 Hourly acoustic energy distribution for each month of the baseline monitoring period (T0). The blue line represents the Loess smoothing shaded by the standard error. Note the data gap during the months of October and November, due to data recording issues. 37
Figure 13 Box plots. Time series of the distribution of Sv values per month during the baseline monitoring period (T0), showing day-night variations. The lower and upper limits of the boxes represent the 25th and 75th percentiles, respectively, and the inner horizontal line represents the median. 38
Figure 14 Vertical energy (Sv; dB re $1m^{-1}$) profile variations across months during the baseline monitoring period (T0). Data is classified in day-night periods. 39
Figure 15 Data sources for the economic assessment. Figure inspired in (Diaz, Schöggl, Reyes, & Baumgartner, 2021). Source: Biogears project. 40
Figure 16: Eco-efficiency portfolio. 43

LIST OF TABLES

Table 1 Phytoplankton baseline monitoring. 36
Table 2 Data requirements and formulas for the economic assessment. 41
Table 3 Description of economic indicators. 43
Table 4 Cost of landfill and composting process. Source: Biogears proyect 44

Symbols, abbreviations and acronyms

BiMEP	Biscay Marine Energy Platform
BoL	Beginning of Life
D	Deliverable
EC	European Commission
EIA	Environmental Impact Assessment
EoL	End-of-life
ESE-ROI	Socio-Economic Return on Investment
EU	European Union
GIS	Geographical Information System
Hybrid NbS	Hybrid blue-grey Nature-based Solutions
IA	Impact Assessments
IUCN	International Union for Conservation of Nature
LBUs	Life Boosting Units
MoL	Middle of Life
NbS	Nature-based Solutions
ROV	Remotely Operated Vehicle
SRUs	Saitec Reef Units
T	Task
WP	Work Package

EXECUTIVE SUMMARY

The deliverable D3.3. "Report on Baseline Monitoring in Project demos" is a document that presents the baseline monitoring strategies and results conducted in the context of TRANSEATION project demonstrators. It is part of WP3 T3.3, which has the main objective to define a common approach and metrics for monitoring standardization.

The project demonstrators are identified as hybrid blue-grey nature-based solutions (herein hybrid NbS); these solutions are increasingly being incorporated into climate change adaptation and disaster risk reduction planning in the coastal and marine environments. This is to address the causes and consequences of climate change in ecosystems, by reducing environmental risks sustainably and adapting to climate change through strong, stable infrastructure and the provision of ecosystem services. However, great uncertainty surrounding hybrid NbS is related to their performances and effectiveness, highlighting the need for relevant monitoring strategies and data as starting point to evaluate these innovative solutions. Advance in the evidence-based effects of hybrid NbS, and their nature and human positive capacities will pay the way to facilitate their scaling up and implementation worldwide. This deliverable establishes the indicators used to monitor the TRANSEATION hybrid NbS, also in synergy with WP8 "Hybrid infrastructures demonstrators: monitoring".

Precisely, the coastal and marine hybrid NbS implemented can be categorized as two coastal protection infrastructures (Coastal Protection Infrastructure Demonstrator I; Coastal Protection Infrastructure Demonstrator II), two artificial reefs as part of the same offshore wind energy infrastructure (Offshore Wind Farm Infrastructure Demonstrator) and two low trophic infrastructures (biobased ropes and raft and long-line) (Low-Trophic Aquaculture Infrastructure Demonstrator). Monitoring the impact of the demonstrators entails a primary focus on environmental, social and economic indicators. These indicators allow changes in coastal and marine habitats to be registered, enabling an assessment of changes in the provision of ecosystem benefits and hazard reduction.

The baseline monitoring is aimed at establishing an initial reference point (T0) for assessing environmental conditions in the first stage of the hybrid NbS implementation. This document provides a first understanding of pre-installation conditions, collecting data on water quality, biodiversity, habitat conditions, other environmental factors, and social and economic conditions. Thus, the baseline will be useful for detecting changes over time, providing a benchmark against which future monitoring results can be compared to detect hybrid NbS-related effects, that will be analyzed under WP14 "Evidence-based effectiveness evaluation of hybrid blue-grey infrastructures in project demonstrators".
Furthermore, collecting these indicators is the first step in facilitating the scaling up of hybrid NbS. With a robust spatial and temporal scale of monitoring, integrating a wide range of ecological and socio-economic indicators, and experimenting with modelling to assess the effectiveness of NbS (WP14), including monitoring based on new data techniques, can support decision-makers in adopting hybrid NbS.

Key words: *Hybrid Nature-Based Solutions, Coastal and Marine ecosystems, baseline monitoring*

1. INTRODUCTION

The European Commission has launched policy initiatives to support transformative NbS that address pressing societal challenges (European Commission, 2021) while promoting nature restoration. As the expansion of coastal and marine infrastructure to meet diverse societal needs continues, including ports, offshore energy facilities, and aquaculture, there is growing interest in hybrid NbS. These solutions aim to maintain infrastructural functionality while also protecting, restoring, or hosting functional ecosystems by integrating natural processes and features into infrastructure design (Anderson et al., 2022).

Coastal waters, continental shelves, and open oceans offer multiple opportunities to test and scale up hybrid blue-grey NbS, supporting environmental restoration, advancing ecosystem-based management (EBM), and responding to multiple societal demands. In addition to policy drivers, public demands for greater attention to biodiversity loss and climate change threats continue to grow at local to global scales. Assessing the impacts of NbS and associated activities is critical to understand their effectiveness in addressing targeted challenges (European Commission: Directorate-General for Research and Innovation, 2021).

This report, D3.3. “Baseline Monitoring in Project Demos”, presents the findings from the baseline monitoring conducted during the first 18 months of the TRANSEATION project. It focuses on blue-grey infrastructure demonstrators across the four TRANSEATION demo sites (i.e., Coastal Protection Infrastructure Demonstrator I; Coastal Protection Infrastructure Demonstrator II; Offshore Wind Farm Infrastructure Demonstrator; Low-Trophic Aquaculture Infrastructure Demonstrator).

Given that hybrid NbS are inherently evidence-based approaches, that is, methods designed and implemented based on scientific research and proven data, they provide reliable and effective solutions tailored to specific environmental and social contexts, accordingly, understanding their function through spatial and temporal indicator evaluation is essential. As such, they are often benchmarked against habitats with similar physical characteristics (Gittman et al., 2016; McGlathery et al., 2012). While the performance and effectiveness of NbS have been widely studied in urban environments (e.g., Chausson et al., 2020; Dumitru et al., 2020; Majidi et al., 2019), leading to the development of several impact evaluation frameworks (e.g., Raymond et al., 2017; Sowińska-Świerkosz & García, 2021; Xing et al., 2017), empirical evidence from marine and coastal environments remains limited (Gonzalez-Ollauri et al., 2023). Additionally, there is no internationally recognized set of indicators and metrics for monitoring the socio-economic sphere of marine and coastal NbS effectiveness (Kumar et al., 2021).

Information on impacts, implementation processes, and monitoring remains fragmented and scarce due to the limited site-specific data due to the relatively recent implementation of NbSs (Chausson et al., 2020; Dumitru et al., 2020; Fernandes & Guiomar, 2018). To maximize the performances and effects of hybrid NbS, it is critical to deepen understanding of the links between coastal biodiversity, ecosystem health, vulnerability, ecosystem functions, and the services they provide (O’Leary et al., 2023). Building a robust evidence base requires standardized and streamlined assessment approaches, including targeted indicators. Applying multiple indicators can offer a more comprehensive picture, while long-term monitoring is essential to assess whether these solutions achieve their intended outcomes (Bilkovic & Mitchell, 2013).

To strengthen the evidence base on hybrid NbS, it is necessary to document co-benefits, synergies, and trade-offs across interventions. This effort also requires comparability across research and application projects (Raymond, Frantzeskaki et al., 2017). A well-structured evidence base helps the public and private sectors implement and scale hybrid NbS because it provides the data, tested models, and proven outcomes needed to guide decisions, reduce risk, justify investments, and enable effective action in the challenging contexts of marine and coastal environments. Indeed, by providing reliable information on hybrid NbS through accurate monitoring, it will help to assess their relative effectiveness against defined targets. In Figure 1 a schematic diagram showing the NbS monitoring cycle adopted in the TRANSEATION project in reported (adapted from Kumar et al., 2021).

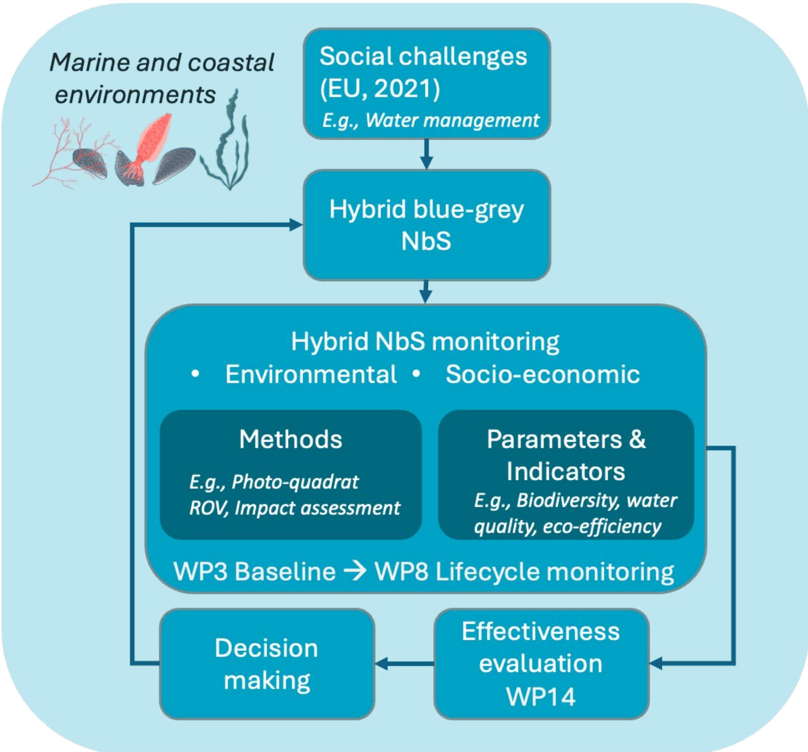


Figure 1 A schematic diagram showing the hybrid NbS monitoring cycle within TRANSEATION.

This deliverable aims to establish a baseline for the TRANSEATION coastal and marine hybrid NbS demonstrators, to enable future effectiveness evaluations (in WP 14) and facilitate their uptake in transformation strategies.

Within T3.3, baseline monitoring was conducted in two phases. First, in the initial reporting period (Milestone 3.3), a list of indicators and metrics for hybrid blue-grey infrastructure monitoring was developed. Second, the social challenges that the hybrid NbS address where evaluated based on the European Commission definitions (Cardinali et al., 2021)[2] (Annex I), and a methodology was defined for baseline monitoring across project demonstrators. These social challenges were selected as they are robust outcomes of a unique collaborative effort of 17 EU-funded Horizon 2020 NbS projects and cooperating institutions such as the European Environment Agency (EEA) and the Joint Research Centre (JRC), as part of the European Taskforce for Nature-Based Solution Impact Assessment. In light of the challenges identified by the International Union for Conservation of Nature (IUCN) (Cohen-Shacham et al., 2016), which cover a wide range of general societal aspects (e.g., climate change, human health), the EC social challenges highlight the unique features of the hybrid NbS approach, emphasizing aspects such as biodiversity enhancement and the creation of new economic opportunities and green jobs. Moreover, a wide range of indicators for NbS assessment are associated with these societal challenges, paving the way to evaluate the impact of hybrid NbS quantitatively and/or qualitatively by adopting these indicators. This set of variables provides the means to assess particular attributes in order to meet explicit objectives.

Given the diversity in characteristics and aims of hybrid NbS in the project, different monitoring methodologies (e.g., photo-quadrat, ROV, impact assessment) were applied for the various environmental and socio-economic parameters.

This deliverable is structured into a preliminary chapter (Section 2) providing an overview of the demonstrators' monitoring framework, and four main sections corresponding to each TRANSEATION demonstrator:

- **Section 3** - Coastal Protection Infrastructure Demonstrator I
- **Section 4** - Coastal Protection Infrastructure Demonstrator II
- **Section 5** - Offshore Wind Farm Infrastructure Demonstrator
- **Section 6** - Low-Trophic Aquaculture Infrastructure Demonstrator

These four sections present the methodology applied for data collection and monitoring, and the results in terms of environmental and socio-economic parameters for the baseline (T0) calculation. Finally, **Section 7** presents the conclusions and outlines future steps.

[2] *Evaluating the Impact of Nature-Based Solutions: A Handbook for Practitioners* and *Evaluating the Impact of Nature-Based Solutions: Appendix of Methods* are the outcomes of a unique collaborative effort of 17 EU-funded Horizon 2020 NBS projects and cooperating institutions such as the European Environment Agency (EEA) and the Joint Research Centre (JRC), as part of the European Taskforce for Nature-Based Solution Impact Assessment.

2. OVERVIEW OF DEMONSTRATORS' MONITORING

The relative performance and efficacy of NbS (and hybrid) compared to grey solutions are essential factors to consider when choosing them to address social challenges. Assessing NbS encourages citizen involvement and builds trust among stakeholder groups during NbS implementation and beyond (Kabisch et al., 2017; Kumar et al., 2020).

The NbS (and hybrid) project monitoring and evaluation process has three main objectives: (1) to provide information and responses for the timely execution and advancement of the project, (2) to account for the economic balance, and (3) to address gaps to ensure the effective and successful implementation of future projects. To monitor the potential effects of NbS implementation on specific areas, precise and measurable parameters and key impact indicators are required.

Monitoring involves measuring, recording, and comparing outcomes against predefined targets. This process informs project progress and supports decision-making for managers and policymakers. Typically, monitoring occurs throughout the lifecycle of NbS and hybrid projects, including the **ex-ante (T0, baseline)**, **in-itinere**, and **ex-post** phases (Veerkamp et al., 2021). It is a continuous process that contributes to long-term planning and goal setting (Kabisch et al., 2016), by incorporating knowledge about how NbS function (Connop et al., 2016) (Raymond et al., 2017a; Raymond et al., 2017b).

In the pre-implementation phase, baseline data is collected using sources such as previous monitoring studies, statistical databases/platforms, municipal records, peer-reviewed and grey literature (i.e., material produced outside traditional academic publishing), as well as interviews, workshops, and questionnaires. TRANSEATION demonstrators' partners exploited this type of input to define their monitoring baseline. In particular, monitoring includes both on-site and off-site data collection of physical and chemical parameters (e.g., water currents, water quality), as well as socio-economic indicators (e.g., cost-benefit data, social changes such as public awareness). Evaluation is then conducted by comparing data across the different NbS implementation phases.

Figure 2 presents sunburst charts summarizing the categories of indicators used to monitor the four TRANSEATION demonstrators. The blue sections represent environmental indicators, while the orange sections show socio-economic indicators. Segment size reflects the number of indicators in each category, enabling visual comparison across the four demonstrators and providing an overview of the indicators being assessed.

Environmental indicators include water quality, biodiversity, infrastructure and physical characteristics. Socio-economic indicators include, among others, economic impact, environmental education, social acceptance, and stakeholder engagement. As shown in Figure 2, all the demonstrators put the attention on the monitoring of biodiversity (e.g., pelagic fish abundance, species diversity, environmental DNA), and water quality (e.g., temperature, salinity, nutrients, chlorophyll-a), underlining that these two aspects are essential for the hybrid NbS monitoring. For the socio-economic aspect the most recurrent indicators are those related to the economic impacts (e.g., boosting eco-tourism, evaluating cost-benefits) and the evaluation of the social acceptance of the NbS, because understanding the community perceptions and expectations is essential for the demontrators' success.

The four demonstrators show different balances between the number of indicators related to environmental parameters and those related to socio-economic aspects. Coastal Protection

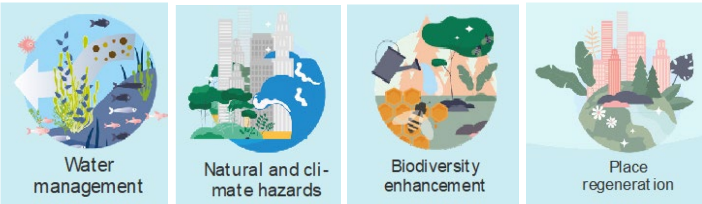
Infrastructure Demonstrator I (a) places strong emphasis on evaluating the socio-economic effects of the hybrid NbS, focusing on economic impacts evaluation, including citizen health and well-being. Instead, Coastal Protection Infrastructure Demonstrator II (b) and Offshore Wind Farm Infrastructure Demonstrator (c) present a more balanced distribution of indicators between environmental and socio-economic dimensions. In addition to the socio-economic aspects already mentioned, these demonstrators also consider stakeholder usage of the NbS (e.g., divers, fishermen), environmental education, governance, and public participation. Environmental aspects are addressed also through indicators related to the infrastructure and physical characteristics of sea conditions. Finally, the Low-Trophic Aquaculture Infrastructure Demonstrator (d) places greater emphasis on environmental parameters, with multiple indicators focused on water quality including the monitoring of biotoxins, biodiversity and physical characteristics of sea conditions (e.g., current speed and direction). Three aggregated indicators were preferred for the socio-economic aspects, i.e., eco-efficiency, private benefits, and social benefits, but they incorporated a wide variety of parameters, such as generated incomes, production costs, and externalities.

Figure 2 Sunburst charts summarizing the categories of indicators used to monitor the four TRANSEATION demonstrators. The blue sections represent environmental indicators, while the orange sections show socio-economic indicators. Segment size reflects the number of indicators in each category, enabling visual comparison across the four demonstrators and providing an overview of the indicators being assessed.

3. COASTAL PROTECTION INFRASTRUCTURE DEMONSTRATOR I

The setting of the coastal protection infrastructure demonstrator I is located along the Mediterranean coast of Israel. It is a sandy beach with a few kurkar (sandstone) outcrops protected by a breakwater that will help protect the adjacent coastal cliff from further erosion. The added infrastructure that is studied in this project is an artificial reef designed by "C-cell" (https://www.ccell.co.uk/), aiming to further reduce wave energy by means of a NbS. The C-cell reef structure is designed to enhance the establishment of a calcium carbonate substrate to stimulate recruitment of a diverse biological community that should both increase coastal protection and enhance the biodiversity on and around these artificial reefs.

The EU societal challenges that this hybrid NbS aims to address are: Water management; Natural and Climate Hazards; Biodiversity; Place Regeneration.



Logos adapted from: Cardinali et al., 2021. European Commission: Directorate-General for Research and Innovation.

3.1. ENVIRONMENTAL PARAMETERS

3.1.1. Methodology

The following section describes the plans for monitoring the submersed marine environment at the artificial reef and nearby, in order to understand the anticipated ecological changes on the backdrop of the natural changes that take place in this region.

A variety of methods to monitor these ecological changes are planned. These include the use of a photo-quadrat system (after Dumas et al., 2009) to document benthos, fish surveys to monitor fish populations and sediment sampling using quadrats to monitor changes in the meiofauna community inhabiting the soft sediments.

Photo-quadrat sampling

This method was developed in the 1980s to enable scientists studying coral reefs and other benthic communities on hard substrates to document both biodiversity and substrate coverage in a quantitative manner. This method is described in detail in Section 3.1, below, and the description there closely represents the Demo I strategy. Briefly, a transect line is established using a 10 m line, marked every 2 meters. At each of the 2m markings, a photograph is taken of the quadrat placed on the substrate being surveyed. The quadrats that will be employed in the demonstrator's survey are 25 cm x 25 cm and we will use these to document invertebrates and algae on the breakwater, the artificial reef and any other exposed hard substrates in the study area. As explained in detail in Section 4.1, the photo-quadrat survey may only be carried out if the sea is very calm, and following the survey, the photographs produced will be assessed using image-analysis software to identify the biota and to calculate surface coverage.

Fish Monitoring

The purpose of this method is to assess the composition of fish in a given area of interest and, based on the results, to evaluate, either spatially or temporally or both, whether the hybrid NbS activities have impacted the fish community. Monitoring surveys are carried out by a pair of divers experienced in the identification of local fish species, equipped with a marked line to determine the length of their transect, a compass to determine the azimuth of the transect, an underwater slate to record visual identifications and counts, and an underwater video camera. Transects will be carried out according to established protocols (Labrosse et al. 2002) for segments of 25 m and diver records will be cross-referenced with video footage of fish during the dives.

Sediment Sampling

The seafloor at the study site is predominantly covered by sandy sediments of Nilotic origins and effects of the artificial reef intervention will most likely affect the near shore soft-sediment biota. In this highly dynamic, fairly oligotrophic eastern Mediterranean environment, abundances of epibenthic macrofauna are low. Demo I monitoring will therefore focus on the meiobenthos that reside between the sand grains, using the methodology described in Somerfield and Warwick (2013). Duplicate sediment samples will be taken at 4 stations at the perimeter of the artificial reef complex at 2 distances: 1 m and 5 m, using round 15 cm diameter jars to a depth of 8 cm. Four sediment samples will also be taken at a reference site situated at the same depth, 50m north of the artificial reef complex. Sediment samples will be preserved using 70% ethanol and brought to the laboratory for sieving, Rose-bengal staining and sorting by means of dissecting microscope for subsequent identification and enumeration of meiofauna.

3.1.2. Results

The C-cell artificial reef complex is currently in the process of construction and will be deployed at the experimental site in the next few months. Prior to deployment, the Demonstrator I team will undertake an initial ecological survey, as described above, to provide a baseline (T0) for future temporal comparisons assessing the development of a natural community on and around the artificial reefs. The baseline monitoring is planned but has not yet been conducted, and therefore no results are available at this stage. The results of the initial survey are expected in summer 2025.

3.2. SOCIO-ECONOMIC PARAMETERS

3.2.1. Methodology

The baseline monitoring for this demonstrator is designed to inform the Impact and Risk Assessments that are the basis for the socio-economic assessments that will be part of WP14 in Task 14.3.1. The rationale for adopting the Impact Assessment framework is that:

1. Regulatory processes in the EU utilize or require one or more of environmental, economic, social, and or health Impact Assessments (IA) (EC 2025a). For example, implementing scaled coastal infrastructures such as the CCELL artificial reef require an Environmental Impact

Assessment under the EU EIA Directive 2011/92 (EC 2025b). Demonstrator I has adopted an approach that integrates the socio-economic dimensions of the potential environmental, health, and social impacts of coastal protection. The impact assessment framework is readily understood and accepted by many of the relevant authorities (Martin-Olmedo & Boccia 2024, Raymond, Berry et al. 2017; IAC 2024)).

2. The IA approach is uniquely suited to assessing potential future impacts that may occur after the TRANSEATION project ends (IAIA 2025). Cliff erosion is a gradual process. Although some events such as rockfalls and collapse may be sudden, they are generally preceding by a long period of erosion. Many of the effects of the CCELL artificial reef in dampening exposure of the cliffs to strong waves, will be realized in the future. While changes in wave activity can be measured during TRANSEATION, the effect on the integrity of the cliffs and the downstream impacts on human activities can be assessed prospectively. In the case of the latter, risk scenarios will be developed based on past events and in the case of the former scenarios for downstream impacts will be informed by evidence from the literature and case studies.

The IA has three modules, plus a fourth module that integrates the first three, each with its own data requirements. Each of the modules and the baseline data collection are described below.

MODULE 1: A **Risk assessment** related to the physical condition of the cliffs in the vicinity of the demonstrator site. The monitoring of the historic condition of the cliffs is being conducted using GIS mapping. Three conditions are being mapped: *i)* Significantly impaired signifying cliffs that have experienced major collapse; *ii)* Moderately impaired, signifying cliffs with significant erosion, recession and/or rock falls; *iii)* Intact, signifying cliffs that have experienced minor damage. The historical data will be used as input into the risk ranking of event types for the site under coastal different protection strategies and wave scenarios that affect the integrity of the cliffs. **The baseline for the risk assessment is the current condition of the cliffs (e.g., height, volume, existing reinforcements) and the likelihood of the emergence of the three conditions.**

MODULE 2: An **exposure assessment** will analyse those urban infrastructures that may be damaged or otherwise impaired as a result of deterioration in the physical condition of the cliffs. Data gathered from a variety of sources including the Netanya municipality; the Ministries of Health, Infrastructure, and Transport; and real estate, tourism, and business databases is being used to create a GIS map of physical infrastructures that could be impacted by the deterioration of the condition of the cliffs in the vicinity of the demonstrator site. **The baseline for the exposure assessment includes a description of current:**

- Number and types of **privately-owned buildings** in three categories (i.e., residential, commercial, industrial (excluding those serving tourists))
- Number and types of **hotels**
- **Public built infrastructures** including emergency services (ambulance and fire stations); power, water, and sanitation utilities; roads; public outdoor spaces (e.g., parks, walkways, public squares, etc.); public buildings (e.g., municipal and other governmental); schools; and medical (e.g., hospitals and large clinics).
- **Beaches and related services**, including businesses.
- **Physical injury and death** resulting from deterioration of the condition of the cliffs
- **Potential sensitive environmental and ecological parameters identified in the baseline monitoring**

MODULE 3: The **Assessment of Socio-Economic Impacts** will include monetary valuation and other quantification methods. The data and models needed to assess the socio-economic impacts of deterioration of the cliffs is being sourced from local Israeli data bases and from the relevant literature. It will be used to value changes caused by damage and impairment related to the physical condition of the cliffs. A systematic review and of the literature in four domains will provide guidance on valuation methods as well as data on the scope and scale of the economic effect. **Israeli sources will provide baseline data (2024-25) on indicators including:**

- **Value of residential, commercial, and industrial property**
- **Business activity statistics (e.g., days of operation, earnings)**
- **Hotel occupancy**
- **Local employment**
- **Usage (e.g., road traffic, emergency services activities, medical services)**
- **Use of public spaces (e.g., parks, beaches and marine areas)**
- **Costs of maintenance, repair and replacement of key infrastructures such as roads and utilities**
- **Intrinsic values of environmental parameters**

MODULE 4: Integration of the first 3 modules will include combining the data from the exposure and risk assessment to create scenarios demonstrating the different levels of damage and impairment sustained as a result of changing cliff conditions. Changes in the economic value will be estimated shifts from the baseline to each of the three scenarios.

3.2.2. Results

Baseline monitoring results for each of the IA modules are presented below:

MODULE 1: **Risk assessment**

Baseline monitoring completed to date: Data gathered supplied by the Israel Geological Survey and the Mediterranean Coastal Cliffs Preservation (MCCP)) company has been used to create a GIS colour-coded mapping of cliffs relevant to study the site (see Figure 3) indicating the location of cliff collapse events (red) since 2010 including areas where debris (talus or scree) accumulated at the base of the cliff (blue), and areas where debris was washed out to sea (green). Talus debris that has accumulated at the base may over time affect rates of erosion over time as well as the accessibility of beach areas. If debris is washed out to sea, it may affect nearshore sediment systems and affect marine habitats and make the cliffs vulnerable to further erosion. Figure 3 shows the data for 2023.

Level of completion: Data acquisition is complete. Analysis is in progress.

Figure 3 Map of showing location of cliff collapse events in 2023. Location *of cliff collapse events (red) since 2010; debris accumulated at the base of the cliff (blue); areas where debris was washed out to sea (green). (data source: MCCP – Mediterranean Coastal Cliffs Preservation).*

MODULE 2. Exposure assessment

Baseline monitoring completed: A GIS map layer has been created. Currently, the layer is populated by geocoded sites for all public utilities such as gas supply and roads; public spaces such as walkways, beaches and parks; and health-related infrastructures such as hospitals and emergency services.

Level of completion: All data sources have been identified, data collection and mapping is indicated above and illustrated in Figure 4.

Additional baseline monitoring in progress: Additional mapping of built areas indicating the location of hotels, residential buildings and businesses, and water and electricity utilities is in progress.

PUBLIC INFRASTRUCTURES	PRIVATE INFRASTRUCTURES
Gas utility	Petrol station
Hospital	Tourism sites
Police station	Theatre and entertainment
Ambulance station	Shopping centre
Fire station	Pharmacy
Municipal government	Sports facilities
Other government	
Community centres	

Figure 4 Mapping of public and private infrastructures potentially impacted by cliff collapse (direct & indirect) (Data source: various including Netanya municipality and National Bureau of Statistics (Israel)).

MODULE 3: **Assessment of Socio-Economic Impacts**

Baseline monitoring completed: Databases on residential real estate have been identified and partial data has been extracted. Partial data has been collected for several Israeli case studies in which cliff collapses led to disruption of business activity. A systematic review of the literature is underway to assess the evidence on the economic impacts of coastal cliff protection. To date, we have determined that available data from the literature and Israeli sources monetary values, days of business lost, employment losses, cost of replacement, and in the case of injury and death, health-economic metrics such as statistical value of life, QALYs (Quality-Adjusted Life Year) and DALYs (Disability-Adjusted Life Year)

Level of completion: The systematic review protocol is nearing completion and is expected to be submitted for publication in Environmental Evidence journal by the end of June 2025. Collection of data on residential property values is nearly complete and ready to be integrated with data on exposed neighbourhoods the exposure and risk assessments are integrated. Data on other economic variables is ongoing.

Additional baseline monitoring in progress: Sources of Israeli data and data extraction are ongoing.

4. COASTAL PROTECTION INFRASTRUCTURE DEMONSTRATOR II

Coastal protection infrastructure demonstrator II, constructed using a gabion revetment coated with Geocorail®, is to be installed off the coast of Le Lavandou's (Var, France) city-center beach. The demonstrator is constituted by an immersed breakwater that can be assimilated for monitoring purposes to an artificial reef. An artificial reef provides a colonization support favorable to the development of local marine biodiversity.

The EU societal challenges that this hybrid NbS aims to address are: Water management; Natural and Climate Hazards; Biodiversity; Place Regeneration; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance;

Logos adapted from: Cardinali et al., 2021. European Commission: Directorate-General for Research and Innovation.

4.1. ENVIRONMENTAL PARAMETERS

4.1.1. Methodology

To monitor the evolution of this ecosystem, different techniques will be used, each with its own specificities. Photoquadrat techniques, linear transects are commonly used in marine ecology, to sample and study benthic communities and monitor the colonization of marine habitats (Bachet et al., 2018; Astruch et al., 2022).

Photoquadrat technique

The photoquadrat technique is a sampling method often used in **artificial reef** installations. It targets a small area, delimited by a frame (quadrat) placed over a surface to be photographed and analyzed (Figure 5). The aim is to identify the different species present within this framework and to determine by extrapolation the surrounding **biodiversity and its abundance** (Pelaprat et al., 2010; Astruch et al., 2022).

Regarding the methodology, two types of quadrats would be used: 25 cm x 25 cm or 50 cm x 50 cm. These quadrats will be positioned at specific points along the breakwater according to an inspection plan to be established prior the dive. One or more points on each side will be photographed. This technique allows to determine a biodiversity percentage of cover depending on the area of the breakwater, the orientation to winds, currents, and waves, as well as its exposure to sunlight and other factors that can influence the diversity present at a given point.

Figure 5 Photo of a diver using a photoquadrat (Scripps).

This technique allows to monitor the studied area, to reduce observational bias by allowing a detailed and repeated analysis of the images and is a non-destructive technique for the habitat.

However, the clarity of the water is a factor that can have an influence on the quality of the photos obtained, analysis and identification can be laborious, time-consuming and requires good in-house expertise in species identification.

Linear transect technique

The linear transect technique is a sampling method that involves observations along a straight line, called a transect, spread across the seafloor over a specific length. This method is used to assess the **distribution, abundance, and diversity of organisms** in a given study area. In this specific case, it would be used to study the organisms present on the breakwater submerged in gabions with Geocorail®.

Regarding the methodology to be implemented, a transect of defined length is placed on the seabed. Divers move along this line and record observations of the diversity and abundance of each species encountered, with any remarkable behaviors that may occur, at regular intervals along this line. The operation will then be repeated all along the breakwater every 20-metre-long sections (Bachet et al., 2018; Astruch et al., 2022).

This technique allows for the systematic and standardized sampling of large areas, provides continuous data along a given study area, and is a good complement to the photoquadrat method.

However, linear transects can be difficult to implement in complex habitats with reliefs and crevices. Environmental conditions can affect the accuracy of observations (current, visibility). It is also a technique that may require some experience and expertise, especially regarding species identification, so as not to create bias in the interpretation of the results.

Fish monitoring

The technique of fish monitoring is a method used to estimate the fish population in a given area. This type of counting collects essential information on the **diversity, abundance and distribution of fish species** (Astruch et al., 2022).

The objective of these counts would be to assess the environmental impact of the implementation of the solution and to quantify the evolution of the stands encountered.

The means put in place would be the technique of linear transects and possibly the installation of an underwater camera. SEACURE's in-house divers are trained in species identification, and in the appropriate approach to optimize the acquisition of results.

The data collected will make it possible to estimate populations, the change in diversity and the distribution of populations within the different biotopes.

4.1.2. RESULTS

The Geocorail artificial reef complex will be deployed at the experimental site in the next few months. Prior to deployment, the Demonstrator II team will undertake an initial ecological survey, as described above, to provide a baseline (T0) for future temporal comparisons assessing the development of a natural community on and around the artificial reefs. The baseline monitoring is planned but has not yet been conducted, and therefore no results are available at this stage.

4.2. SOCIO-ECONOMIC PARAMETERS

4.2.1. METHODOLOGY

Coastal protection infrastructure demonstrator II will be located in the Le Lavandou sealine. Le Lavandou down-town beach is classified as “highly urbanized” (ICTP, 2022) that is to say that the background of the beach is heavily constructed with passing roads and accommodations, not much space on the beach. The following actions will be implemented and monitored as part of the deployment of the coastal demonstrator II:

Environmental education:

- Installation of information panels for awareness of natural areas near the beach
- Display of environmental code for good practices
- Display of 5 activities for environmental education

Waste disposal:

- Bins near the beach with visible and clear sorting instructions
- Beach cleaning awareness

Water quality management:

- Minimum 5 water samplings for analysis per summer with maximum 31 days between 2 analyses
- Display of water quality analysis results on the beach
- Sanitary sanitation
- Drinkable water spots

General environment:

- Display of beach plan

- Security ensured by people and equipment
- At least one beach accessible to people with reduced mobility,
- Regulation of vehicle traffic on the beach,
- No pet allowed on the beach

The socio-economic impact will be assessed through the following key factors:

Identification of Potential Users: The reef is expected to interact with multiple stakeholder groups, including:

- Fishermen: Potential changes in fish stocks and fishing opportunities
- Tourism operators: Enhanced snorkeling and diving attractions with the Geocorail® breakwater right in front of the main beach
- Nature conservation groups: Increased marine biodiversity and habitat restoration efforts
- Local residents and beachgoers: Changes in recreational use and coastal aesthetics

Economic Impact: The reef could influence local businesses and livelihoods by:

- Boosting eco-tourism activities such as diving excursions and guided snorkeling tours
- Providing additional fishing opportunities and potential revenue increases for small-scale fisheries in the surrounding
- Contributing to coastal protection, reducing costs linked to erosion management (i.e., fewer beach nourishment campaigns expected)

Social Acceptance: Understanding community perceptions and expectations will be essential for the project's success. Public consultations and surveys will be conducted to:

- Gauge community support and concerns regarding the reef
- Identify perceived benefits or risks among local stakeholders
- Promote awareness of the ecological and economic advantages of the artificial reef

Governance and Participation: Local actors will be involved in the planning and management through:

- Collaborative workshops with fishermen, tourism operators, and environmental groups
- Participatory decision-making processes to ensure stakeholder engagement
- Ongoing monitoring and adaptive management strategies to address concerns and optimize benefits.

4.2.2. RESULTS

Socio-economic monitoring will be conducted through a range of activities involving stakeholder participation, with results to be delivered within the project's timeframe. The baseline monitoring is planned but has not yet been conducted, and therefore no results are available at this stage.

5. OFFSHORE WIND FARM INFRASTRUCTURE DEMONSTRATOR

This demonstrator consists of the installation and implementation of two NbS technologies, SRUs and LBUs, on a floating offshore wind platform, DemoSATH[3], at BiMEP, i.e. the open-sea test site in the Basque Country (Spain), aimed at increasing the biodiversity of the area.

SRUs consist of a set of elements, joint together, made of sections of wind turbine blades; each element is subjected to surface covered with mollusc shells, to boost invertebrate settlement on it. The hollow sections provide caves with different sizes, which provide shelter to different species. All together serve as an artificial reef that facilitates the proliferation of marine organisms of different nektonic and benthic communities' species of vertebrates and invertebrates. Those elements should serve both as protection against anchors or fishing gear and as biodiversity enhancing artificial reefs for offshore wind farms.

LBU devices provide natural substrate for colonization and development of fully functional ecosystems. Through effective monitoring, they can better understand the changes in an ecosystem, the biodiversity generated, and the CO_2 sequestered by the artificial reef of the offshore windmills.

The EU societal challenges that this hybrid NbS aims to address are: Climate Resilience; Biodiversity enhancement; New Economic Opportunities and Green Jobs; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance.

Logos adapted from: Cardinali et al., 2021. European Commission: Directorate-General for Research and Innovation.

5.1. ENVIRONMENTAL PARAMETERS

5.1.1. Methodology

All monitoring activities are highly dependent on sea and weather conditions. In the case of the SRU, the baseline campaign has already been done. In the case of the LBUs, while the baseline campaign is scheduled to coincide with the installation phase in May/June 2025, adjustments may be necessary. Logistical constraints, equipment availability, and diver safety protocols will determine the feasibility of specific tasks, such as biological sampling or advanced sensor deployment. In addition, the quality of ROV imagery may be affected by underwater visibility and current conditions. Here the baseline activities, indicators and monitoring zones of the SRU and LBU are reported:

[3] DemoSATH link to the website: https://saitec-offshore.com/en/projects/demosath/

SRU

The baseline environmental monitoring (T0) was conducted before the installation of the SRU on the DemoSATH platform surroundings. Data was obtained from various sources:

- Direct data obtained by Saitec, prior to the installation of the DemoSATH platform and during its operation.
- Direct data obtained by scientific entities on the species present at the installation site.
- Data from bibliographic sources that helped to compare and complete the data obtained.

This data serves as a reference point for assessing future ecological changes by documenting the initial environmental conditions of the area before the influence of the SRU. The monitoring focuses on **biological parameters** and establishes control conditions on the DemoSATH surroundings for comparisons in subsequent campaigns. The methodology integrates ROV (Remotely Operated Vehicle) footage, and sediment and water sampling for environmental DNA.

LBU

The baseline environmental monitoring (T0) will be conducted during the installation of the LBUs on the DemoSATH platform at BiMEP. This first campaign provides a reference point against which future ecological changes can be assessed. The monitoring focuses on **physical, chemical, and biological parameters** that can be measured immediately upon deployment. It also establishes control conditions on the DemoSATH structure to enable meaningful comparisons during subsequent campaigns.

The goal of this baseline is to document the initial environmental conditions of the area prior to the influence of the LBUs. The methodology integrates ROV footage, biological and water sampling, and in-situ sensor measurements, following the adapted offshore protocol developed by Ocean Ecostructures.

Baseline Activities and Indicators

- Biological and Visual Monitoring
    - ROV Survey of SRU and LBUs and Control Zones (SRU and LBU).

ROV/camera footage will be collected for the SRU and for each LBU location and designated control areas on the DemoSATH structure. In the case of the LBUs, the ROV will follow a systematic zig-zag pattern to capture high-resolution video from all surfaces of the LBU. Control zones (columns without SRU nor LBUs) will also be recorded at the same depth and orientation to serve as reference points.

    - Wall Scraping for Clean Surface Baseline (LBU)

- During installation, divers will scrape defined sections (60x60 cm) of nearby columns to remove all biological material. These areas will be marked and filmed to document the "zero growth" condition and will serve as a control for biodiversity development on the LBUs.
- Water Sampling
    - Nutrient Analysis (LBU)

Water samples will be taken at approximately 20 cm from the LBUs and control zones. If ROV sampling is not feasible, professional divers will collect samples during the installation. Three replicates per zone will be collected and stored for later nutrient analysis.

  - Environmental DNA (SRU and LBU)
- Water and sediment samples are also being taken for detecting early presence of marine organisms through molecular techniques (environmental DNA). From the installation of the SRU until its removal, several campaigns will be carried out. With the help of a vessel and the necessary equipment (Niskin, Van Veen dredge, filtration material, etc.), samples will be taken at different points and depths.
- Physicochemical Measurements
  - In-Situ Sensor Readings (LBU)

Measurements of dissolved oxygen, turbidity, and pH will be performed using ROV-mounted sensors. Where additional equipment is available (e.g. SAITEC's sensors), parameters such as temperature, salinity, or chlorophyll concentration may also be recorded.

  - Weighting of LBUs

Pre-Deployment Biomass Reference: Each LBU (if possible) will be weighed immediately before installation. This weight will be compared to post-retrieval measurements to determine net biomass accumulation over the monitoring period, and therefore the CO2 fixed.

  - Installation of Control Plates in the LBUs

Control plates will be installed on the LBUs during deployment to allow future quantification of biomass generation, and therefore the CO2 fixed. These plates provide a standardized surface for assessing the biological material accumulated over time.

Monitoring Zones

SRU

  - SRU Zone: one single zone located near the platform's mooring lines
  - Control Zone 1: an area close to the platform
  - Control Zone 2: an area far from the platform, inside BiMEP
  - Control Zone 3: an area far from the platform, outside BiMEP

LBU

  - LBU Zones: Three zones, each with two LBUs, located on different structural columns of the DemoSATH.
  - Control Zone 1: Cleaned sections of DemoSATH columns, adjacent to LBUs, used as biodiversity growth controls.
  - Control Zone 1.1: Cleaned sections of one of DemoSATH column but at a major distance, will be used as biodiversity growth controls.
  - Control Zone 2: A distant location in the BiMEP area without artificial structures, used for water quality baseline data.

5.1.2. Results

<u>SRU</u>

In the case of the SRU, the results regarding the baseline monitoring are as follows:

- Baseline period (T0): June 2024

Given the difficulty of monitoring the SRU structure because it is located at a depth of approximately 75-85 meters, monitoring will be based preliminarily on the following campaigns:

- **1st monitoring campaign: before its installation (June 2025)**
- 2nd monitoring campaign: few months after its installation
- 3rd monitoring campaign: once it is recovered

The data related to the **1st monitoring campaign: before its installation** are as follows:

- <u>Images for measuring the visual colonization (Figure 6).</u>

The results regarding the visual colonization at Baseline period are images taken at the time prior to installation:

Figure 6 Images for measuring the visual colonization in SRU.

- Environmental DNA

The results regarding the colonization measured through e-DNA at baseline period are summarized below (Figure 7):

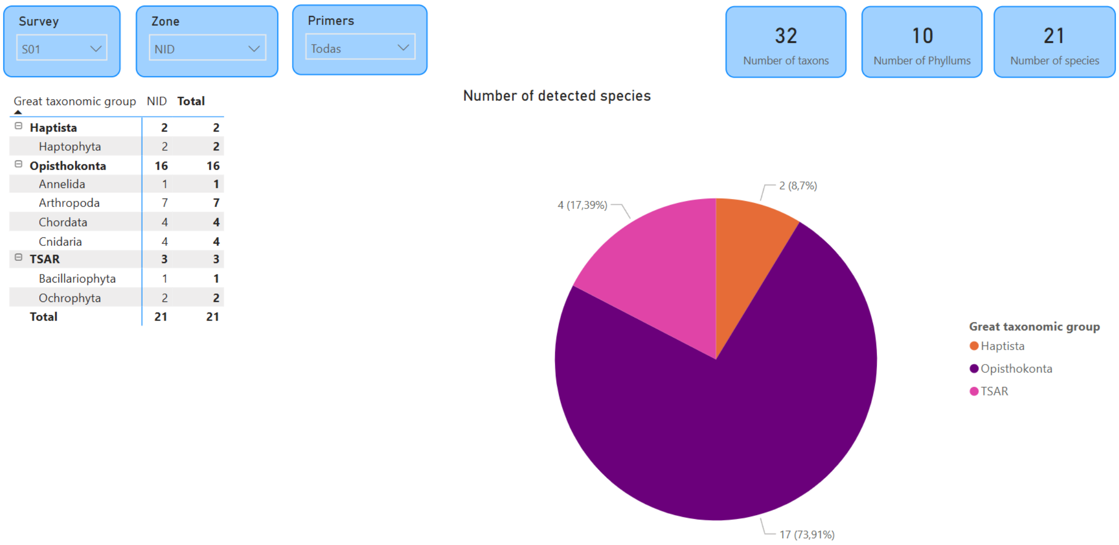


Figure 7 Results regarding the colonization measured thought e-DNA at baseline period in the SRU.

LBU

LBU will be deployed at the experimental site within June 2025. Baseline monitoring of the LBU will be conducted in June 2025, and the results are expected in summer 2025.

5.2. SOCIO-ECONOMIC PARAMETERS

5.2.1. METHODOLOGY

The baseline socio-economic monitoring (T0) establishes an initial reference point prior to the installation of both the SRU and the LBUs on the DemoSATH platform at BiMEP. This baseline is essential for evaluating the future impact of the deployed NbS by allowing comparisons over time. Only those indicators that can meaningfully reflect the pre-installation conditions have been selected for this phase, focusing primarily on spatial context, public awareness, communication presence, and initial economic data.

The selected baseline indicators are here reported:

Social Parameters

- Proximity of NbS to individuals or households

A spatial analysis using GIS and household mapping will be conducted to evaluate the symbolic and geographical proximity of the DemoSATH platform to nearby coastal communities. This serves as a reference to understanding potential reach and perception of the intervention.

- General awareness about the NbS and its benefits

Surveys will be administered to local populations, students, and relevant stakeholders to assess existing knowledge and perceptions regarding the project. This provides a benchmark for future awareness-raising efforts.

- Communication and visibility of the NbS

A media analysis will be performed to identify current levels of online and offline presence related to the project. This includes social media activity, news articles, institutional publications, and website traffic, offering insight into the initial public visibility of the NbS.

- Visitation of the NbS and frequency of interaction (virtual and professional)

Although direct public visitation is not feasible due to the offshore location, the number and type of professional visits (e.g., by researchers or engineers) as well as virtual interactions (website visits, social media engagement) will be recorded at this early stage.

Economic Parameters

- Implementation and initial operating costs

Project financial records will be used to establish a baseline of the economic investment required for the installation of the LBUs and SRU, including materials, logistics, labor, and basic monitoring equipment. This information forms the foundation for later analysis of cost-effectiveness and return on investment.

- Projected life cycle costs

While full cost accounting will evolve over the project's duration, preliminary estimates of life cycle costs (installation, maintenance, and decommissioning) will be compiled as part of the baseline reference.

Environmental and Socio-Economic Return on Investment - ESE-ROI:

The Environmental and Socio-Economic Return on Investment (ESE-ROI) methodology is an integrated assessment framework that evaluates the full value of projects by accounting for environmental, social, and economic returns. It incorporates natural capital and ecosystem services into investment decisions, enabling a more holistic understanding of project impacts beyond traditional financial metrics. This approach is especially relevant for sustainable infrastructure, nature-based solutions, and climate-resilient initiatives. The study will capture the multiple returns (social, environmental, economic) on private actors’ investments, in this case, SAITEC, in nature regeneration, the methodology followed combines elements of the United Nations System for Environmental Economic Accounts (SEEA) and the Return on Sustainability Investment (ROSI ™) methodology. The methodology is centered around two main elements, the “investment”, and the “return” on this investment.

In turn, the investment is understood as those direct and indirect economic costs incurred by an organization for the regeneration of natural capital, in this case through the purchasing and maintenance of LBUs®. The returns on this investment can be direct benefits reaped by the investor or buyer, both monetary and non-monetary benefits, and societal benefits that benefit other actors.

In order to fully grasp the benefits, opportunities, and abated risks that nature regeneration can provide to customers (i.e. the return on their investment), through the installation of LBUs®), the following steps will be followed:

1) Collection of yearly direct and indirect (e.g. maintenance) costs incurred by the customer for the installation and maintenance of LBUs.

2) Identification of ecosystem services

Following a brief Livestock Environmental Assessment and Performance (LEAP) assessment, a sub-set of business-driven benefits, categorized under cultural and maybe recreational ecosystem services could be selected together with SAITEC.

3) Quantification of ecosystem services

4) Valuation of ecosystem services

5.2.2. RESULTS

Socio-economic monitoring will be conducted through a range of activities involving stakeholder participation, with results to be delivered within the project's timeframe. These selected indicators represent the socio-economic parameters considered most relevant for the baseline phase. The baseline monitoring is planned but has not yet been conducted, and therefore no results are available at this stage.

However, the final scope of implementation will depend on the available project resources, including budget allocation, staff capacity, and the level of effort that can be dedicated to socio-economic monitoring at this stage. Additional indicators, such as employment generation, public participation, tourism value, or perceived physical beauty, will be more relevant for future monitoring phases (T1–T3) once the NbS interventions begin to produce tangible ecological and social impacts.

6. LOW-TROPHIC AQUACULTURE INFRASTRUCTURE DEMONSTRATOR

The low-trophic aquaculture demonstrator is aimed at managing the growth of mussel and seaweed cultures by including a new nature-based raft and long-line infrastructures based on biodegradable ropes. Mussel productions are assessed as nature-based sustainable infrastructure enhancing the local economy while providing environmental benefits (e.g. water quality). At the same time, it has the potential to serve as an emission, capture and utilization GHGs technology while also contributing to human development along several UN SDGs (SDGs 2 Zero Hunger, 3 Good Health and Well-being, 7 Affordable and Clean Energy, 13 Climate Action, and 14 Life Below Water).

The EU societal challenges that this hybrid NbS aims to address are: Water management; Biodiversity enhancement; New Economic Opportunities and Green Jobs; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance.

Logos adapted from: Cardinali et al., 2021. European Commission: Directorate-General for Research and Innovation.

6.1. ENVIRONMENTAL PARAMETERS

6.1.1. Methodology

The baseline monitoring for the low-trophic aquaculture demonstrator in Mendexa (South-east of the Bay of Biscay, Spain), includes the elements enumerated below. The full details of parameters, methods and frequencies can be consulted in Deliverable 7.2.

Water Quality Physico-Chemical Parameters

The following measurements are monitored at Station MM-W (43° 20.668´ N, 2° 26.948´ W), which is located at a depth of approximately 35-40 m:

- In-situ water temperature, salinity, density, chlorophyll-a concentration, light transmission, PAR (Photosynthetically Active Radiation) and dissolved oxygen (concentration and saturation). The data will be obtained every 1-2 months at each meter of the water column, from the surface (-1 m) to the bottom, by Sea-Bird SBE-25plus CTD casts.
- Chlorophyll-a concentration will be measured in-situ by a continuous fluorometer sensor Cyclops-7 Logger installed in the infrastructure at 3m depth. The sensor provides 10-minute readings that are saved in the instrument's memory. The instrument, which includes an AQUATEC temperature sensor, will be uninstalled for data recovery and sensors maintenance and re-installed as soon as possible. The fluorometer is equipped by a self-contained wiping device to prevent biofouling interference.

- Monthly averages of pH values obtained from a continuous "SAMI 2 pH Sensor" installed at 20-m depth in the demonstrator area will be provided to TRANSEATION by AZTI's Marine observatory for climate change in the Bay of Biscay (NATURKLIMA project). The temporal coverage of this data will depend on the deployment and data processing calendar of the aforementioned project.
- Daily records of chlorophyll-a and SST (Sea Surface Temperature) will be retrieved from the satellite MODIS-AQUA OC5 product distributed by CERSAT-IFREMER[4] and from the SST OSTIA product (European Union-Copernicus Marine Service, 2015), respectively.
- Finally, water column temperature, salinity and current components will be retrieved from EUSCOMvu coastal model based in CROCO (Coastal and Regional Ocean COmmunity model) numerical modelling tool. The model domain extends from 43.24° N to 44° N and from 3.4° W to 1.3° W and has a mean horizontal resolution of 670 m. Vertically, the water column is divided into 32 sigma-coordinate levels. It provides 96-hour forecasts and will be run daily. The hourly atmospheric forcing data used in CROCO is provided by MeteoGalicia. The marine conditions applied to the open boundaries are estimated using IBI-MFC (Iberia Biscay Irish - Monitoring Forecasting Centre) data from CMEMS (Copernicus Marine Environment Monitoring Service). It also assimilates the freshwater discharges of the main rivers in the study domain (i.e., Barbadun, Nerbioi, Butroe, Oka, Lea, Artibai, Deba, Urola, Oria, Urumea, Oiartzun, Bidasoa and Adour).

Biological parameters

The offshore station MM-W (see above) will be sampled for the characterization of phytoplankton, biotoxins and microbiological parameters:

- **PHYTOPLANKTON COMMUNITIES.** Cell abundance of the micro- and nanoplankton, including toxic as well as harmless taxa, have been monitored in March, April and May during 2024 and 2025. Sampling will integrate the first 10 m of the water column by means of a hose. Then, the water samples will be preserved with acidic Lugol´s solution and analyzed using inverted microscopes (Utermöhl sedimentation method).
- **MARINE BIOTOXINS.** The sampling scheme is like the phytoplankton (in spring, once a month). Mussels will be collected from the growing ropes (12 m long) and then analysed with methods in compliance with the current legislation (European Commission, 2011; 2019; 2021). These are chemical methods: HPLC (High Performance Liquid Chromatography) with UV detector for domoic acid, HPLC with Fluorescence detector for paralytic toxins, and LC-MS/MS (Liquid Chromatography-Mass Spectrometry/Mass Spectrometry) for lipophilic toxins (okadaic acid, dinophysistoxins, pectenotoxins, yessotoxins and azaspiracids).
- **MICROBIOLOGICAL PARAMETERS.** Mussels will be collected from the ropes every two months. The method for the detection and enumeration of *E. coli* in live bivalve molluscs will be carried out by means of the liquid-medium culture technique and calculation of the 'most probable number' (MPN) as specified in ISO 16649-3, while confirmation of *Salmonella* will be carried out by real-time PCR (European Commission, 2019).

[4] IFREMER web page: https://www.ifremer.fr/en

Pelagic Fish Abundance

Acoustic buoys technical specifications

In this study, acoustic backscatter energy (Sv; dB re $1/m^{-1}$) was used as a proxy for pelagic fish abundance because it can provide detailed information on variations in abundance at different vertical and horizontal scales over time. To correctly interpret the data, it is important to pay close attention to the units, as they are presented on a logarithmic scale. Data was collected by TSE Zunibal buoys equipped with three triple frequency single beam echosounders (50, 120 and 200 kHz). The TSE buoys transmit a summary of the collected data (features) and remotely manage buoy position and acoustic data collection. In addition, a full resolution raw data version of the acoustic files can be recorded and stored on a 32 GB internal drive, while low resolution data can be visualized using the Zuntrack software, in real-time. Every 3 months the buoys are replaced by a spare set for data downloading and maintenance.

Located two miles offshore on the coast between the municipalities of Ondarroa and Lekeitio (Basque coast, Spain) in the southeast of the Bay of Biscay (Figure 8). Figure 8 illustrates the production area designated by the Basque Government in 2016 as a Mollusc Production Zone (MPZ) for the cultivation of bivalves. AZTI will use one of the 12 longlines installed in the MPA as an experimental demonstrator for validation tests at sea.

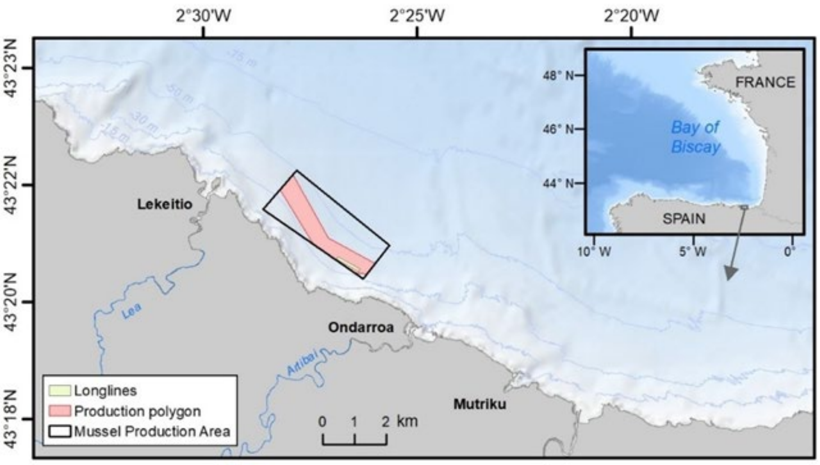


Figure 8 Detail of the bivalve mollusc production area (MPA) (black square), the production polygon (red square) and the area where the longlines are located (green square).

The TSE acoustic buoys developed by Zunibal were deployed attached to the main longline according to the following scheme (Figure 9). The three buoys were installed 20 m, 60 m and 95 m from the head buoy of the longline, respectively.

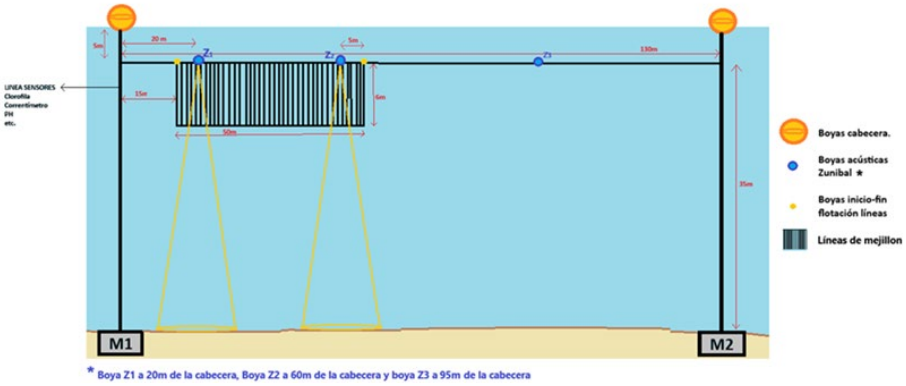


Figure 9 Diagram of the installation of the acoustic buoys on the longline. The orange circles represent the head buoys supporting the longline. The acoustic buoys are marked as blue circles connected to the line, one at the beginning and one near the end of the cultivation area (suspended ropes planted with mussels). Two acoustic buoys were installed at two heights of the mussel line to estimate the possible aggregation or avoidance effect of the line on the pelagic fish communities in the area.

Each acoustic buoy was connected to the main longline by a damping system to prevent entanglement (Figure 10 left). In October 2024, the three acoustic buoys were installed on the longline (Figure 10 right).

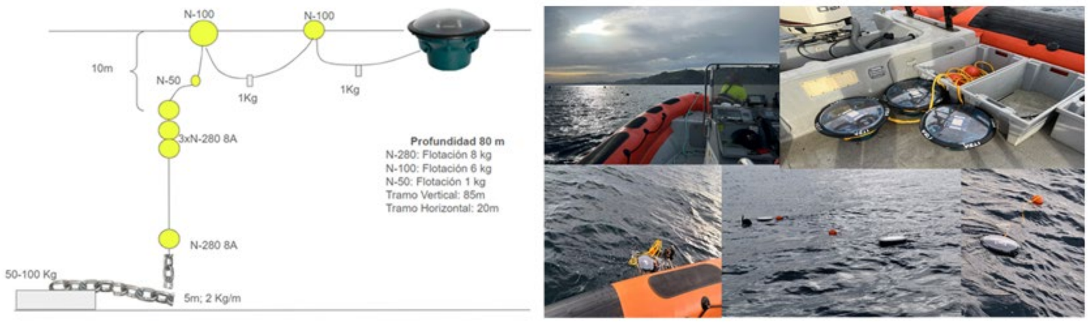


Figure 10 (Left) Wet connection system between each buoy and the main line of the longline (Right) Deployment of Zunibal acoustic sensors attached to the main longline in the experimental area.

The **data processing** is done by layered echo integration with a resolution of 60 minutes per 1 m depth along the entire water column. To obtain this parameter, it is first necessary to remove unwanted echoes that may interfere with a correct interpretation of the data. Surface and bottom lines are drawn to define the upper and lower processing limits. The surface line is set at an average depth of 7m below the mother line and is corrected to exclude areas of bubbling caused by wind or waves. In severe bad weather conditions, the signal may be attenuated throughout the water column, and, similarly, if acoustic interference from other acoustic equipment is observed, high energy spikes might appear. In both cases, the affected data is eliminated by applying specific signal filters.

Considerations and limitations

There was a storm that tore off one of the line attachments to the marker buoy, so it came loose and sank the line, sinking the buoy installed at the far end, so it had to be collected and the attachments reconditioned, so that during the period from 23 October 2024 to 5 November only two buoys were left installed in the facilities. Once everything was reconditioned the buoy was reinstalled.

Benthic biodiversity

Epibenthos

In order to assess the effect of the demonstrator on the epibenthic communities inhabiting the study area, a visual inspection of the seabed will be carried out using an ROV (Remotely Operated Vehicle).

This is an underwater vehicle equipped with a video camera, which is manoeuvred and directed from the surface This allows images of the benthic habitats to be obtained *in situ*, mainly focusing on epibenthic habitats, in contrast to infaunal communities that can be assessed by samples taken with grabs.

A ROV model SIBIU Pro, owned by AZTI, will be used. It is designed to operate at depths of up to 300 m and reach speeds of up to 1.54 $m \cdot s^{-1}$. For image capture, the ROV is equipped with a high-definition digital varifocal video camera (4K: 3840×3260 px) with optical zoom (focal distance: 3,6-11 mm).

Both at the long-line demonstrator and the raft study areas, 5 to 7 transects will be recorded at increasing distances from the demonstrator, in the direction of the main currents in the area and in the opposite direction. The recordings will last approximately 3 minutes and 30 seconds.

Once in the office, the recordings will be viewed on large screens and the biological characterization of the filmed seabed will be carried out. The identification of the filmed organisms will be done visually, proposing in all cases the identification to the lowest possible taxonomic level. With this information, a semi-quantitative analysis of the epibenthic communities inhabiting the study area will be carried out.

The recordings will also allow the identification of litter in the area (mainly biological and non-biological material released from the structure).

Infauna

In order to assess the status of the infaunal macroinvertebrate communities in the vicinity of the long-line demonstrator, 5-7 sampling stations will be defined at increasing distances from the installation both in the direction of the main currents in the area and in the opposite direction.

At each sampling station, three replicates will be taken by means of a Van Veen grab (sampling surface: 0,1 m^2) and then sieved *in situ* with a 1 mm mesh, sufficient for the retention of almost all species (Viéitez, 1976; Seapy and Kitting, 1978; Andrade and Cancela da Fonseca, 1979; Mora, 1982). The retained organisms will be preserved on board in a formaldehyde solution (stabilised with chemically pure methanol and buffered to pH=7) in seawater at 4%.

Once in the laboratory, with the help of a binocular magnifying glass, the benthic macroinvertebrates will be separated, identified and counted, and their biomass will be estimated, after keeping the samples in an oven at 65 ºC for 48 hours (dry weight). The nomenclature of the species will be supported by the European Register of Marine Species

(ERMS: www.marbef.org/data/erms) and the World Register of Marine Species (WoRMS: www.marinespecies.org).

From the count data, the main structural parameters of the community will be estimated, such as total abundance and specific **abundance**, total biomass and specific **biomass**, specific **richness** and specific **diversity** using the Shannon index (Shannon and Weaver, 1963), both from density and biomass data (Wilhm, 1968). Maximum diversity and **equitability** will be also estimated (for densities and biomasses).

In addition, given the differences in ecological requirements presented by benthic organisms, the presence of species or *taxa* representative of various degrees of environmental quality (Ecological Group; GE) will be determined: pollution indicators, high environmental quality indicators, opportunistic species, etc. Based on the relative density per sample of these GEs, the AMBI biotic index (Borja *et al.*, 2000; Muxika, 2007) will also be determined. This index ranges on a continuous scale from zero (all identified individuals are sensitive species indicating high environmental quality) to six (all identified individuals are first-order opportunists, indicators of pollution), with a value of seven for azoic sediments. Therefore, low AMBI values indicate high environmental quality, while high values indicate the presence of extremely altered sediments.

6.1.2. Results

Regarding **phytoplankton in the water column** (Table 1), the micro- and nanoplankton cells have been identified and counted, and three main variables have been derived: Total Abundance (i.e., the cell density of the whole community), Richness (i.e., the number of taxa present) and Diversity (Shannon index). The **baseline period (T0)** refers to the campaigns conducted in **spring 2024**. For the first 10 m of the water column during this period, the next table contains the statistics of these phytoplankton variables, and Figure 11 shows the general taxonomic composition (major groups contribution to cell abundance). To have a more accurate picture of the phytoplankton communities present in the area before the start of the activities, previous scientific publications by AZTI on this area could be consulted (e.g., Muñiz et al., 2019; Solaun et al., 2025).

Table 1 Phytoplankton baseline monitoring.

Potential Monitors	Parameter name	Unit	Depth	Count	Average	Median	Minimum	Maximum	Standard Deviation
BIOLOGICAL PARAMETERS	Phytoplankton Total Abundance	cells/L	0-10	3	373494	332185	174124	614174	222914
BIOLOGICAL PARAMETERS	Phytoplankton Richness	-	0-10	3	2.64	2.61	2.51	2.80	0.14
BIOLOGICAL PARAMETERS	Phytoplankton Diversity	bit/cell	0-10	3	42	46	31	49	10

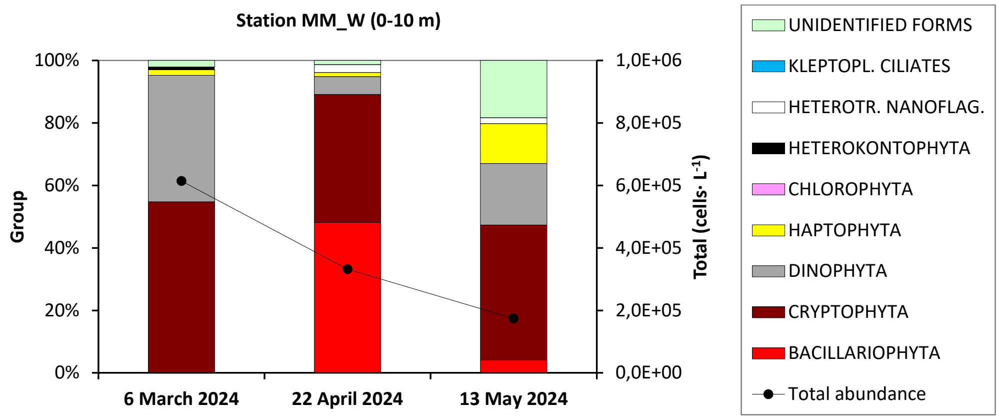


Figure 11 Taxonomic composition of the phytoplankton community (% of major groups) and cell abundance in spring 2024 at the offshore station.

PELAGIC FISH ABUNDANCE

The pelagic fish acoustic abundance baseline monitoring period (T0) ran from 7 October 2024 to 10 March 2025. This period was divided into two to allow for the replacement of acoustic buoys for maintenance and data download. Various analyses were carried out to describe the patterns of variation in acoustic energy at different scales. The maximum vertical and temporal resolution is 1-metre depth and 1 hour, respectively. Analyzing the variation in energy over 24 hours provides information on the nycthemeral distribution patterns over the study period (see Figure 12). In December and January, a clear pattern emerges, with the highest energy concentration detected during the central hours of the day (approximately 9 am–3 pm). In the other months of the study, the pattern is less defined. In particular, the October and November data were incomplete due to issues with data recording.

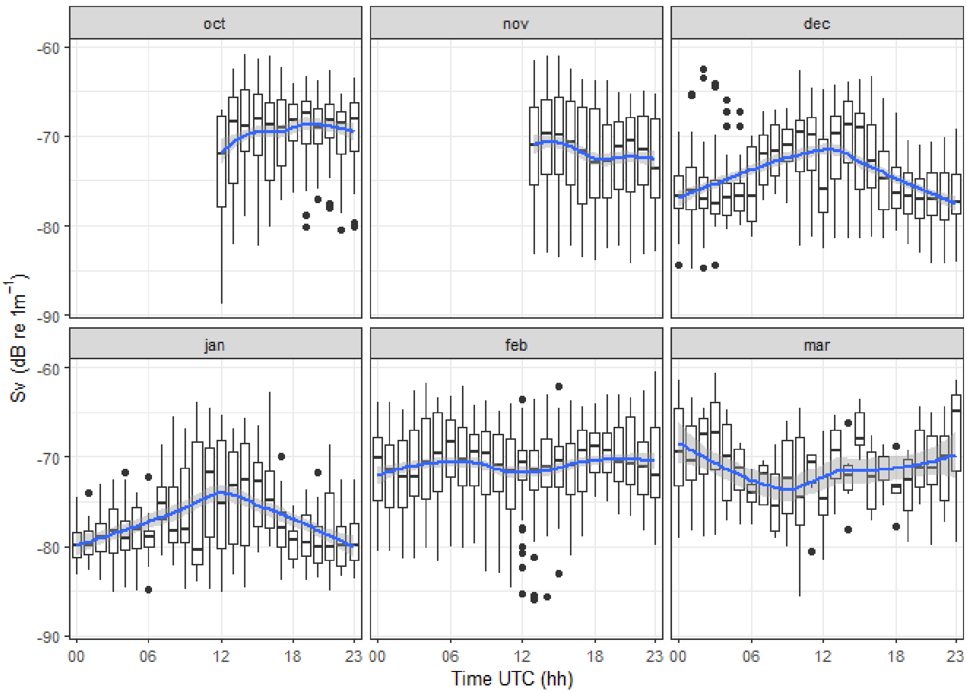


Figure 12 Hourly acoustic energy distribution for each month of the baseline monitoring period (T0). The blue line represents the Loess smoothing shaded by the standard error. Note the data gap during the months of October and November, due to data recording issues.

Analysis of diurnal variation on a monthly basis (Figure 13) showed a general decrease from October to January, accompanied by an increasing disparity between daytime and night-time energy levels. While the day and night averages were almost identical in October, by January, the daytime average was almost 4 dB higher than the night-time average. It should be noted that the data loss during the first two months affects evenly to both time periods, with a 7 hour loss at night and a 6 hour loss during the day (daytime was considered from 7am to 9pm UTC). In February, the pattern reversed, with higher average night energy levels.

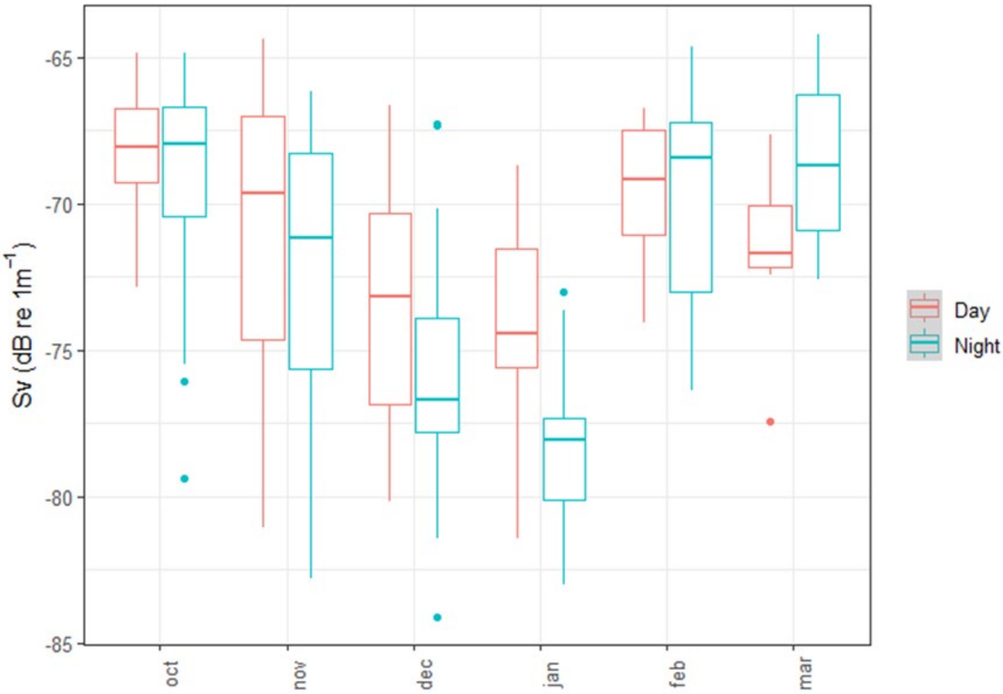


Figure 13 Box plots. Time series of the distribution of Sv values per month during the baseline monitoring period (T0), showing day-night variations. The lower and upper limits of the boxes represent the 25th and 75th percentiles, respectively, and the inner horizontal line represents the median.

Comparing the diurnal and nocturnal vertical profiles provides insight into the nichthermal migratory behavior of organisms. In the shallower layers, the highest energy values are observed at night (see Figure 14), whereas in the deeper layers, the average energy tends to be higher during the day.

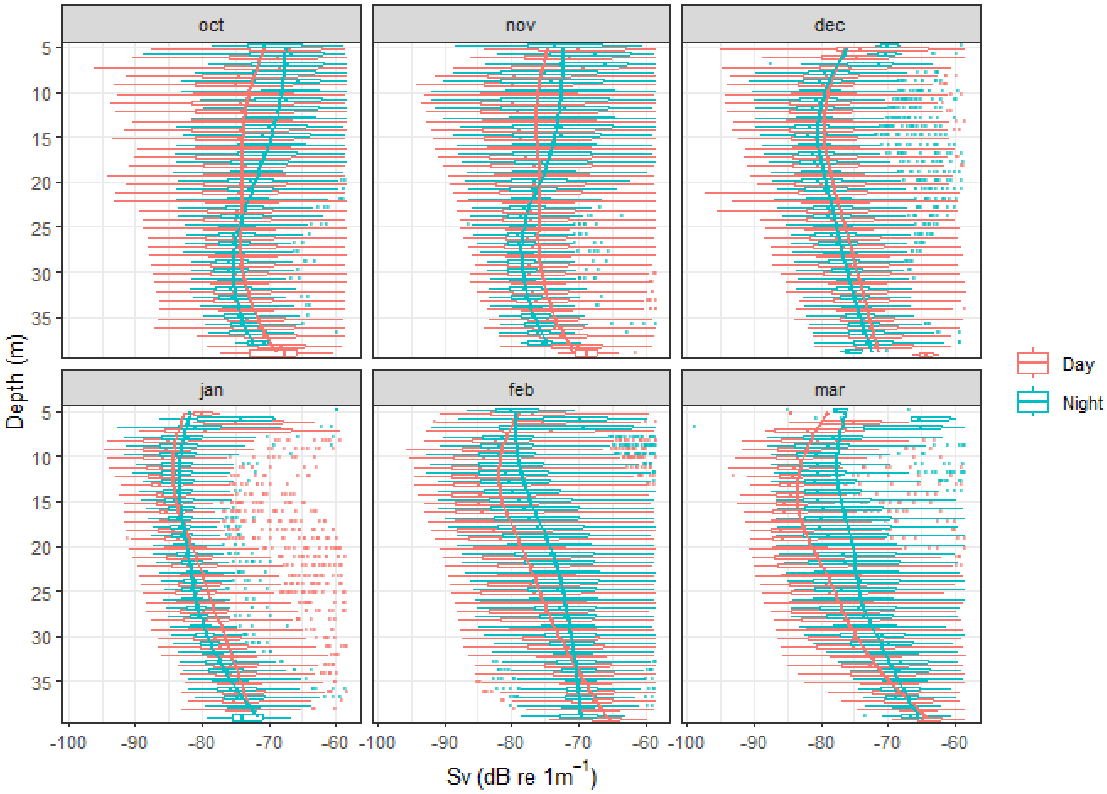


Figure 14 Vertical energy (Sv; dB re 1m^{-1}) profile variations across months during the baseline monitoring period (T0). Data is classified in day-night periods.

These different energetic distributions across vertical and temporal scales can prove useful as a reference baseline measure and help identifying changes in behaviour against changes in the local environment.

6.2. SOCIO-ECONOMIC PARAMETERS

6.2.1. Methodology

The economic assessment of the implementation of BioGears, i.e. biobased gears, in the aquaculture market will be analysed from all phases of its lifecycle, according to Circular Economy approach. The Beginning of Life (BoL) phase encompasses the pre-production phases; the Middle of Life (MoL) phase, includes the use-phase of the product; and the End-of-life phase (EoL), covers product disposal. Figure 15 shows a synthesis of the data requirements for the economic analysis, which is described in detail in this section.

The economic assessment of BioGears prototypes and the commercial rope, that is considered as the reference system, was performed following the methodology explained in this section.

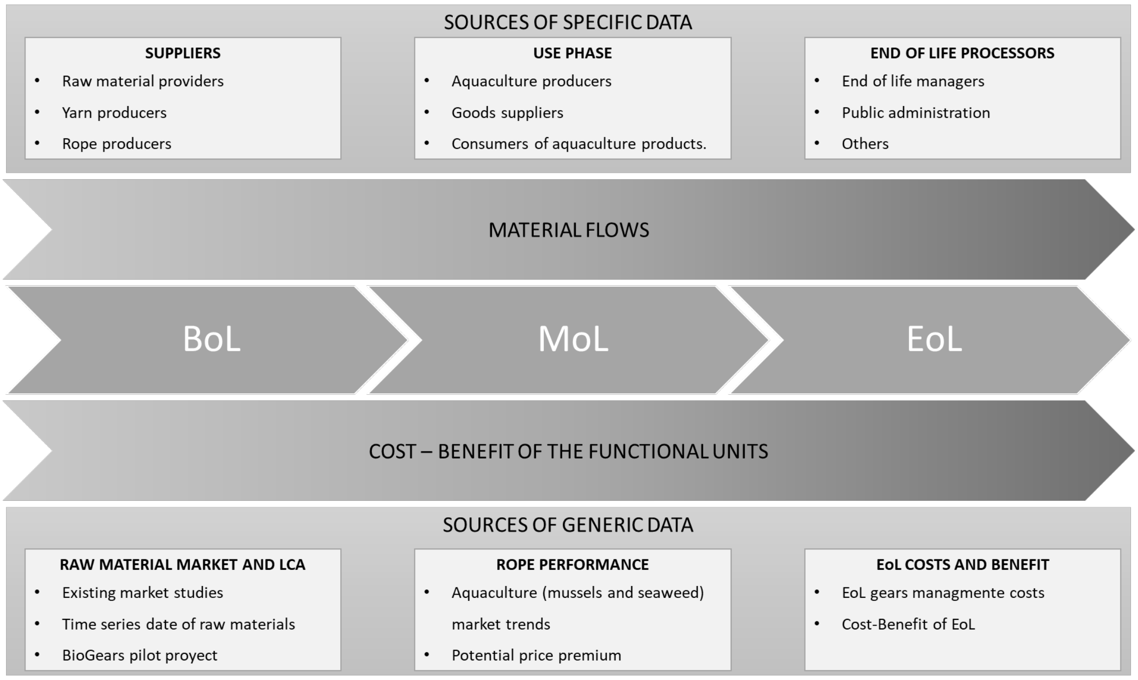


Figure 15 Data sources for the economic assessment. Figure inspired in (Diaz, Schöggl, Reyes, & Baumgartner, 2021). Source: Biogears project.

In the **BoL phase**, the raw material, processing costs and material flow will be assessed. Regarding raw material, biocompatibility and eco-friendliness are the main advantages of biopolymers, but this material also has limitations: includes low thermal stability, flammability, vulnerability to microorganism attacks (e.g., fungi and bacterial), high processing cost and low production volume (Andrew & Dhakal, 2022). Rope processing costs of the ropes will be assessed in all the production phases (compounding, yarn production and rope manufacturing). Some of the available values will be at Lab-level and these values need to be scaled up at the industrial level to simulate more realistic scenarios. Material flow is an important issue to be addressed to estimate the costs and to analyse the material loss. Although at lab level the material loss of BioGears is higher than for the Gears, since the process is well calibrated and material well known, at industrial level it is expected to have similar material loss.

In the **MoL phase** the first we need is to explore the production yield. The productivity by a kilogram of rope will be estimated after the sea tests to assess the potential income that the rope can produce in a maximum of one year-round. Note that the life span of a commercial rope can be 10 years (data from Itsaskorda) or even 30 years (information from Irish farmers), but BioGears has not been probed in that time horizon.

In the **EoL** phase, recycling technologies such as mechanical, chemical, or solvent-based methods are assessed from an environmental perspective, compared to waste incineration (Maga et al., 2016). However, according to the BLUENET project, aquaculture ropes may have parts of the mussel embedded, making the cleaning process for recycling costly. The approach followed is that, considering compostability as the differential feature of BioGears at the EoL compared to traditional ropes (GROPE), composting is taken as the EoL option for BioGears, while landfilling is taken as the EoL option for traditional ropes.

The emphasis of the decision-making tools on sustainability performance meant that the focus was placed on BoL, with data collection in the MoL and EoL phases being much less frequent (Diaz et al. 2021). In this study we approached from the BoL to the EoL of the ropes. The limitation of applying this approach to the Low-Trophic aquaculture infrastructure is that it can be not possible to consider the lifespan of the biobased ropes or biogear, because the sea test will be only for a maximum of one year.

An **externality** is a cost or benefit caused by a producer that is not financially incurred or received by that producer. Externality can be both positive or negative and can stem from either the production or consumption of a good or service. The costs and benefits can be both private, to an individual or an organization, or social. Aquaculture generates marine litter and other types of land waste due to the petrol-based ropes used in the offshore aquaculture. In economy theory, this is known as a production negative externality. A negative production externality is when the production system of the company affects negatively to other agents or society, and marine litter or fuel depletion affects society as a whole[5]. Along the lifecycle of the ropes, negative externalities can arise in all the stages (BoL, MoL and EoL). In the BoL phase, the externality can be considered the fossil energy depletion (Haider et al., 2019) that contributes to the climate change problem (Höök & Tang, 2013). Marine litter is pointed out as the MoL externality because the ropes can be lost at sea generating marine litter (Skirtun et al., 2022). And finally, the EoL externalities are related to the waste management of the ropes after their lifespan.

Associating all those externalities to the life cycle stages and producers, all data and formulas for the economic assessment to compare the commercial ropes against BioGears are defined in Table 2. The externalities we have considered refer only to CO2 emissions, as this variable has a predefined market value. The production costs of MoL have not been considered as far as the costs of producing mussels are considered the same whether conventional ropes or BioGears are used.

Table 2 Data requirements and formulas for the economic assessment.

		Commercial Ropes (GR)	BioGears (BG)
BoL (Rope producer)	Income	$p_{gr} \cdot q_{gr}$	$p_{bg} \cdot q_{bg}$
	Production costs	$c_{gr} \cdot q_{gr}$	$c_{bg} \cdot q_{bg}$
	Externalities associated costs	$x_{gr} \cdot q_{gr}$	$x_{bg} \cdot q_{bg}$
MoL (Aquaculture producer 'a_')	Income	$p_{a\_gr} \cdot q_{a\_gr}$	$p_{a\_bg} \cdot q_{a\_bg}$
	Production costs	*NA*	*NA*
	Externalities associated costs	$x_{a\_gr} \cdot q_{a\_gr}$	$x_{a\_bg} \cdot q_{a\_bg}$
EoL Landfill (GR) & Composting (B1 & B2)	Income	0	$p_{EoL\_bg} \cdot q_{EoL\_bg}$
	Production costs	$c_{EoL\_cr} \cdot q_{EoL\_cr}$	$c_{EoL\_bg} \cdot q_{EoL\_bg}$
	Externalities associated costs	$x_{EoL\_cr} \cdot q_{EoL\_cr}$	$x_{EoL\_bg} \cdot q_{EoL\_bg}$

Variables: p = price; q = quantity; x = estimation of the costs of a given externality.
Subscripts: gr = conventional ropes; bg = biogears; a_gr = aquaculture product produced with conventional ropes; a_bg = aquaculture product produced with BioGears; EoL_gr = conventional rope at the End of Life; EoL_bg = BioGears at the End of Life.

The private benefit, that does not consider externalities, is defined as:

$$Private\_Benefit\_GR: \; PB\_GR = [p_{gr} \cdot q_{gr} + p_{a\_gr} \cdot q_{a\_gr} + 0] - [c_{gr} \cdot q_{gr} + c_{EoL\_gr} \cdot q_{EoL\_gr}]$$

[5] Externality Definition & Examples (investopedia.com)

And for Biogears the private benefit is estimated as:

$$Private\_Benefit\_BG:\ PB\_BG = [p_{bg} \cdot q_{bg} + p_{a\_bg} \cdot q_{a\_bg} + p_{EoL\_bg} \cdot q_{EoL\_bg}] - [c_{bg} \cdot q_{bg} + c_{EoL\_bg} \cdot q_{EoL\_bg}]$$

But, when considering the externalities, the social benefit is estimated as follows:

$$Social\_Benefit\_GR:\ SB\_GR = [p_{gr} \cdot q_{gr} + p_{a\_gr} \cdot q_{a\_gr} + 0] - [c_{gr} \cdot q_{gr} + c_{EoL\_gr} \cdot q_{EoL\_gr}] - [x_{gr} \cdot q_{gr} + x_{a\_gr} \cdot q_{a\_gr} + x_{EoL\_cr} \cdot q_{EoL\_gr}]$$

and

$$Social\_Benefit\_BG:\ SB\_BG = [p_{bg} \cdot q_{bg} + p_{a\_bg} \cdot q_{a\_bg} + p_{EoL\_bg} \cdot q_{EoL\_bg}] - [c_{bg} \cdot q_{bg} + c_{EoL\_bg} \cdot q_{EoL\_bg}] - [x_{bg} \cdot q_{bg} + x_{a\_bg} \cdot q_{a\_bg} + x_{EoL\_bg} \cdot q_{EoL\_bg}]$$

Thus, both private and social benefit will be compared to assess which rope provides higher benefits from the private perspective and from the social perspective. To make comparable two process, a functional unit is needed.

Functional unit

To compare the costs and benefits along the whole value chain, a functional unit needs to be set. The functional unit is the reference unit to which the costs and benefits are related. In this analysis, the functional unit is the **kilogram of aquaculture rope**. But in the analysis, the productivity for each type of rope may be different, therefore, a second functional unit has been also considered: **the kilogram of harvested mussel by kilogram of rope**.

Indicators

Three indicators were defined for the economic assessment. Two of the indicators are related to the private and social benefits. But note that it is not always possible to quantify in monetary terms all the negative externalities. Thus, additional indicators were calculated: eco-efficiency. The concept focuses on practices of resource-use attaining economic and environmental progress through more efficient uses of resources and lower pollution. Thus, eco-efficiency is a more general expression of the concept of resource efficiency – minimizing the resources used in producing a unit of output – and resource productivity – the efficiency of economic activities in generating added value from the use of resources. While eco-efficiency is a useful tool for the business sector to achieve greater value with lower adverse environmental impacts, it should also be applied beyond the business sector and production patterns. The adoption of eco-efficiency principles in production patterns can be mandated by government policies/regulations, market-based instruments, and technological improvements. However, the improvement of eco-efficiency of consumption patterns would be more complex and challenging than in production patterns due to the characteristics of society's culture and existing socio-economic systems[6]. According to ISO 14045:2012 - Eco-efficiency assessment of product systems, the Eco-efficiency is defined as is described in Table 3.

[6] https://sustainabledevelopment.un.org/content/documents/785eco.pdf

Table 3 Description of economic indicators.

Acronym	Description	Formula	Interpretation
R_PB	Ratio between PB_GR and PB_BG to measure the private benefits achieve with each rope	$\frac{PB\_BG}{PB\_GR}$	If the ratio is higher than 1, then the private benefits are higher for BioGears. If it is smaller, GR present higher benefits.
R_SB	Ratio between SB_GR and SB_BG to measure the social benefits achieve with each rope	$\frac{SB\_BG}{SB\_GR}$	If the ratio is higher than 1, then the social benefits are higher for BioGears. If it is smaller, GR present higher benefits.
EE	Eco efficiency	$\frac{Value\ of\ the\ product}{Environmental\ impact}$	The ecoefficiency is defined as a ratio between economic performance and environmental impact.

Once the indicators were calculated; the representation is done in an Eco-Efficiency Portfolio following Huisman and Tapia approaches (Huisman & Stevels. 2008; Tapia et al., 2016) represented in Figure 16.

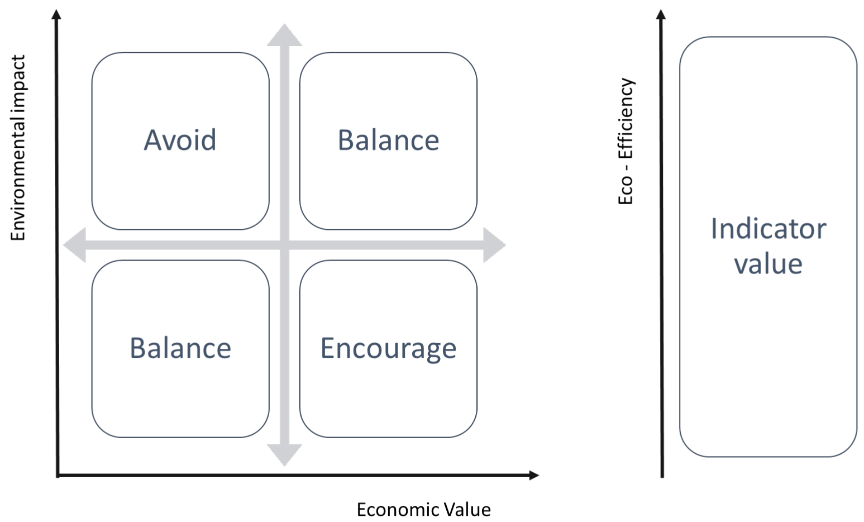


Figure 16: Eco-efficiency portfolio.

This analysis will be carried out for the commercial rope (baseline negative), biogear base prototype (baseline positive), biogear improved prototype 1 and biogear improved prototype 2.

6.2.2. Results

At the current stage of the study, experimental results are not yet available; consequently, the baseline monitoring relies on data from the existing literature and prior research findings.

BoL phase: nowadays, biopolymers have a huge limitation of higher pricing compared to conventional polymers. While the conventional commonly used polymers cost around 0.96 EUR/kg, biopolymers cost from about 3.8 EUR/kg to as high as 14 EUR/kg for material such as *polyhydroxybutyrates*. However, some studies indicate that bioplastic market is expected to grow 14.2% by 2025, while the expected groth for the synthetic fiber will be 5% (Shanmugam et al., 2021). In other study analysis, it points out that the fabrication of materials from feedstock is likely to rise from 5% in 2004 to ~18% in 2020, and up to ~25% in 2030 (Andrew & Dhakal, 2022). According to the latest market data compiled by European Bioplastics in cooperation with the nova-Institute (2024), global bioplastics production capacities are set to increase from around 2.47 million tonnes in 2024 to approximately 5.73 million tonnes in 2029 (Bioplastics Market Development Update 2024, https://www.european-bioplastics.org/bioplastics-market-development-update-2024/). Currently, bioplastics still represent less than one percent of the more than 367 million tonnes of plastic produced annually.

MoL phase: This assessment will be carried out after the sea tests.

EoL phase: Both, composting and landfilling costs will be included also in this analysis. To assess the potential costs of EoL possibilities of BioGears in comparison to reference systems, the costs of landfilling and composting will be estimated as well as environmental cost as value of CO2 emission of both processes (Table 4).

Table 4 Cost of landfill and composting process. Source: Biogears proyect

		Composting costs (EUR/kg)		Landfill costs (EUR/kg)	
Reference		**Min**	**Max**	**Min**	**Max**
(Slorach et al. 2019)		0,105	0,165	0,157	0,169
(Gadaleta et al. 2022)	Plastic	0,116	0,116		
	Mixed waste	0,115	0,115		
Libro Verde (1)	Closed composting costs	0,158	0,317	0,058	0,058
(Hogg 2001)		0,037	0,318		
European Envornment Agency (2)				0,004	0,182
Cewep (3)				0,005	0,110
Magrama 2012 (4)		0,020	0,150	0,048	0,193
Average costs		**0,092**	**0,197**	**0,054**	**0,142**
(Hogg 2001)	Sale of compots	0,001	0,012		
Green Taxation (5)				0,316	0,032
Ley 7/2022, de 8 de abril (6)	TAX for non-recycled plastic			0,450	0,450

Data in current euros (base year 2023)
(1) Libro Verde sobre la gestión de los biorresiduos en la Unión Europea
(2) https://www.eea.europa.eu/data-and-maps/figures/typical-charge-gate-fee-and
(3) https://www.cewep.eu/wp-content/uploads/2021/10/Landfill-taxes-and-restrictions-overview.pdf
(4) https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/publicaciones/GUIA_MO_DEF_tcm30-185554.pdf
(5) https://environment.ec.europa.eu/system/files/2021-11/Green%20taxation%20and%20other%20economic%20instruments%20%E2%80%93%20Internalising%20environmental%20costs%20to%20make%20the%20polluter%20pay_Study_10.11.2021.pdf
(6) https://www.boe.es/boe/dias/2022/04/09/pdfs/BOE-A-2022-5809.pdf

Considering the polluter pays principle, that is a simple idea at the core of EU environmental policy: those responsible for environmental damage should pay to cover the costs, and external costs should be added. There are green taxation and other economic instruments to internalize environmental costs to make polluters pay[7]. In the case of composting, the unique external cost that was considered is the value of the C02 emissions. Compost could also have a market price.

[7] https://environment.ec.europa.eu/system/files/2021-11/Green%20taxation%20and%20other%20economic%20instruments%20%E2%80%93%20Internalising%20environmental%20costs%20to%20make%20the%20polluter%20pay_Study_10.11.2021.pdf

According to literature (Gilbert and Siebert. 2022) compost have a weighted average price of 0.1 EUR/kg (fresh mass).

7. CONCLUSION

This deliverable presented the baseline framework and monitoring setup for evaluating the performance and impacts of hybrid NbS across the TRANSEATION demonstrators. By defining parameters and indicators, and determining and implementing the monitoring methodologies, the project establishes a solid foundation for assessing the environmental, social, and economic benefits of hybrid NbS interventions in addressing key social challenges such as natural climate hazards and biodiversity enhancement.

The baseline data at T0 collected in this phase captures the baseline conditions necessary for meaningful impact assessment over time, that will proceed under WP8. This enables comparison of 'before and after' states and supports the adaptive management of hybrid NbS strategies throughout the project lifecycle. The parameters monitored cover a wide range of aspects, from water quality to biodiversity, using methodologies such as photo-quadrats or ROVs for environmental monitoring, and ecosystem services and socio-economic assessments using methodologies such as ESE-ROI, cost-benefit analysis, and impact assessment for socio-economic monitoring. The re-analysis study (D3.1) conducted in Task 3.1 revealed that socio-economic assessments frequently lack adequate representation in the monitoring and evaluation of hybrid NbS. Therefore, examples from TRANSEATION demo sites' socio-economic assessments, in particular, provide valuable insights and examples which can be included in the tailor-made Systems Approach Framework to hybrid NbS (Task 14.4).

The collected information will also provide critical input for evaluating the effectiveness and performance of hybrid NbS in WP14. Indeed, it has been proven that there is social skepticism regarding the effectiveness of NbS associated with a preference for grey measures (Anderson et al., 2022). While blue measures are ideal if effective, they are also weaker and more uncertain. In this regard, hybrid measures can be favored to balance the perceived trade-offs of blue and grey. However, there is a need to reduce the uncertainty of hybrid NbS and manage expectations to ensure lasting public acceptance and determine their real value. This will be addressed under WP14 "Evidence-based effectiveness evaluation of hybrid blue-grey infrastructures in project demonstrators", where baseline data and monitoring methodologies will be used to pave the way to provide evidence-based knowledge driving effective blue-grey infrastructures implementation and scaling-up. In particular, technical evidence from effective implementation of blue-grey infrastructures will be collected (T14.1), ecological and environmental evidence on the effectiveness of implemented blue-grey infrastructures will be acquired (T14.2), and finally financial, economic and social evidence of impact of blue-grey infrastructures implementation will be gathered (T14.3).

Moreover, the collaborative approach across pilot sites ensures the replicability and scalability of the methodology, contributing to the broader knowledge base on hybrid NbS implementation in coastal and marine contexts.

ANNEX I: EU SOCIAL CHALLENGES ADDRESSED BY TRANSEATION DEMONSTRATORS. DEFINITIONS ARE EXTRACTED FROM CARDINALI (2021).

Social challenge	Definition
Climate Resilience 	Nature-based solutions can enhance resilience to the impacts of climate change by providing ecosystem services, and by increasing social awareness and actions to mitigate climate change. For example, nature-based solutions can: • Remove carbon via storage in vegetation and/or soil • Contribute to reduced greenhouse gas emissions through reduced energy consumption in buildings by passive cooling and/or insulating • Reduce local temperatures, providing relief from heatwaves and urban heat islands
Water Management 	Nature-based solutions can be used to effectively address both water quality and quantity (flooding, drought) issues, contributing to water security and environmental quality. Some of the water management benefits that nature-based solutions can provide include: • Reduced surface runoff following rain events • Increased surface water storage and/or groundwater recharge • Improved water quality, including reduced pollutant loads
Natural and Climate Hazards 	Nature-based solutions can reduce the risks associated with natural and climate hazards. They can mitigate risks related to both the increasingly frequent and intense storm events associated with climate change as well as other natural hazards, like landslides and avalanches. Nature-based solutions can, for example: • Reduce the number of persons adversely impacted by natural disasters • Reduce direct and indirect financial losses due to natural and climate hazards • Mitigate risks to critical infrastructure
Place Regeneration 	**Place Regeneration:** Nature-based solutions support regeneration of the built environment by enhancing the quantity and quality of green space, fostering people-nature connections and by contributing to reductions in our environmental footprint. Some of the ways that nature-based initiatives can do this include: • Reclaiming of derelict land for nature-based solutions • Enhancing the place identity or "sense of place" among citizens • Increasing the recreational and aesthetic value of public green spaces
Biodiversity Enhancement 	Biodiversity loss and ecosystem collapse are among the greatest threats our society faces in the near term. The implementation of nature-based solutions supports increased biodiversity, yielding benefits such as: • Reduced fragmentation/increased connectivity of natural areas • Increased number of native species, including pollinators • Increased species diversity of both flora and fauna

Knowledge and Social Capacity Building for Sustainable Urban Transformation 	Environmental education opportunities can foster social connectivity and trust, and increase environmental knowledge and associational and volunteer involvement. Nature-based solutions offer collective opportunities for citizen involvement in stewardship actions, like community gardening and tree planting, intergenerational learning and collective decision-making, yielding benefits such as: • Increased citizen involvement in environmental education activities • Supporting social learning regarding ecosystems and their functions • Enhancing pro-environmental behaviour among citizens
Participatory Planning and Governance 	Urban environmental transformation is a highly complex undertaking that requires open collaborative governance and robust capacities for participatory planning. Nature-based solutions require approaches to planning and governance that support accessibility to green spaces, while maintaining their quality for ecosystem services provision. Implementing nature-based solutions can support: • Increased openness of participatory processes, and an in-crease in the proportion of citizens involves in these processes • Increased sense of empowerment among citizens • Increased trust in decision-makers and indecision-making procedures • Supporting social learning regarding ecosystems and their functions • Enhancing pro-environmental behaviour among citizens
New Economic Opportunities and Green Jobs 	The adoption and implementation of nature-based solutions has the potential to create new economic opportunities and jobs in the green sector by enabling low-carbon, resource-efficient and socially inclusive economic growth. Benefits can include: • Increased value of natural capital, including an increase in average land productivity and profitability • Increased land or property value in proximity to nature-based solutions • Increased retail and commercial activity in proximity to nature-based solutions

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