

## D4.5 Sustainability indicators



***REstoration of WETlands to minimise emissions and maximise carbon uptake –  
a strategy for long term climate mitigation.***

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## EXECUTIVE SUMMARY

This document presents the selected indicators for evaluating the sustainability of wetland restoration efforts in the REWET project. The assessment is structured around the three core pillars of sustainability: environmental, economic, and social.

In selecting **environmental indicators**, we prioritised technical feasibility and practical applicability across the project's Open Labs. Emphasis was placed on indicators that are both measurable and meaningful in capturing the ecological value of restored wetlands, ensuring robust, accessible data collection.

For **economic indicators**, we draw on specialised literature and stakeholders' collaboration to identify the economic benefits and potential impacts of wetland ecosystems. This framework provides a comprehensive view of the economic dimensions of wetland restoration, capturing benefits across ecosystem services, natural disaster mitigation, and local economic contributions.

Our approach to **social indicators** is grounded in both social science literature and stakeholder research on wetland ecosystem services. By aligning these indicators with the United Nations' 17 Sustainable Development Goals (SDGs), we evaluate how REWET's activities impact societal aspects during project implementation and beyond, fostering a holistic understanding of social value and community engagement.

The **Matter-Element Extension Method** has been selected as the methodology for calculating the overall sustainability index. This method offers flexibility, enabling the integration of qualitative and quantitative data to provide a nuanced analysis of sustainability dimensions. Its capacity to handle diverse data types makes it well-suited for evaluating the complex and interconnected aspects of wetland restoration sustainability.

Together, these indicators and methodologies form a cohesive framework that supports a comprehensive evaluation of the REWET project's impact on wetland ecosystems and the surrounding communities.



## 1. INTRODUCTION

### 1.1 DESCRIPTION OF THE DOCUMENT AND PURSUE

This deliverable outlines the indicators that will be used in the REWET project to evaluate the sustainability of wetland restoration activities. It specifies the objectives within each of the three pillars of sustainability – social, economic, and environmental – as they apply to REWET’s restoration efforts, considering the unique technical constraints of the project.

The document provides a clear explanation of the process for selecting these indicators, including a brief description of each indicator and the specific data required for its calculation. By doing so, it establishes a framework to guide consistent measurement and analysis of sustainability impacts across different aspects of the project.

In the final section, the document details the mathematical methodology chosen for calculating the sustainability index. This index will serve as a comprehensive tool for assessing whether the project’s restoration activities are effectively enhancing the overall sustainability of the wetlands involved in REWET.

### 1.2 WPS AND TASKS RELATED WITH THE DELIVERABLE

This deliverable is directly linked to **Task 4.2 Sustainability indicators** within **WP4: Modelling**, where IDE is responsible for developing sustainability indicators that reflect the environmental, social, and economic dimensions of the Open Labs. Task 4.2 serves as the foundation for broader sustainability assessments (**Task 4.5**) and decision-support tools (**Task 4.6**) by providing quantitative benchmarks essential for effective wetland management.

The selection of environmental sustainability indicators in each Open Lab has been guided by the types of measurements and activities outlined in **WP2: Open Labs and Monitoring**. This approach ensures that indicators are contextually relevant and aligned with the specific monitoring protocols and methodologies adopted across Open Labs. Additionally, **Task 2.5 Developing a social monitor to track the acceptance of REWET activities** will play a critical role in measuring the social sustainability indicators by assessing social acceptance and perception of REWET activities among directly impacted stakeholders (e.g., farmers, landowners) and the wider public. Finally, **Task 2.8 Data management of Open Labs results** will support Task 4.2 by ensuring data consistency, integration, and applicability, creating a centralised database to store and standardise OL monitoring data, allowing seamless access and analysis.



## 2. ECOSYSTEM SERVICES

Ecosystem Services (ES) are fundamental for assessing the broad impact of wetland restoration projects, particularly in their contribution to sustainable development and human well-being. Defined as “**any positive benefit that wildlife or ecosystems provide to people**”<sup>1</sup>, these services capture the tangible and intangible benefits derived from healthy ecosystems. Wetlands, as one of the planet's most productive ecosystems, provide a wide range of ES<sup>2</sup> that are categorised into provisioning, regulating, cultural, and supporting services<sup>3</sup>. Restoration initiatives, like those in the REWET project, are designed to enhance these services, addressing environmental, economic, and social sustainability indicators in interconnected ways. By examining each ES in a wetland context, we can understand their vital role and potential social impacts.

### 2.1. MAIN TYPES OF ECOSYSTEM SERVICES

#### 2.1.1. Provisioning Services

Provisioning services refer to the tangible outputs' wetlands provide to local and broader communities, including food, fresh water, raw materials, and/or biochemical products<sup>1</sup>. These resources directly benefit human populations by providing critical inputs for food security, healthcare, and resource-based livelihoods:

- **Food Production:** Wetlands support the production of fish, algae, and invertebrates, which are essential for local diets and economies. The preservation of biodiversity in wetland ecosystems promotes sustainable harvests, supporting local fisheries and improving food security<sup>4</sup>.
- **Fresh Water Storage and Retention:** Wetlands play a crucial role in the storage and retention of water, ensuring water availability in drier seasons and for agricultural purposes<sup>5</sup>.
- **Raw Materials:** Resources such as timber, peat, and fodder are sourced sustainably from wetlands, supporting local industries and reducing the reliance on less sustainable alternatives<sup>6</sup>.
- **Medicinal Resources and Genetic Material:** Many plants in wetlands are sources of biochemicals with medicinal value, while genetic material from wetland species contributes to agricultural resilience by enhancing pathogen resistance in crops<sup>7</sup>.

These provisioning services are directly measurable in terms of resource output (e.g., kilograms of fish per hectare), which provides a tangible indicator of the economic sustainability impacts of restoration.

#### 2.1.2. Regulating Services

Regulating services are the benefits obtained from an ecosystem's natural processes, including climate regulation, water purification, air quality improvement, and erosion control. These functions are particularly essential in wetlands due to their roles in mitigating environmental challenges such as climate change and pollution.

- **Climate Regulation:** Wetlands act as significant carbon sinks, sequestering carbon in their soil and vegetation, which helps mitigate greenhouse gas emissions and stabilise local and global climates<sup>8</sup>.



- **Water and Pollution Control:** Wetlands are natural filters that retain and detoxify pollutants, improving water quality by reducing nutrient loads and filtering heavy metals, thus decreasing the need for costly water treatment<sup>9</sup>.
- **Hydrological Regulation:** By managing groundwater recharge and discharge, wetlands help regulate water availability, benefiting both agriculture and industry<sup>6</sup>.
- **Erosion and Hazard Mitigation:** Vegetation in wetlands anchors soil and reduces erosion, while wetlands buffer against natural hazards, providing flood control and coastal protection during extreme weather events<sup>10</sup>.

These regulating services are particularly valuable in the face of increasing climate and pollution pressures, marking them as crucial indicators of environmental sustainability.

### 2.1.3. Cultural Services

Cultural services relate to the non-material benefits people derive from ecosystems, such as recreation, aesthetic enjoyment, educational value, and spiritual inspiration. Wetlands are rich in cultural services due to their biodiversity, scenic landscapes, and cultural significance for many communities.

- **Recreation and Aesthetic Value:** Wetlands offer unique opportunities for ecotourism, recreation, and outdoor education. Activities like birdwatching, photography, and boating attract visitors, promoting local economies and enhancing well-being through nature appreciation<sup>11</sup>.
- **Cultural Heritage and Spiritual Inspiration:** Wetlands are often embedded in local heritage and spiritual practices, fostering a sense of place and identity among communities. This connection enhances cultural sustainability, linking ecological health with social values<sup>12,13,14,15</sup>.
- **Educational and Scientific Research:** Wetlands serve as natural laboratories for educational programmes and scientific research. They offer hands-on learning experiences, enhancing environmental awareness and promoting future conservation efforts<sup>16</sup>.

The cultural services provided by wetlands support the development of socio-environmental education and contribute to social sustainability by fostering a connection between people and their environment.

### 2.1.4. Supporting Services

Supporting services are the fundamental ecological processes that sustain other ecosystem functions, such as soil formation, nutrient cycling, and biodiversity. Wetlands are highly productive in these supporting services, which underpin the overall resilience of the ecosystem:

- **Soil Formation and Nutrient Cycling:** Wetlands support sediment retention and organic matter accumulation, aiding soil fertility and enabling nutrient cycling processes that sustain local plant and animal life<sup>17,18,19</sup>.
- **Biodiversity:** Wetlands are biodiversity hotspots that provide breeding, feeding, and resting habitats for various species, including migratory birds, insects, and amphibians. This biodiversity ensures ecosystem resilience and adaptability, which benefits human populations by sustaining ecosystem services long-term<sup>20</sup>.



These supporting services are critical to wetland restoration projects, as they provide a foundation for other ecosystem services and thus amplify the environmental and economic sustainability benefits of restoration.

## 2.2. INTEGRATING ECOSYSTEM SERVICES INTO SUSTAINABILITY INDICATORS

Evaluating the impacts of ecosystem services provided by wetlands enables the measurement of sustainability indicators across economic, environmental, and social dimensions:

- **Environmental:** Regulating and supporting services directly contribute to environmental indicators, such as carbon sequestration rates, water quality, and biodiversity indices, highlighting the ecological benefits of wetland restoration.
- **Economic:** Provisioning services align with economic sustainability by providing resources that foster local industries and reduce the cost of managing resources, as in water filtration and flood control.
- **Social:** Cultural services resonate with social indicators, as they promote community well-being, cultural heritage, and educational opportunities that support social cohesion and identity.

In conclusion, ecosystem services are central to the success of wetland restoration projects. By enhancing provisioning, regulating, cultural, and supporting services, these projects can contribute to comprehensive sustainability outcomes, demonstrating that investing in natural ecosystems generates enduring benefits for both people and the planet.



### 3. SUSTAINABILITY INDICATORS

#### 3.1. ENVIRONMENTAL INDICATORS

The primary objective of using environmental indicators within the REWET project is to systematically measure and assess the complex impacts of wetlands on their surrounding environments. These indicators play a critical role in quantifying the dynamic relationships between wetlands and their ecological settings, as well as in tracking how these relationships evolve over the course of the project. This comprehensive monitoring allows us to illustrate the effectiveness and significance of key wetland services, including climate regulation, pollution control, erosion prevention, and biodiversity support.

The selection of indicators has been guided by several considerations:

- **Technical Feasibility:** Practicality and reliability are central to the selection of environmental indicators. Although a wide array of potential indicators exists, not all are feasible or relevant for the REWET project. Therefore, **we have prioritised indicators that can be effectively and consistently measured throughout the project's duration**, ensuring that the data collected is both actionable and aligned with project goals.
- **Project-Specific Relevance:** Given the unique goals and objectives of the REWET project, the selected indicators are tailored to reflect its specific aims. This targeted approach ensures that the data generated directly contributes to achieving the project's milestones, enabling a focused assessment of environmental outcomes.
- **Adaptability to Open Labs:** Recognising the diverse environmental conditions and challenges within each Open Lab, the selection of indicators is adaptable across varied contexts. This flexibility allows indicators to be applied effectively across different Open Labs, accommodating local environmental particularities and enhancing the project's overall relevance and robustness.

This enhanced framework for environmental indicators supports REWET's overarching mission of advancing wetland restoration by providing a robust, scalable approach to assessing environmental impacts in real time.



### 3.1.1. Identification of environmental sustainability indicators

Below are listed the identified environmental indicators to provide specific insights into wetland ecosystem health, hydrological function, or biodiversity. By combining some of these measures, the REWET project can comprehensively evaluate wetland services and identify ecological changes or potential environmental stressors over time.

En-1: Wetland Area (m <sup>2</sup> )	
<b>Purpose</b>	To quantify the physical size of the wetland at a specific time.
<b>Justification</b>	The extent of a wetland area is directly tied to its ecological and hydrological functions, as larger wetlands generally provide more ecosystem services, such as carbon sequestration, biodiversity support, and flood control <sup>6,9</sup> .
<b>Methodology</b>	Wetland area is measured through geographic information system (GIS) analysis, using satellite or drone imagery to capture the boundary of the wetland over time.

En-2: Wetland Area Evolution (m <sup>2</sup> )	
<b>Purpose</b>	To track changes in the wetland's spatial extent over time.
<b>Justification</b>	Monitoring area evolution is crucial to understanding the wetland's resilience and identifying potential threats such as encroachment, climate impacts, or water scarcity <sup>21</sup> . One of the most important parameters to track the wetland evolution is the leaf area index (LAI), an indicator of an ecosystem's capacity to capture CO <sub>2</sub> from the atmosphere.
<b>Methodology</b>	Historical satellite images or yearly surveys are used to assess expansion or reduction in the wetland area. Calculations require comparing present and past area measurements.

En-3: Soil Nutrient Concentration (mg/kg)	
<b>Purpose</b>	To monitor nutrient content in wetland soils, including nitrogen, phosphorus, and total organic carbon (TOC).
<b>Justification</b>	Soil nutrient levels indicate fertility and the potential for nutrient pollution, which may stem from agricultural runoff or atmospheric deposition <sup>22</sup> .
<b>Methodology</b>	Soil samples are collected and analysed for organic nitrogen, phosphorus, and TOC using chemical assays or spectrophotometry.

En-4: GHG Net Balance per Area (CO <sub>2</sub> -eq/m <sup>2</sup> )	
<b>Purpose</b>	To assess the wetland's role in greenhouse gas emissions or sequestration.
<b>Justification</b>	Wetlands are significant in climate regulation, either as carbon sinks or sources, depending on the balance between methane emissions and carbon sequestration <sup>23</sup> .
<b>Methodology</b>	Calculations involve measuring CO <sub>2</sub> and CH <sub>4</sub> fluxes using portable flux chambers or eddy covariance towers, combined with standard GHG modelling techniques. Emissions data is converted to CO <sub>2</sub> equivalents for comparison.

En-5: Water Level (m)	
<b>Purpose</b>	To monitor changes in water depth within the wetland, indicating hydrological health.
<b>Justification</b>	Fluctuations in water level influence wetland biodiversity, vegetation types, and nutrient cycling. Persistent low levels can signal issues with groundwater recharge or surface drainage <sup>24</sup> .
<b>Methodology</b>	Water level is measured using automated sensors or manually with graduated gauges at fixed intervals throughout the year.

En-6: Water Nutrient Concentration (mg/m <sup>3</sup> )	
<b>Purpose</b>	To assess nutrient levels in the water, particularly nitrogen and phosphorus.
<b>Justification</b>	Excessive nutrient levels can lead to eutrophication, which disrupts ecosystems and leads to loss of biodiversity and oxygen depletion <sup>25</sup> .
<b>Methodology</b>	Water samples are collected and analysed for nutrient concentrations using spectrophotometry or chromatography, focusing on nitrogen and phosphorus levels.

En-7: Water Temperature (°C)	
<b>Purpose</b>	To monitor the temperature of water as an indicator of habitat conditions.
<b>Justification</b>	Temperature affects species distribution, metabolic rates, and dissolved oxygen levels, impacting overall ecosystem health <sup>26</sup> .
<b>Methodology</b>	Temperature is measured at various points and depths using digital thermometers or automated sensors, often linked to data loggers for continuous monitoring.

En-8: Dissolved Oxygen (DO) (mg/L)	
<b>Purpose</b>	To assess the oxygen availability within the wetland ecosystem.
<b>Justification</b>	DO levels are critical for aquatic life and are a direct indicator of water quality; low DO often signals pollution or eutrophication <sup>27</sup> .
<b>Methodology</b>	DO is measured using oxygen probes or Winkler titration, with data collected at regular intervals to detect fluctuations. <b>UniPR</b> can measure the DO using YSI 556 multiple probes.

En-9: Number of Autochthonous Species	
<b>Purpose</b>	To measure biodiversity by counting native species within the wetland.
<b>Justification</b>	Biodiversity is a key indicator of ecosystem health; a rich presence of native species reflects a stable, well-functioning ecosystem <sup>28</sup> .
<b>Methodology</b>	Species inventory surveys are conducted across different taxonomic groups, including insects, mammals, flora, and fish. Observations and species identification rely on field surveys or DNA barcoding.

En-10: Number of Non-Autochthonous Species	
<b>Purpose</b>	To monitor the presence of invasive species that can threaten ecosystem stability.
<b>Justification</b>	Invasive species often outcompete native flora and fauna, leading to ecological imbalances <sup>29</sup> .
<b>Methodology</b>	Surveys focus on identifying non-native species using observational data and/or environmental DNA (eDNA) testing.

En-11: Dominance of Native Plants ( $m^2_{\text{autochthonous}}/m^2_{\text{total plants}}$ )	
<b>Purpose</b>	To determine the extent of area covered by native plant species relative to the total vegetation.
<b>Justification</b>	High native plant dominance supports wetland resilience and provides habitat stability, whereas non-native dominance can be a threat to biodiversity <sup>6</sup> .
<b>Methodology</b>	Vegetation analysis is conducted using aerial imagery or on-ground surveys to differentiate between native and non-native plants. Data is used to calculate the proportion of native plant coverage.

En-12: EPT Index (Ephemeroptera, Plecoptera, and Trichoptera)	
<b>Purpose</b>	To gauge water quality based on the presence of sensitive aquatic insects.
<b>Justification</b>	The EPT Index is widely recognised as a biological indicator of water quality, as these species are sensitive to pollution and habitat degradation <sup>30</sup> .
<b>Methodology</b>	Aquatic insect populations are sampled using nets or traps. The proportion of EPT taxa in the community is calculated to assess wetland health. Only OL #1 has the capability to measure this indicator.

### 3.1.2. Preliminary analysis of environmental sustainability indicators

The selection of environmental sustainability indicators in each Open Lab has been carried out **considering the types of measurements and activities conducted during the implementation of WP2: Open Labs and Monitoring, as outlined in the Grant Agreement**. A summary of the selected environmental indicators for each Open Lab can be found in Table 1.

Colour legend:

- **In green:** The indicator is feasible to measure and obtain directly with the resources of the REWET project.
- **In yellow:** The indicator is not directly obtainable or can only be partially measured and would need to be derived from historical data or third-party sources.
- **In red:** The indicator is not considered in that case due to OL restrictions or Grant Agreement limitations.



Table 1. Preliminary analysis of environmental sustainability indicators.

Env. Indicator		Description	OL #1	OL #2	OL #3	OL #4	OL #5	OL #6	OL #7
En-1	Wetland area	Measurement feasible using remote sensing (RSS) to assess wetland area.							
En-2	Wetland area evolution	Monitoring LAI using remote sensing (RSS) to observe changes in area over time.							
En-3	Soil nutrient concentration	Measurement includes organic carbon, phosphorus, and nitrogen content in soil, except where limited by the Grant Agreement (GA)	TOC, DOC, P, N	TOC despite not included in GA	Not included in GA	TOC, DOC, P, N	TOC, DOC (P and N not included)	TOC, DOC, P, N	TOC despite not included in GA
En-4	GHG net balance per area	Measured via Eddy Covariance (EC) or portable chamber for greenhouse gas (GHG) balance data.	EC	EC	EC	EC	Portable chamber	Portable chamber	EC
En-5	Water level	Periodic measurements will be taken to monitor water level changes.							
En-6	Water nutrient concentration	Feasibility varies by OL; some will measure directly, while others depend on data from local authorities.	Local authorities	Local authorities	Direct measurement	Direct measurement	Not included in GA	Direct measurement	Direct measurement
En-7	Water temperature	Periodic water temperature measurements will be taken to monitor changes over time.							
En-8	Dissolved oxygen	Measurement uncertain; some OLs may send samples to UniPR (Italy) for potential analysis if required.	Potential analysis	Potential analysis	Potential analysis	Potential analysis	Potential analysis	YSI probe available	Potential analysis
En-9	Autochthonous species count	Quantification of native species, including birds and insects (mainly beetles).							
En-10	Non-autochthonous species count	Count of non-native species alongside native species for biodiversity monitoring. Still to be decided if it will be carried out or not.							
En-11	Dominance of native plants	Analysis of native plant dominance using historical vegetation data, except where unavailable.	Historical data available	Historical data available	Historical data available	Historical data available	Historical data available	Historical data still pending	Historical data still pending
En-12	EPT Index	OL #1 only: Ephemeroptera and Trichoptera may be monitored for EPT Index, though unclear if used in the project.	Caddisflies & mayflies						

## 3.2. ECONOMIC INDICATORS

To evaluate the economic impact of natural restoration activities, such as those conducted within the REWET project, it is essential to recognise that, **during the restoration process, the economic impacts are predominantly negative** until the ecosystem reaches a certain level of recovery. At that point, the ecosystem can begin to provide valuable services that contribute positively to the economy.

As previously exposed, wetlands offer a variety of ecosystem services. Some of these services can be directly measured using economic indicators – such as food production from crops and fish – while others, including aesthetic and cultural values, are less easily quantified in economic terms yet play a significant role in sectors like tourism. One of the most critical functions of wetlands is their potential to mitigate the impacts of extreme weather events. For instance, wetlands were estimated to have prevented over \$625 million in damages during Hurricane Sandy in 2012<sup>10</sup>.

To assess how REWET activities impact the economy, we have selected a range of economic indicators recommended by the **Ramsar Convention Secretariat**, as outlined in "Managing Wetland"<sup>2</sup> and "Valuing Wetlands: Guidance for Valuing the Benefits Derived from Wetland Ecosystem Services"<sup>31</sup>. These resources outline three primary monetary valuation approaches: Direct Market Valuation, Indirect Market Valuation, and Survey-Based Valuation:

1. **Direct Market Valuation:** Direct market valuation methods rely on the market prices of goods and services directly produced by ecosystems. This approach primarily applies to goods with active markets, such as food production, recreational activities, and some regulatory services.
  - **Market Price:** This is the value assigned to ecosystem goods and services based on their exchange rate in the market. For example, wetlands contribute to food production through aquaculture, with fish and crops harvested from wetland areas being sold in markets. The economic value of these services can be derived directly from their market prices.
  - **Factor Income:** Some ecosystem services indirectly enhance income levels by improving productivity. An example is natural water filtration, which can enhance fishery yields, thus increasing the incomes of local fishers. While using this method, it is essential to avoid double counting by ensuring that the economic contributions are attributed solely to ecosystem services rather than overlapping economic factors.
  - **Public Investment:** Strictly speaking, public pricing is not “market based” but is real money involved in transactions related to ecosystem services reflecting the public willingness to pay for their use or conservation. The Public Pricing Method assesses the economic value of ecosystem services through public investments and policy interventions, such as land purchases, subsidies, or tax incentives, aimed at ecosystem conservation or restoration. Governments may invest in ecosystem conservation by purchasing land for watershed protection, which, in turn, provides drinking water services without requiring extensive infrastructure. Monetary incentives like subsidies can encourage sustainable practices, promoting the preservation and use of ecosystem services. However, establishing property rights can be challenging, and caution is needed to prevent unintended negative outcomes, or "perverse incentives," where incentives may inadvertently discourage conservation. A compelling example of the value of natural services is found in New York City’s decision to preserve undeveloped watersheds, which avoided the need

for a \$6 billion water filtration plant. This decision reflects a recognition of the significant value inherent in natural water regulation services. Wetland trading programmes further illustrate this value, where wetlands can be 'banked' and sold, with prices ranging from \$74,100 to \$493,800 per hectare<sup>31</sup>.

2. **Indirect Market Valuation:** For many wetland services lacking explicit markets, an alternative strategy is required to estimate their economic value. Common approaches to derive indirect market valuation include:

- **Avoided Cost (AC):** Some services help society avoid costs that would otherwise be incurred in their absence. Flood control, for instance, is a wetland service that prevents potential flood-related expenses. Since the REWET project focuses on two specific natural disasters, floods and droughts, here follows an **example of the AC method for the 'Economic mitigation of natural disaster per area' indicator:**

- *Flood cost per water ( $B_{Fc} / m^3_{water}$ ):*

The flood cost will establish a relationship between the cost of flood effects in a particular location and a metric of water.

- *Water retained by wetland ( $Wr = m^3$ ):*

This is the amount of water retained in the wetland during the flood events.

- *Mitigation of floods ( $M_f = \text{€ or \$}$ ):*

$$M_f = \frac{B_{Fc}}{m^3_{water}} \cdot Wr = \text{€ or \$} \quad (1)$$

This indicates the financial savings achieved through wetlands in mitigating flood-related damages.

- *Drought cost per water ( $B_{Dc} / m^3_{water}$ ):*

Similar to flood cost, drought cost establishes a relationship between the cost of drought-related effects in a specific location and the volume of water transported from other locations.

- *Water provided by wetland ( $Wp = m^3$ ):*

This represents the amount of water supplied by the wetland, particularly during periods of drought.

- *Mitigation of drought ( $M_d = \text{€ or \$}$ ):*

$$M_d = \frac{B_{Dc}}{m^3_{water}} \cdot Wp = \text{€ or \$} \quad (2)$$

- *Economic Mitigation of Natural disaster per area ( $E_{MN} = \text{€ or \$ per } m^2$ ):*

$$E_{MN} = \frac{M_d + M_f}{area_{wetland}} \quad (3)$$

- **Replacement Cost (RC):** This method estimates the cost of replacing natural services with man-made systems. An example is the use of wetlands for waste treatment, a service that could alternatively require expensive infrastructure.

3. **Survey-Based Valuation Methods:** Survey-based methods are used to capture the perceived economic value of ecosystem services that lack direct market values.
  - **Contingent Valuation (CV):** This approach utilises surveys and questionnaires to capture the community's willingness to pay for the preservation of wetland services such as biodiversity, aesthetic enjoyment, and cultural heritage. It effectively gauges public support and perceived value beyond direct economic benefits<sup>32,33</sup>.
  - **Group Valuation:** Building on contingent valuation, group valuation involves public deliberation to assign economic values. By engaging community members in discussions, this method fosters consensus and ensures that valuations represent collective rather than individual preferences.
  
4. **Other Valuation Methods for Non-Market Ecosystem Services:** In response to recommendations for improving the assessment of perceived wetland values, several methodologies can be employed to quantify non-market values<sup>34</sup> that are harder to measure with traditional economic indicators:
  - **Travel Cost Method (TCM):** The TCM assesses the economic value of recreational activities within wetlands by examining visitor spending on travel, accommodations, and associated activities. This approach captures the indirect economic impact of wetlands on local tourism<sup>35</sup>.
  - **Hedonic Pricing:** This method analyses property values in proximity to wetlands, as properties in these areas often appreciate in value due to enhanced aesthetics, improved flood control, and other wetland benefits<sup>36</sup>.
  - **Benefit Transfer Method:** In cases where direct valuation is challenging, benefit transfer can apply estimates from similar studies in comparable regions. This method allows for the economic valuation of ecosystem services that are challenging to quantify but are known to have significant economic contributions in other wetland areas<sup>37</sup>.

By integrating some of these valuation approaches, REWET can present a more comprehensive understanding of the economic impacts of wetland restoration, highlighting both tangible and intangible benefits that wetlands contribute to local and regional economies.

### 3.2.1. Identification of economic sustainability indicators

The following tables show a comprehensive set of economic indicators to quantify the value of wetlands. This approach provides a more complete picture of the ecological and economic benefits that wetland ecosystems offer.



Ec-1: Cost of restoration and maintenance per area (€/€ per m <sup>2</sup> )	
Purpose	Quantifies the financial resources required for wetland restoration and maintenance, facilitating a comparison between costs and economic benefits over time.
Justification	This indicator is critical for evaluating restoration projects' economic viability, providing insights into funding needs and cost-effectiveness <sup>31,38</sup> .
Methodology	1) Data Collection: Track initial restoration costs and ongoing maintenance expenses, such as labour, equipment, and resource inputs; 2) Cost-Benefit Analysis: Compare restoration and maintenance costs with the economic returns from ecosystem services provided, such as flood prevention and carbon sequestration.

Ec-2: Direct Market Valuation: Revenue from economic activities per area (€/€ per m <sup>2</sup> )	
Purpose	Measures income generated from ecosystem services with direct market values, such as <b>food production</b> (crops, fish, aquaculture...), bio-resources (e.g., wood), tourism, and recreation.
Justification	This indicator captures the direct economic benefits that wetlands provide to local economies, including food production (e.g., fish, aquaculture, crops), revenues from ecotourism, and recreational activities. Studies show that integrating wetland food production into economic evaluations can highlight its role in food security, income generation, and biodiversity conservation <sup>31,39</sup> . These benefits align with global sustainability goals, such as SDG 2: Zero Hunger and SDG 8: Decent Work and Economic Growth <sup>40</sup> . By evaluating these activities, the indicator highlights wetlands' potential to foster both income generation and sustainable ecosystem management.
Methodology	<p><u>Revenue Tracking</u>: Record income from tourism (e.g., entrance fees, guided tours), fishing, aquaculture, and any related services.</p> <p><u>Market Analysis</u>: Assess the direct economic impact by calculating revenue generated from these activities per square meter of wetland.</p> <p><u>Food/Bio-resources production valuation</u>:</p> <ul style="list-style-type: none"> <li>• Data Collection: Identify specific food production activities within the wetland area, such as fishery yields, crop production, or aquaculture, and quantify the annual volume of each product type harvested.</li> <li>• Economic Valuation: <ul style="list-style-type: none"> <li>- Market Price Valuation: Multiply the volume of harvested food (e.g., kilograms of fish, tonnes of crops, kilograms of wood) by the current market price for each product type in the region. This approach aligns with Direct Market Valuation, as discussed in the Ramsar guidelines.</li> <li>- Cost-Benefit Analysis: Compare production costs, including labour, resource inputs, and maintenance, with revenues from food sales to provide a comprehensive view of economic contributions.</li> </ul> </li> </ul>

Ec-3: Economic mitigation of natural disasters per area (€/€ per m <sup>2</sup> )	
<b>Purpose</b>	Quantifies the economic benefits from disaster mitigation functions of wetlands, such as flood and drought prevention.
<b>Justification</b>	Wetlands act as natural buffers that can reduce the economic impact of floods and droughts, potentially saving millions in avoided damages <sup>31,41</sup> .
<b>Methodology</b>	As previously shown in the example, use the Avoided Cost (AC) method to estimate how wetland restoration helps reduce costs associated with natural disasters. Calculate savings from reduced flood, drought, and erosion impacts.

Ec-4: Value of water purification services (€/€ per m <sup>2</sup> )	
<b>Purpose</b>	Assigns economic value to the natural water filtration provided by wetlands, lowering the need for artificial water treatment systems.
<b>Justification</b>	Wetlands filter pollutants, benefiting communities and industries by reducing downstream water treatment costs <sup>39,42</sup> .
<b>Methodology</b>	Use the Replacement Cost (RC) method by estimating what it would cost to substitute natural filtration with artificial systems. Compare these costs with local water treatment expenses to establish valuation.

Ec-5: Carbon sequestration value (€/€ per ton CO <sub>2</sub> )	
<b>Purpose</b>	Quantifies the economic benefit of carbon stored by wetlands, contributing to climate change mitigation.
<b>Justification</b>	Wetlands capture and store significant amounts of CO <sub>2</sub> , providing economic benefits linked to climate stability <sup>38,43</sup> .
<b>Methodology</b>	The social cost of carbon (SCC) is a metric used to quantify the economic damages associated with an incremental increase in CO <sub>2</sub> emissions <sup>44</sup> . Within this approach, various estimation methods and models, such as Integrated Assessment Models, can be used to assess the value of avoided CO <sub>2</sub> emissions, supported by carbon accounting techniques.

Ec-6: Cultural and recreational value (€/€ per visit or per m <sup>2</sup> )	
<b>Purpose</b>	Captures the economic benefit associated with recreational, aesthetic, and cultural services provided by wetlands.
<b>Justification</b>	Wetlands hold intrinsic cultural value and are sites for recreational activities, contributing significantly to local economies <sup>39,28</sup> .
<b>Methodology</b>	Apply the Travel Cost Method (TCM), which estimates the value of cultural and recreational services based on visitor expenses (e.g., travel, accommodation).

Ec-7: Biodiversity support value (€/€ per m <sup>2</sup> )	
<b>Purpose</b>	Provides economic valuation for the habitat and biodiversity support function of wetlands, which helps preserve local flora and fauna.
<b>Justification</b>	Biodiversity is essential for ecosystem stability, resilience, and tourism appeal, translating into economic benefits <sup>39,45</sup> .
<b>Methodology</b>	Use the Contingent Valuation (CV) method to assess willingness to pay for biodiversity preservation and habitat conservation among stakeholders.

Ec-8: Nutrient cycling value (€/€ per m <sup>2</sup> )	
<b>Purpose</b>	Quantifies the value of nutrient cycling and soil formation, both critical for agriculture and maintaining soil fertility in surrounding areas.
<b>Justification</b>	Wetlands cycle nutrients effectively, preventing nutrient loss, supporting plant growth, and benefiting nearby agricultural areas <sup>38,39</sup> .
<b>Methodology</b>	Calculate the cost of artificial nutrient cycling systems and compare to natural nutrient retention capacity.

Ec-9: Health and well-being value (€/€ per person impacted)	
<b>Purpose</b>	Assesses the value of wetland contributions to public health through improved air quality, mental health, and recreational space.
<b>Justification</b>	Proximity to green spaces, such as wetlands, is associated with improved physical and mental well-being <sup>39,46</sup> .
<b>Methodology</b>	Use health metrics such as reduced healthcare costs and improved mental health outcomes related to green space access.

### 3.2.2. Preliminary analysis of economic sustainability indicators

This section is focused on the preliminary analysis of the economic sustainability indicators for each Open Lab. This analysis has been conducted considering the resources of each ecosystem, through dialogue and consensus with the Open Labs coordinators, as well as through seeking stakeholders who can participate in decision-making and corroborate the selection.

In the particular case of the economic indicators, it is important to note that:

- In **green** are those that, after a preliminary analysis, seem to have a consensus regarding their collection and measurement.
- Those indicators not yet defined in terms of how to measure and implement them will appear in **yellow**, representing a **preliminary idea**.
- In **red** are those that present limitations in their collection and/or cannot be considered or measured due to some restriction.

Table 2 below describes all the preliminary analyses carried out to address the economic sustainability indicators.

Table 2. Summary of economic sustainability indicators.

Indicators		Feasibility						
		OL#1	OL#2	OL#3	OL#4	OL#5	OL#6	OL#7
Ec-1	Restoration and maintenance	Green	Yellow	Red	Yellow	Green	Green	Yellow
Ec-2	Direct market valuation	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Green
Ec-3	Mitigation of natural disasters	Green	Green	Yellow	Yellow	Yellow	Green	Yellow
Ec-4	Value of water purification services	Green	Green	Red	Red	Yellow	Yellow	Yellow
Ec-5	Carbon sequestration value	Green	Green	Green	Green	Green	Green	Green
Ec-6	Cultural and recreational value	Green	Green	Yellow	Yellow	Yellow	Green	Green
Ec-7	Biodiversity support value	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Ec-8	Nutrient cycling value	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Ec-9	Health and well-being value	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

OL #1 Netherlands – Weerribben-Wieden National Park (WENR)		
Economic Indicator	Description	
Ec-1	Restoration and Maintenance	Historical budget analysis and interviews with key stakeholders can provide a baseline cost estimate.
Ec-2	Direct Market Valuation	The economic value of ecosystem services in the area can be assessed through a direct market valuation of products such as harvested reed, transformed biomass, and drinking water. Sales revenue, including that generated by Dunea©'s innovative revenue model for water management, serves as a key metric for calculating annual market valuation. Additionally, initiatives like introducing a quality mark for reed and sales data from organisations such as Dunea© and Vitens© offer valuable insights into pricing trends and the financial contribution of these services (these elements will be further detailed in <i>D6.3: Initial Plan of REWET Business Models</i> ). However, the area's status as part of the Natura 2000 network prioritises biodiversity conservation and ecosystem health, which limits its suitability for significant food production activities. The fen peatland ecosystem further restricts traditional agricultural practices, making it unsuitable for large-scale food production valuation. This balance between economic potential and ecological constraints underscores the importance of aligning market valuation efforts with conservation priorities, ensuring that economic activities remain sustainable and compatible with the area's protected status.
Ec-3	Mitigation of Natural Disasters	Wetlands act as natural buffers, reducing the impact of floods. The Avoided Cost method will be employed to estimate economic savings related to flood prevention, based on regional flood data and associated damage costs.
Ec-4	Value of Water Purification Services	The Weerribben-Wieden National Park contributes to the natural filtration of water, which improves the quality of water extracted by Vitens©. To value this service, the Replacement Cost method will be used, estimating the costs Vitens© would incur if artificial filtration systems were required to match natural purification levels. This calculation will include regional water

		quality standards and the associated expenses for water treatment.
Ec-5	<b>Carbon Sequestration Value</b>	With the park's soils storing over 175 tons of carbon per hectare, its carbon sequestration capacity is significant. The social cost of carbon will be used to calculate the economic value of stored carbon, multiplying the per-hectare carbon storage by the social cost per ton. This methodology quantifies the ecosystem's contribution to climate change mitigation.
Ec-6	<b>Cultural and Recreational Value</b>	The site attracts significant tourism, with over 2,000 jobs in the leisure industry. The Travel Cost Method could be used to calculate the economic impact of recreational activities, assessing visitor spending on travel, accommodation, and park fees. Surveys to evaluate spending patterns and visitor numbers could be conducted annually to assess changes in recreational value. Additionally, the Business Investment Zone (BIZ) model <sup>47</sup> could be analysed to track collaborative financial contributions from local businesses.
Ec-7	<b>Biodiversity Support Value</b>	Weerribben-Wieden is home to over 500 endangered species, which contributes to its biodiversity value. A Contingent Valuation Method could be employed by surveying residents and visitors about their willingness to pay for the conservation of endangered species. Additionally, the costs of conservation programmes could be documented to provide a tangible biodiversity support valuation.
Ec-8	<b>Nutrient Cycling Value</b>	The Replacement Cost method could estimate what it would cost to replicate nutrient cycling services artificially. Data on nutrient concentrations in soil and water could be monitored to measure nutrient cycling effectiveness
Ec-9	<b>Health and Well-being Value</b>	Access to green spaces like Weerribben-Wieden supports physical and mental health. The Contingent Valuation Method could capture the community's perceived health benefits by surveying residents and visitors on their willingness to pay for access to green spaces. Public health statistics, such as reductions in local healthcare costs associated with physical and mental well-being, could further support valuation.
<b>OL #2 Austria – Morava River (BOKU)</b>		
<b>Economic Indicator</b>		<b>Description</b>
Ec-1	<b>Cost of Restoration and Maintenance per Area</b>	Floodplain and riverbank restoration for flood risk mitigation and water supply regulation: To measure this indicator, historical cost data from restoration projects, especially those following the 2006 flood, should be analysed to calculate annual and project-specific expenditures. This will enable a cost-benefit comparison with flood mitigation and water supply benefits.
Ec-2	<b>Direct Market Valuation</b>	<u>Water supply for agriculture</u> : The market value of water could be assessed based on the economic value of agricultural yield supported by this water. This calculation involves estimating the total volume of water withdrawn for agricultural purposes and multiplying it by regional water market rates. <u>Food provision through fishing</u> : Fishing is a provisioning service that directly benefits the local community, even though it is primarily for private use. The economic value of fishing will be estimated by assessing the quantity of fish caught for personal consumption and calculating the equivalent market value of this

		catch. This approach provides an estimate of the river's food provision role in supporting community sustenance.
Ec-3	<b>Economic Mitigation of Natural Disasters per Area</b>	Given the Morava River's natural flood-buffering ability, especially highlighted during the 2006 flood events, the Avoided Cost Method will be used. By estimating the potential damage costs to infrastructure, agricultural lands, and homes during flood events without the river's natural buffer, the economic savings from flood mitigation can be quantified. Historical flood impact data and restoration costs post-2006 will serve as baselines for this analysis.
Ec-4	<b>Value of Water Purification Services</b>	The river provides natural filtration, maintaining water quality for agricultural use. To value this service, the Replacement Cost method will estimate the expense of artificial water filtration systems needed to achieve similar water quality for crop irrigation. Water quality data from the local water authority will help establish baseline filtration benefits. It would be necessary to identify which organisations are responsible for supplying water to the region, as these appear to be public entities operating at a regional level. Their involvement would be crucial in validating data and ensuring an accurate assessment of the river's contribution to local water supply systems.
Ec-5	<b>Carbon Sequestration Value</b>	The Morava River's floodplains, aquatic vegetation, and riparian zones act as natural carbon sinks, absorbing CO <sub>2</sub> through photosynthesis and trapping organic carbon in sediments. The social cost of carbon will be applied to the estimated amount of CO <sub>2</sub> sequestered by the ecosystem annually. This calculation will be based on vegetation cover, sediment carbon content, and local carbon sequestration rates.
Ec-6	<b>Cultural and Recreational Value</b>	The river provides substantial recreational value through activities like fishing, hunting, and hiking. The Travel Cost Method will estimate the economic impact of these activities by assessing visitor spending related to travel, accommodations, and associated recreational expenses. Surveys capturing visitor numbers, their spending patterns, and overall satisfaction will be essential in valuing this indicator accurately.
Ec-7	<b>Biodiversity Support Value</b>	The river supports diverse flora and fauna, including species in riparian and floodplain ecosystems. A Contingent Valuation Method could assess the community's willingness to pay for biodiversity conservation, reflecting the value of biodiversity for local residents. Additionally, biodiversity indices based on species counts and conservation statuses could provide a tangible metric for this indicator.
Ec-8	<b>Nutrient Cycling Value</b>	The Replacement Cost Method could estimate the cost of artificial nutrient cycling or fertilisation required to match the natural cycling benefits provided by the river and floodplains. Data on nutrient levels in the soil and water could be collected and monitored to assess the effectiveness of natural nutrient retention.
Ec-9	<b>Health and Well-being Value</b>	The Contingent Valuation Method could survey visitors and local residents regarding their perceived health benefits from access to the river's green spaces, as well as their willingness to pay for the preservation of these areas. This indicator could also be supported by public health statistics related to outdoor activities and their impact on local healthcare costs.
<b>OL #3 Finland – Ylpässuo, Kiruvesi (UEF, UOULU)</b>		
<b>Economic Indicator</b>		<b>Description</b>

Ec-1	<b>Cost of Restoration and Maintenance per Area</b>	Given the protected status and remote location of OL #3, costs for maintaining this ecosystem will not be documented.
Ec-2	<b>Direct Market Valuation</b>	Given OL #3's protected status and lack of direct food provisioning services (e.g., fishing or agriculture), this indicator does not apply.
Ec-3	<b>Economic Mitigation of Natural Disasters per Area</b>	Although flood risk mitigation is more relevant to local communities and has less direct economic impact due to OL #3's remote location, it does provide flood buffering benefits during heavy rain events. The Avoided Cost method could estimate the value of this service by assessing how the mire's buffering reduces the potential for overflow and downstream flooding. While the economic impact may be limited, this assessment will help quantify the value of wetland flood buffering within the broader watershed.
Ec-4	<b>Value of Water Purification Services</b>	Water extraction is prohibited in OL #3.
Ec-5	<b>Carbon Sequestration Value</b>	Ylpässuo Open Lab, as a mire, captures substantial carbon levels in its soil layers, with estimates ranging from 63 to 121 tonnes of carbon per hectare, depending on soil age. Using the social cost of carbon, this indicator will calculate the economic value of carbon sequestration, multiplied by the annual carbon capture rate per hectare. Data on carbon content from mire soil studies will support this valuation.
Ec-6	<b>Cultural and Recreational Value</b>	The Ylpässuo Open Lab could offer significant educational value, particularly in studying wetland roles in climate change mitigation. The Travel Cost Method could evaluate this by assessing spending related to educational visits by research groups, universities, and student field trips. While tourism is limited by the site's remote location, expenses related to educational access, equipment, and travel for scientific studies could provide an indirect valuation of its educational contribution.
Ec-7	<b>Biodiversity Support Value</b>	The Contingent Valuation Method could be used to assess the willingness of research institutions and the Finnish public to pay for the preservation of this biodiversity-rich site. Additionally, the costs associated with biodiversity conservation efforts, including habitat protection and species monitoring, could be documented.
Ec-8	<b>Nutrient Cycling Value</b>	Using the Replacement Cost Method, the valuation could estimate the cost of artificially maintaining nutrient levels that the mire naturally sustains. Soil nutrient data and mire vegetation health could be monitored to establish nutrient cycling efficiency.
Ec-9	<b>Health and Well-being Value</b>	Although OL #3's remote location limits direct recreational use, its educational role indirectly supports mental and physical well-being through knowledge advancement in wetland restoration and climate change research. The Contingent Valuation Method could survey the Finnish public and academic institutions regarding the perceived health and educational benefits of preserving natural wetlands, providing a qualitative measure of well-being value associated with OL #3.
<b>OL #4 Estonia – Ess-soo (UT)</b>		
<b>Economic Indicator</b>		<b>Description</b>

Ec-1	<b>Cost of Restoration and Maintenance per Area</b>	Restoration efforts are crucial for achieving the full carbon storage potential of the bog. This indicator could track the costs associated with soil rehabilitation, water table management, and Sphagnum cultivation. Budget records from ongoing restoration activities could provide data, allowing for a cost-benefit comparison between restoration expenses and the economic value of services such as carbon sequestration and sustainable timber production.
Ec-2	<b>Direct Market Valuation</b>	<u>Provision through berry harvesting:</u> The Ess-soo bog is known for its seasonal abundance of berries, which are locally gathered for personal consumption. This indicator will use local market prices for similar wild berries to estimate the economic value of berry harvesting. Seasonal berry yield data will be collected to assess the area's annual food production potential. <u>Biomass provision and potential timber use:</u> Despite historical over-extraction of wood for the pulp and paper industry, OL #4 presents an opportunity to implement a business model for the sustainable use of timber resources. This indicator could quantify the economic value of sustainably harvested timber by calculating revenue from sales under a controlled, eco-friendly model. Additionally, if feasible, the volume and market value of sustainably harvested biomass could be tracked annually to assess revenue potential.
Ec-3	<b>Economic Mitigation of Natural Disasters per Area</b>	Although this indicator is less directly applicable due to the bog's distance from densely populated areas, the restored bog may still provide flood buffering in heavy rain events. The Avoided Cost Method could be applied, using data on flood prevention in bog ecosystems to estimate potential disaster mitigation savings in surrounding agricultural or low-lying areas.
Ec-4	<b>Value of Water Purification Services</b>	The bog's capacity for water purification remains limited due to past degradation, making it unfeasible to measure this economic indicator at present.
Ec-5	<b>Carbon Sequestration Value</b>	Like other OLs, Ess-soo bog, when fully restored, will serve as an important carbon sink. The social cost of carbon will be used to determine the economic value of the stored carbon, based on annual carbon capture rates in the peat and soil. Carbon storage estimates from peatland restoration data will support the valuation
Ec-6	<b>Cultural and Recreational Value</b>	Local residents have a strong connection to Ess-soo bog, engaging in berry picking and hiking activities. The Travel Cost Method could evaluate the economic impact of these recreational activities by surveying participants' travel expenses and time investment. Surveying residents for qualitative feedback on their recreational experiences will also provide insights into the cultural value of the bog.
Ec-7	<b>Biodiversity Support Value</b>	Ess-soo bog is a valuable habitat for various species, particularly in the restored areas with Sphagnum cultivation. The Contingent Valuation Method could assess public willingness to pay for biodiversity preservation in the bog. Additionally, biodiversity monitoring data for species richness and abundance could provide a quantitative measure of the site's biodiversity support.
Ec-8	<b>Nutrient Cycling Value</b>	Nutrient cycling in the bog helps sustain soil health, benefiting surrounding habitats and supporting biomass production. Using the Replacement Cost Method, this indicator could estimate the expense of artificial nutrient cycling or fertilisation needed to match the natural cycling benefits provided by the bog. Soil

		nutrient data and vegetation health could be regularly monitored to assess nutrient cycling efficiency.
Ec-9	Health and Well-being Value	Ess-soo Bog's aesthetic and recreational value has a positive effect on local mental and physical well-being, as residents engage with nature through berry picking, hiking, and observing scenic landscapes. The Contingent Valuation Method could assess public willingness to pay for access to these recreational activities. Public health benefits, such as reduced stress levels and increased outdoor activity, could be gathered through visitor surveys to further quantify this value.
<b>OL #5 Belgium – River Bêche (WI-EA, STROMING)</b>		
<b>Economic Indicator</b>		<b>Description</b>
Ec-1	Cost of Restoration and Maintenance per Area	Restoration expenses will cover hydrological rehabilitation and habitat recovery, with data derived from site management budgets. Annual comparisons of restoration costs to the benefits of improved water retention and carbon storage can support a cost-benefit analysis.
Ec-2	Direct Market Valuation	As restoration progresses, the expansion of small water bodies is expected to provide limited water resources for local use, which can be valued based on estimated demand and local water pricing. This improved water availability also has the potential to enhance agricultural productivity in adjacent areas by supporting irrigation and maintaining soil moisture. The economic value of these benefits can be assessed by tracking annual agricultural output and local crop market prices, providing insights into how the restored ecosystem supports local farming practices while contributing to broader economic development through water supply and increased agricultural yields.
Ec-3	Economic Mitigation of Natural Disasters per Area	Flood mitigation is one of the main anticipated benefits, as the area has significant potential for natural water retention. The Avoided Cost method could be used to calculate savings from flood prevention, estimating the economic value of reduced infrastructure damage, lower emergency response costs, and protection of agricultural land. By comparing discharge rates between the restored Emmels and Meyeroderbach valleys, this indicator could reflect the mitigation benefits gained from restoration.
Ec-4	Value of Water Purification Services	As water bodies within the restored area expand and interconnect, they will contribute to water purification through natural filtration processes. The Replacement Cost method could estimate the expense of artificial water treatment systems that would provide similar results, using data from local water authorities on required water quality standards for agricultural or recreational use.
Ec-5	Carbon Sequestration Value	The restored Emmels Valley will function as a carbon sink in the long term, storing carbon in its soil and vegetation. Using the social cost of carbon, this indicator will value the economic benefit of the site's carbon retention. Estimates of carbon capture rates for the valley's restored ecosystems will be used to calculate annual sequestration value.
Ec-6	Cultural and Recreational Value	Currently limited to casual hiking due to the degraded landscape, OL #5 has substantial potential for expanded recreational use once restoration is complete. The Travel Cost

		Method could assess the economic value of anticipated recreational activities, such as hiking, nature observation, and eco-tourism. Surveys and visitor logs could be used to evaluate spending patterns related to travel, accommodation, and recreational activities, projecting future benefits as the site becomes more accessible and appealing.
Ec-7	<b>Biodiversity Support Value</b>	The Contingent Valuation Method could be applied to survey the public's willingness to pay for biodiversity preservation, while biodiversity metrics, including species abundance and richness, could be used to provide quantitative support for this indicator.
Ec-8	<b>Nutrient Cycling Value</b>	Using the Replacement Cost Method, this indicator could estimate the expense of artificial nutrient cycling if it were needed to achieve similar results. Data on soil and water nutrient levels could be collected and monitored to assess the effectiveness of natural nutrient cycling.
Ec-9	<b>Health and Well-being Value</b>	The aesthetic and recreational potential of a restored Emmels Valley has implications for mental and physical health, particularly as outdoor recreational opportunities expand. The Contingent Valuation Method could assess the public's willingness to pay for access to these green spaces, and surveys will gather qualitative data on perceived well-being benefits. This indicator could provide insight into the health benefits derived from interacting with natural environments, such as stress reduction and increased physical activity.
<b>OL #6 Italy – Gussola oxbow lake, Po Grande (UniPR, ADBPO)</b>		
<b>Economic Indicator</b>		<b>Description</b>
Ec-1	<b>Cost of Restoration and Maintenance per Area</b>	Restoration activities include embankment adjustments and soil retention improvements to enhance flood mitigation and support carbon sequestration. Tracking restoration and maintenance costs over time can provide a basis for comparing these expenses against economic benefits gained from flood protection and carbon retention. Cost data from <b>AdbPo</b> 's management budgets could be used for long-term cost-benefit analysis.
Ec-2	<b>Direct Market Valuation</b>	<u>Poplar cultivation for FSC-certified timber production:</u> The Gussola area supports sustainable poplar growth, which contributes directly to the local economy by supplying high-quality timber for particleboard production. The market value of FSC-certified poplar could be calculated based on timber prices and annual yield. Sales records and market data from poplar producers in the region could be used to assess this indicator's economic impact, capturing revenue from timber as a direct market service.
Ec-3	<b>Economic Mitigation of Natural Disasters per Area</b>	The oxbow lake's impermeable soil and water retention capacity reduce the severity of flooding in nearby agricultural lands and residential areas. The Avoided Cost Method will calculate savings related to flood protection by estimating potential damage costs averted due to enhanced water retention and flood buffering. Historical flood damage data and restoration impacts, including embankment adjustments, will be used to quantify economic benefits from flood risk mitigation.
Ec-4	<b>Value of Water Purification Services</b>	As the lake and floodplain ecosystems recover, they provide water purification services by filtering pollutants and supporting cleaner water for downstream agricultural use. The Replacement Cost Method will estimate the expense of artificial water treatment systems that would provide similar results. Water quality data from local authorities before and after

		restoration will serve as baselines for calculating purification benefits.
Ec-5	<b>Carbon Sequestration Value</b>	Restoration of Gussola's oxbow lake and floodplains contributes to long-term carbon storage in the soil and vegetation, mitigating greenhouse gas emissions. UniPR's ongoing research on soil carbon content will provide data on carbon retention levels, while the social cost of carbon will be used to value annual carbon sequestration. This methodology highlights the oxbow lake's economic contribution to climate change mitigation.
Ec-6	<b>Cultural and Recreational Value</b>	Restoration has improved the area's attractiveness for recreational fishing, hunting, and nature observation, enhancing its economic value as a recreational destination. The Travel Cost Method will assess this indicator by evaluating spending patterns from local and visiting anglers, hunters, and tourists. Surveys will capture data on recreational spending, as well as perceptions of improved ecosystem quality.
Ec-7	<b>Biodiversity Support Value</b>	The Gussola area supports biodiversity by providing habitat for various plant and animal species, including species valuable for recreation and hunting. The Contingent Valuation Method could gauge public willingness to pay for biodiversity conservation. Additionally, species diversity and abundance metrics will quantify this indicator, providing insights into the area's biodiversity support value.
Ec-8	<b>Nutrient Cycling Value</b>	Nutrient cycling in the oxbow lake ecosystem enhances soil and water quality, benefiting agricultural lands in the surrounding floodplain. The Replacement Cost Method could estimate the expense of artificial nutrient cycling, comparing these costs with the natural cycling benefits provided by the lake's ecosystem. Data on soil and water nutrient levels could be collected to assess cycling efficiency.
Ec-9	<b>Health and Well-being Value</b>	The Gussola area provides educational benefits for students, researchers, and local residents who use the lake for recreation and learning. The Contingent Valuation Method could assess local and visitor willingness to pay for access to these green spaces. Additionally, surveys could capture qualitative data on perceived well-being, reduced stress levels, and educational impacts, which reflect the site's health and mental well-being value.
<b>OL #7 Portugal – Paul da Gouxa (UEVORA, CMA)</b>		
<b>Economic Indicator</b>		<b>Description</b>
Ec-1	<b>Cost of Restoration and Maintenance per Area</b>	Restoration actions could focus on reconnecting the wetland with the Tagus River and other local water sources, enhancing water availability and supporting carbon storage. Restoration and maintenance costs will be tracked over time, and these figures will be compared against the economic benefits derived from enhanced water supply, carbon retention, and reed production. Cost data could be sourced from project budgets to support a cost-benefit analysis.
Ec-2	<b>Direct Market Valuation</b>	The site supports <u>reed production</u> as part of paludiculture practices, benefiting local agriculture and tourism ventures, such as those conducted by Quinta da Atela vineyard. Direct market valuation will calculate the economic contribution of these services by assessing annual reed yield and revenue from tourism-related activities. Market prices for common reed, combined with sales data from guided tours and wine production, will establish an economic baseline for this indicator.

		On the other hand, the park's influence on surrounding agricultural activities supports <u>vineyard and crop growth</u> at Quinta da Atela. This value will be assessed by evaluating crop yield improvements due to ecosystem benefits, such as enhanced water availability and improved soil quality. The market prices for wine and other agricultural products will be applied to quantify this service, tracking annual productivity increases.
Ec-3	<b>Economic Mitigation of Natural Disasters per Area</b>	The wetland's capacity for water retention and carbon storage can play a role in reducing the impact of extreme weather events, helping mitigate flood risks and stabilise carbon levels. Using the Avoided Cost method, this indicator could quantify the value of reduced flood damage and lower GHG emissions. Local flood damage records and estimates of CO <sub>2</sub> sequestration potential could be employed to assess the cost savings associated with these ecosystem functions.
Ec-4	<b>Value of Water Purification Services</b>	As restoration reconnects the wetland with nearby rivers, the park's natural filtration system improves water quality downstream. The Replacement Cost Method could estimate the expense of artificial water treatment systems required to achieve similar water quality levels. Water quality data from local sources could provide a baseline for valuing purification benefits.
Ec-5	<b>Carbon Sequestration Value</b>	The park's freshwater marsh and peatland are significant carbon sinks, with carbon stored in soil, vegetation, and riparian forests. This indicator will use the social cost of carbon to value the park's sequestration capacity.
Ec-6	<b>Cultural and Recreational Value</b>	The site attracts visitors for outdoor activities and offers educational programmes that foster environmental awareness. The Travel Cost Method will estimate the economic impact of these activities by capturing visitor spending on travel, accommodations, and local services. Visitor surveys will gather data on spending patterns and the perceived recreational and educational value of the park.
Ec-7	<b>Biodiversity Support Value</b>	As home to the largest population of the endemic Sorraia horse, Paúl da Gouxa plays a critical role in species conservation. The Contingent Valuation Method could be used to gauge the public's willingness to pay for biodiversity preservation, particularly for the Sorraia horse and local flora and fauna. Data on species abundance, along with survey results, could provide a quantitative measure of biodiversity value.
Ec-8	<b>Nutrient Cycling Value</b>	Nutrient cycling supports soil fertility and water quality in the surrounding agricultural and wetland areas. The Replacement Cost Method could estimate the cost of artificial nutrient cycling systems if needed to match the natural cycling benefits of the wetland. Soil and water nutrient levels could be monitored to assess the park's nutrient cycling efficiency, contributing to sustained agricultural productivity and ecosystem health.
Ec-9	<b>Health and Well-being Value</b>	The park's accessible trails and scenic landscapes enhance well-being for local residents and visitors. The Contingent Valuation Method could capture the public's willingness to pay for access to green spaces, alongside surveys to collect qualitative data on perceived health benefits. This indicator could reflect the mental health and stress reduction benefits associated with nature-based recreational activities.

### 3.3. SOCIAL INDICATORS

The assessment of social impacts in projects has gained significant importance in recent years, emerging as a vital component of sustainability evaluations. This growing emphasis can be attributed to the increasing recognition of extended life cycle assessments for products and processes, which have traditionally focused predominantly on environmental and economic impacts<sup>48</sup>.

#### 3.3.1. Identification of social sustainability indicators

The indicators listed below assess the social value of wetlands within communities, capturing various dimensions of social wellbeing, engagement, and community benefits linked to wetland ecosystems. To ensure these social indicators are effective, they should align with one or more of the **17 Sustainable Development Goals (SDGs)** established by the United Nations<sup>40</sup>.

By considering the ecosystem services of wetlands in the context of the SDGs, the following indicators are provided:

S-1: Cultural visitors per area (n <sup>o</sup> cultural_visitors / m <sup>2</sup> )	
<b>Purpose</b>	To measure the level of public engagement with wetland areas for cultural and educational purposes, helping to assess the social value of wetlands as community resources.
<b>Justification</b>	Public engagement through cultural visits raises awareness and fosters community support for wetland conservation, essential for long-term sustainability (SDG 4: Quality Education, SDG 15: Life on Land) <sup>40,49</sup> .
<b>Methodology</b>	Track the number of organised cultural and educational visits, including school programs, guided tours, and workshops. Data from visitor logs and event attendance records provide quantitative insights, while surveys can capture visitor satisfaction and learning outcomes.

S-2: Number of education actions related to wetlands (n <sup>o</sup> education_actions)	
<b>Purpose</b>	To quantify the educational initiatives aimed at raising awareness of wetland conservation.
<b>Justification</b>	Environmental education is crucial for fostering sustainable attitudes and behaviours in the community, particularly among younger populations (SDG 4: Quality Education, SDG 13: Climate Action) <sup>40,50</sup> .
<b>Methodology</b>	Record educational events and programmes related to wetlands, noting their reach, target audience, and content. Surveys or interviews can assess the effectiveness of these programmes in terms of knowledge gained and behavioural change.

S-3: Number of sport visitors per area ( $n^{\circ}_{\text{sport\_visitors}} / \text{m}^2$ )	
Purpose	To ensure access to wetlands for recreational activities, indicating their role in promoting physical health within the community.
Justification	Access to natural recreational spaces can enhance physical and mental health, supporting community wellbeing (SDG 3: Good Health and Wellbeing) <sup>40,51</sup> .
Methodology	Measure the density of sports visitors through visitor logs or digital tracking tools (e.g., GPS) and evaluate the accessibility and quality of sports facilities within the wetland.

S-4: Employees directly displaced by restoration per area ( $n^{\circ}_{\text{emp\_destr}} / \text{m}^2$ )	
Purpose	Assesses the economic and social costs of restoration by counting job losses directly related to the restoration project.
Justification	Understanding the impact of job losses in specific sectors helps plan for retraining programmes and mitigate negative social impacts (SDG 8: Decent Work and Economic Growth) <sup>40,38</sup> .
Methodology	Identify and categorise job losses by sector and region, focusing on industries adversely affected by the restoration. Interviews with affected workers can provide qualitative insights into the broader social impact.

S-5: Employees directly created by restoration per area ( $n^{\circ}_{\text{emp\_created}} / \text{m}^2$ )	
Purpose	Measures job creation stemming from restoration activities.
Justification	Restoration can create new employment in sectors like conservation and tourism, benefitting local economies (SDG 8: Decent Work and Economic Growth) <sup>40,52</sup> .
Methodology	Track the number of new jobs created in restoration-related sectors. Use surveys to measure job satisfaction and local hiring rates for these positions.

S-6: Aesthetic value ( $A_{\text{value}}$ )	
Purpose	Evaluates the perceived beauty and cultural significance of wetland areas.
Justification	Aesthetically valuable landscapes contribute to local identity and attract visitors, promoting conservation (SDG 11: Sustainable Cities and Communities, SDG 15: Life on Land) <sup>40,53</sup> .
Methodology	In developing <b>Task 2.5</b> , specific questions will gather essential data to calculate a value that captures the aesthetic essence of the environment under consideration. This process will involve public surveys to assess aesthetic perceptions, allowing the indicator to reflect both qualitative descriptions and the landscape's cultural or historical significance.

S-7: Community natural site ownership	
<b>Purpose</b>	Measures the sense of ownership and emotional connection that community members feel toward their local wetlands.
<b>Justification</b>	A strong sense of attachment fosters stewardship and supports sustainable conservation practices (SDG 11: Sustainable Cities and Communities) <sup>40,54</sup> .
<b>Methodology</b>	To determine this metric within <b>Task 2.5</b> , specific questions have been designed to collect data that quantifies the community's connection to the environment by assessing levels of attachment through targeted surveys. These surveys aim to explore correlations between attachment levels and community involvement in conservation initiatives, providing a comprehensive view of environmental engagement.

S-8: Social cohesion and community engagement in wetland activities	
<b>Purpose</b>	Measures the level of social interaction and community engagement facilitated by wetland-related activities.
<b>Justification</b>	Wetland activities foster social cohesion, helping strengthen community ties and build a shared sense of responsibility for conservation (SDG 11: Sustainable Cities and Communities) <sup>40,55</sup> .
<b>Methodology</b>	Assess participation rates in community wetland activities (e.g., clean-up days, tree planting) and evaluate feedback from participants. Survey data can also capture the perceived impact on social bonds and community trust.

S-9: Perceived health benefits from wetland access	
<b>Purpose</b>	Captures the community's perception of health benefits gained from accessing and using wetland areas.
<b>Justification</b>	Studies show that green spaces enhance physical and mental health, reducing healthcare costs and promoting wellbeing (SDG 3: Good Health and Wellbeing) <sup>40,56</sup> .
<b>Methodology</b>	Conduct surveys to capture self-reported health benefits from wetland access, such as reductions in stress or improvements in fitness. Combine with visitor counts to identify any correlation between frequency of access and perceived health benefits.



S-10: Local environmental knowledge level	
<b>Purpose</b>	Measures the level of local environmental knowledge regarding wetlands and their ecological functions.
<b>Justification</b>	Enhanced environmental literacy supports informed decision-making and conservation efforts within communities (SDG 4: Quality Education) <sup>40,57</sup> .
<b>Methodology</b>	Conduct pre- and post-assessment surveys among community members involved in educational programmes or activities related to wetlands.

S-11: Perceived safety of wetland areas	
<b>Purpose</b>	Assesses community perceptions of safety within wetland environments, which can affect accessibility and willingness to visit.
<b>Justification</b>	Safety concerns can limit engagement with natural areas, impacting the physical and mental health benefits these spaces offer (SDG 16: Peace, Justice, and Strong Institutions) <sup>40,58</sup> .
<b>Methodology</b>	Conduct surveys to gather perceptions of safety among visitors and local residents. Track reported incidents, if any, and use the data to improve security measures in the wetland area.

### 3.3.2. Preliminary analysis of social sustainability indicators

A summary of the selected social indicators for each Open Lab can be found in Table 3. Efforts will be made to measure as many of these social indicators as possible throughout the execution of **Task 2.5 Developing a social monitor to track the acceptance of REWET activities**.

Colour legend:

- **In green:** Feasible. The indicator can be measured effectively.
- **In yellow:** Partially feasible. Measurement is limited due to factors like low visitor numbers, restricted resources, or infrastructure constraints, potentially impacting data representativeness.
- **In red:** Not feasible. Measurement of the indicator is not practical in the Open Lab due to a lack of interest, relevance, or difficulty in implementing evaluation methods.



Table 3. Preliminary analysis of social sustainability indicators.

Social Indicator		Description	OL #1	OL #2	OL #3	OL #4	OL #5	OL #6	OL #7
S-1	Cultural visitors per area	Count of cultural visitors through surveys and observations at key events.			Limited access	Low visitor count			
S-2	Educational actions related to wetlands	Record of educational activities, such as workshops and guided visits.			Not educational but research activities				
S-3	Number of sport visitors per area	Count of visitors participating in sports activities using event records and observation.			Low sports participation				
S-4	Employees displaced by restoration per area	Track jobs lost due to restoration via interviews and employment data.			Limited impact				
S-5	Employees created by restoration per area	Documentation of new jobs created by restoration in ecotourism and conservation.							
S-6	Aesthetic value	Assessment of aesthetic value through visitor and local resident surveys during Task 2.5 execution.							
S-7	Community natural site ownership	Evaluation of community sense of ownership via perception surveys during Task 2.5 execution.			Protected area		Limited community interest		
S-8	Social cohesion and community engagement in wetland activities	Measurement of community participation in conservation activities.							
S-9	Perceived health benefits from wetland access	Surveys to assess perceived physical and mental health benefits from wetland access.							
S-10	Local environmental knowledge level	Assessment of environmental knowledge through questionnaires and pre/post-activity surveys.							
S-11	Perceived safety of wetlands area	Surveys on perceived safety of wetlands, particularly regarding natural hazards. Still to be decided whether it will be carried out or not.							

## 4. SUSTAINABILITY INDEX: MATTER-ELEMENT EXTENSION METHOD

One of the primary objectives of this project is to evaluate the sustainability of the restorative initiatives within REWET, considering a wide range of diverse indicators outlined in Section 3. Each of these indicators assesses different aspects of environmental, economic, and social impact. The challenge, however, lies in **translating these complex assessments into a format that is accessible and understandable to the general public**, rather than being confined to expert audiences. Achieving this will also support governance bodies in making well-informed decisions regarding restoration efforts.

Our primary objective, therefore, is to accurately assess and deliver the sustainability index of the project. In order to accomplish this, we have chosen the **Matter-Element Extension Method as our principal methodology for determining the sustainability index**.



Figure 1. Simplified scheme of sustainability index objective.

This approach has been successfully employed in the past to calculate a variety of indices for numerous purposes, including the assessment of sustainability indices for several projects<sup>59,60,61</sup>.

The methodology follows a sequence of steps (as illustrated in Figure 2) to derive the final index, which, in this instance, provides a **definitive numerical representation of the project's sustainability level**. Consequently, **the final index value serves as an indicator of the project's degree of sustainability**.

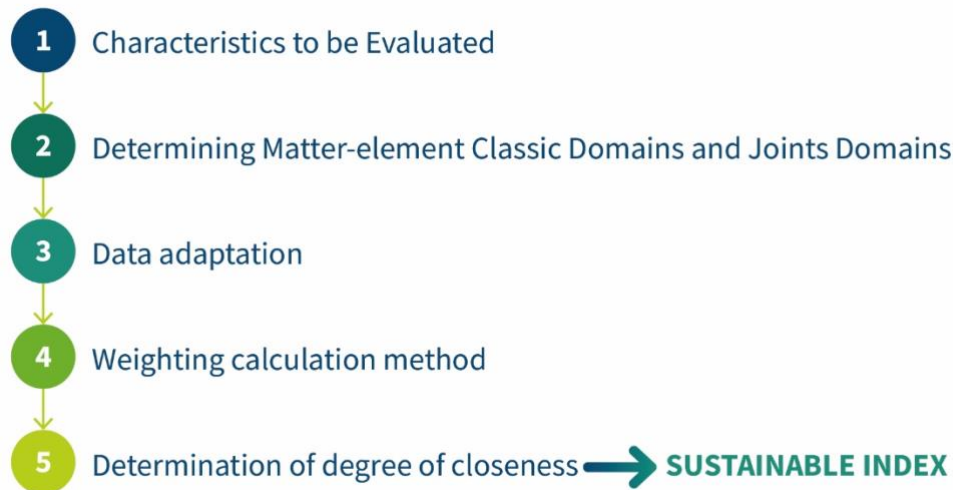


Figure 2. Matter-Element Extension Method simplified scheme.

#### 4.1. CHARACTERISTIC TO BE EVALUATED

The first step of the methodology involves establishing the characteristics to be evaluated, which, within the matter-element theory, are referred to as indices. These indices can be categorised into various groups such as mechanical properties, economic impacts, etc. **In our case, the categories will be environmental, social, and economic.** The indices under consideration have been explained in Sections 2 and 3.

#### 4.2. DETERMINING MATTER-ELEMENT CLASSIC DOMAINS AND JOINTS DOMAINS

In matter-element theory, there are three types of matter-elements: the joint domain, the classical domain, and the evaluation object. The last one is associated with the measurements obtained from the project. Therefore, **the focus of this section will be on the first two elements: the joint domain and the classical domain.**

##### 4.2.1. Joint domain

The joint domain establishes the maximum and minimum values of the indices under consideration, creating a matrix that encompasses all these values. The mathematical definition is as follows:

$$R_p = (N, C_i, V_{pi}) = \begin{bmatrix} N & C_1 & (a_{p1}, b_{p1}) \\ & C_2 & (a_{p2}, b_{p2}) \\ & \cdot & \cdot \\ & \cdot & \cdot \\ & \cdot & \cdot \\ & C_n & (a_{pn}, b_{pn}) \end{bmatrix}, (i = 1, 2, \dots, n) \quad (4)$$

Equation (4),  $R_p$  represents the defined joint domain matrix.  $N$  denotes the set of objects across all levels,  $C_n$  signifies the characteristic index under consideration, with  $n$  indicating the total number of indices being considered. Here,  $a_{pn}$  is the minimum value of index  $n$ , and  $b_{pn}$  is the maximum value of index  $n$ .

It is important to note that these values do not necessarily require uniform units or to be quantitative in nature. Qualitative units, such as "yes", "no", "good", "bad", and so on, are also acceptable.

#### 4.2.2. Classical domain

The classical domain divides the joint domain into a series of levels defined as follows:

$$R_j = (N_j, C_i, V_{ji}) = \begin{bmatrix} N_j & C_1 & (a_{j1}, b_{j1}) \\ & C_2 & (a_{j2}, b_{j2}) \\ & \vdots & \vdots \\ & \vdots & \vdots \\ & C_n & (a_{jn}, b_{jn}) \end{bmatrix}, (i = 1, 2, \dots, n) \quad (5)$$

In Equation (5),  $R_j$  represents the classical domain at the level denoted by  $j$ . The set of objects within this specific level is represented by  $N_j$ . Meanwhile,  $C_n$  refers to the characteristic index under examination, with  $n$  representing the total number of indices being considered.

Within this framework,  $a_{jn}$  is defined as the minimum value of the index  $n$  at the level  $j$ , and  $b_{jn}$  represents the maximum value of index  $n$  at the same level. Each  $C_n$ , has a division that is unique to it.

The number of divisions is not fixed and typically varies based on the desired segmentation rather than any strict criteria. It is crucial to recognise that increasing the number of divisions not only introduces more complexity but also amplifies the effort required to define these levels. However, this additional work is counterbalanced by a gain in accuracy. Conversely, reducing the number of levels will diminish the precision but also decrease the effort needed to define them.

Once the classical domain ( $R_j$ ) is established, it is normalised (Equation (6)) using the joint domain ( $R_p$ ). **This normalisation, ranging from 0 to 1, must ensure that 1 represents the optimal result and 0 the least favourable.** To achieve this, Equations (7) and (8) are employed.

$$R_j = (N_j, C_i, V_{ji}) = \begin{bmatrix} N_j & C_1 & (a_{j1}, b_{j1}) \\ & C_2 & (a_{j2}, b_{j2}) \\ & \vdots & \vdots \\ & \vdots & \vdots \\ & C_n & (a_{jn}, b_{jn}) \end{bmatrix}, (i = 1, 2, \dots, n), 0 \leq (a_{jn}, b_{jn}) \leq 1 \quad (6)$$

$$z_{ij} = \frac{y_{ij} - y_{\min}}{y_{\max} - y_{\min}} \quad (7)$$

$$z_{ij} = \frac{y_{\max} - y_i}{y_{\max} - y_{\min}} \quad (8)$$

Equation (7) is used when a higher value of  $C_n$  indicates a better result, whereas Equation (8) is applied when a lower value of  $C_n$  signifies a more favourable outcome. The term  $y_{ij}$  represents the value being evaluated, while  $y_{\min}$  and  $y_{\max}$  are the minimum and maximum values defined within the joint domain ( $R_p$ ), respectively.

### 4.3. DATA ADAPTATION

With the definition of the classical and joint domains established, it is now time to measure the current values of the index  $C_n$  as defined in the system under study. The mathematical definition of the value matrix is as follows:

$$R_p = (N_p, C_i, V_i) = \begin{bmatrix} N_p & C_1 & V_1 \\ & C_2 & V_2 \\ & \cdot & \cdot \\ & \cdot & \cdot \\ & C_n & V_n \end{bmatrix}, (i = 1, 2, \dots, n), 0 \leq V_n \leq 1 \quad (9)$$

Here,  $N_p$  represents the index set, and  $V_n$  is the current value of the index  $C_n$ .

Concurrently, the measured values must be normalised using the methodology outlined in Equations (7) and (8), with the joint domain once again serving as the reference values.

### 4.4. WEIGHTING CALCULATION METHOD

Following the methodology of matter-element extension evaluation, the next step is to precisely establish the weight of each index. The methods for determining these weights can be classified into two types: subjective and objective.

Subjective weighting methods rely on the knowledge, experience, and preferences of decision-makers (such as experts, politicians, and the public). In contrast, objective weights are derived from empirical data with a solid mathematical foundation.

#### 4.4.1. Subjective weight design

The subjective weight will be determined based on the outcomes of a series of questionnaires that will pose questions to various stakeholders, such as politicians, conservation experts, and the general public, about the importance of each index being studied.

Once the questionnaire results have been compiled, the weight is calculated as follow:



$$w_t^i = \sum_{e=1}^x w_e^i \quad (10)$$

$$w_s^i = \frac{w_t^i}{\sum_{i=1}^n w_t^i} \quad (11)$$

Being  $w_e^i$  the answer of respondent  $e$  regarding the index  $i$ ;  $w_t^i$  represents the sum of responses from all respondents for index  $i$ ;  $w_s^i$  is the final weight of the index  $i$ , where the subscript  $s$  indicates a subjective weight.

#### 4.4.2. Objective weight design: Entropy method

Entropy serves as a measure of a system's disorder, assessing the quantity of valuable information each index contains. **The more useful the information an index conveys, the greater the entropy weight assigned to that index.** Conversely, a reduction in the utility of the information leads to a lower entropy weight<sup>62</sup>. This methodology has been extensively employed in a variety of contexts, including the assessment of water quality<sup>63</sup> and the evaluation of safety in underground gas storage<sup>59</sup>.

The calculation of entropy values proceeds as follows:

$$f_{ij} = \frac{z_{ij}}{\sum_{j=1}^n z_{ij}} \quad (12)$$

$$H_i = - \left( \frac{\sum_{j=1}^n f_{ij} \cdot \ln f_{ij}}{\ln n} \right) \quad (13)$$

Being  $z_{ij}$  the dimensionless value of index  $i$  at time  $j$ .  $H_i$  represents the entropy value.

The formula for the final weight calculation is as follows:

$$w_o^i = \frac{1 - H_i}{m - \sum_{i=1}^m H_i} \quad (14)$$

Being  $w_o^i$  the final objective weight of index  $i$ , with  $m$  representing the total number of indices.

#### 4.4.3. Combination weighting method.

There are various alternative methods for combining weights<sup>64</sup>. For this particular case, a fundamental methodology will be employed that assigns **equal importance to both objective and subjective weights**. The calculation is as follows:

$$w^i = \frac{w_s^i \cdot w_o^i}{\sum_{i=1}^n w_s^i \cdot w_o^i} \quad (15)$$



#### 4.4.4. Different views weighting method

The evaluation will consider different stakeholder perspectives based on four main overviews: **egalitarian**, **governance**, **business**, and **society**, in relation to the three sustainability pillars: economy, environment, and social. The **business** perspective will focus on prioritizing economic gain, whereas the **society** perspective will place greater emphasis on environmental aspects. In contrast, the **egalitarian** overview will assign equal importance to all three pillars. Moreover, we will evaluate all combinations to check which option is the best, depending on the specific case.

### 4.5. DETERMINATION OF DEGREE OF CLOSENESS

In this final step, the focus is on measuring the degree of proximity between the values obtained for each index and the various levels defined within the classical domains.

Initially, the distance between the classical domain and the measured values is calculated:

$$D_j(v_i) = \left| v_i - \frac{a_{ij} + b_{ij}}{2} \right| - \frac{1}{2} \cdot (b_{ij} - a_{ij}) \quad (16)$$

Being  $D_i(v_i)$  the distance, where  $v_i$  is the measured value of index  $i$ ,  $b_{ij}$  is the maximum value, and  $a_{ij}$  is the minimum value of index  $i$  at level  $j$ .

Then, the degree of closeness is calculated as follows:

$$K_j(N_j) = 1 - \frac{1}{n \cdot (n + 1)} \cdot \sum_{i=1}^n D_j(v_i)w_i \quad (17)$$

Being  $K_j(N_j)$  the degree of closeness to the level  $j$ . Then, each  $K_j$  is normalised:

$$\overline{K}_j(N) = \frac{K_j(N) - \min K_j(N)}{\max K_j(N) - \min K_j(N)} \quad (18)$$

Finally, it becomes possible to calculate the  $j$  level of the measured values:

$$j^* = \frac{\sum_{j=1}^m j \cdot \overline{K}_j}{\sum_{j=1}^m \overline{K}_j} \quad (19)$$

Being  $m$  the total number of  $j$  levels, and  $j^*$  the level of the data obtained. The value of  $j^*$  may not necessarily be an integer and can include decimals. **These decimals signify a tendency towards a specific level:** if the decimal is greater than 0.5, there is an inclination towards the next higher level, and if the decimal is less than 0.5, the tendency is towards the next lower level.

## 5. CONCLUSIONS

The assessment framework for wetland restoration sustainability was developed, focusing on the three core pillars of sustainability: social, economic, and environmental. Relevant indicators were identified for each pillar to evaluate the impact of restoration activities comprehensively across various dimensions.

### **Environmental Sustainability Indicators:**

- Indicators such as wetland area, soil nutrient concentration, and greenhouse gas balance were selected to capture key aspects of environmental sustainability.
- Technological feasibility, including the use of remote sensing and monitoring of biodiversity indicators, is critical to ensure consistent data collection across Open Labs.
- Challenges were noted for some indicators due to limitations in equipment, funding, or expertise, but adjustments, such as relying on local authority data or historical records, were identified as potential solutions.

### **Economic Sustainability Indicators:**

- The economic indicators primarily focus on the potential economic benefits and impacts of wetland ecosystems, drawing insights from specialised literature and collaboration with stakeholders.
- These indicators consider both direct and indirect economic benefits, such as the direct economic valuation of water provided to the community or materials/food supplied, and indirect benefits like the money saved through risk mitigation.
- Feasibility varies based on local economic conditions and existing infrastructure around each Open Lab, which may influence the availability of economic data and participation from local businesses.

### **Social Sustainability Indicators:**

- A range of social indicators, such as cultural visitors, educational activities, social cohesion, and perceived health benefits, were selected to assess the social impact of the REWET project.
- Feasibility assessments revealed that some indicators, such as community engagement and environmental knowledge level, are applicable across most Open Labs, while others may face challenges due to limited resources or low visitor numbers.
- The recommended methods for gathering data on social indicators include surveys, event records, and direct observation, with feasibility varying depending on the specific Open Lab context.

The **Matter-Element Extension Method** was chosen to calculate the sustainability index due to its adaptability and capacity to integrate both qualitative and quantitative data, enhancing comparability and allowing for more nuanced interpretations of project impact.



## 5.1. NEXT STEPS

- Implement pilot data collection for each indicator across the Open Labs to test methodologies and refine data collection protocols, and address feasibility issues identified for specific indicators in certain Open Labs, potentially adjusting methods or seeking additional resources to ensure consistent data availability. Regularly review the selected indicators and adapt them as necessary based on pilot findings and evolving project needs. Consider additional indicators if pilot testing reveals critical data gaps, especially those related to the social and economic impact of wetland restoration.
- Continue to collaborate with stakeholders, particularly local communities and authorities, to improve data accuracy and ensure social and economic indicators reflect local values and priorities. Strengthen partnerships with local educational institutions and organisations to facilitate community engagement and enhance environmental knowledge levels.
- Begin initial application of the Matter-Element Extension Method with the collected pilot data to establish baseline sustainability scores for each Open Lab. Use preliminary results to inform adjustments in project activities, enhancing areas that score lower on sustainability and optimising efforts across the three pillars.
- Document findings from pilot testing and initial data collection in a comprehensive report (potentially in the Deliverable 4.7 Report containing results of wetlands multi-objective optimisation), providing stakeholders with insights into the sustainability progress of wetland restoration efforts.



## REFERENCES

1. *Ecosystems and Human Well-Being: Synthesis: A Report of the Millennium Ecosystem Assessment.* (Island, 2005).
2. Managing wetlands Ramsar Handbooks 4 th edition Handbook 18. (2010).
3. Roy Haines-Young, by & Potschin, M. Common International Classification of Ecosystem Services (CICES) V5.1 Guidance on the Application of the Revised Structure. (2018).
4. Brouwer, R., Brander, L., Kuik, O., Papyrakis, E. & Bateman, I. TEEB follow-up study for Europe A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB Final Report. (2013).
5. Costanza, R. *et al.* Twenty years of ecosystem services: How far have we come and how far do we still need to go? (2017) doi:10.1016/j.ecoser.2017.09.008.
6. Zedler, J. B. & Kercher, S. Wetland resources: Status, trends, ecosystem services, and restorability. *Annu Rev Environ Resour* **30**, 39–74 (2005).
7. Newman, D. J. & Cragg, G. M. Natural Products as Sources of New Drugs from 1981 to 2014. *J Nat Prod* **79**, 629–661 (2016).
8. Mitsch, W. J., Bernal, B. & Hernandez, M. E. Ecosystem services of wetlands. *Int J Biodivers Sci Ecosyst Serv Manag* **11**, 1–4 (2015).
9. Mitsch, William J, Gosselink, J. G. Wetlands Fifth Edition. *Wi Ley* **91**, 721 (2015).
10. Narayan, S. *et al.* The Value of Coastal Wetlands for Flood Damage Reduction in the Northeastern USA. *Scientific Reports 2017 7:1 7*, 1–12 (2017).
11. Balvanera, P. *et al.* Ecosystem Services. *The GEO Handbook on Biodiversity Observation Networks* 39–78 (2017) doi:10.1007/978-3-319-27288-7\_3.
12. Fish, R., Church, A. & Winter, M. Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. *Ecosyst Serv* **21**, 208–217 (2016).
13. Cooper, N., Brady, E., Steen, H. & Bryce, R. Aesthetic and spiritual values of ecosystems: Recognising the ontological and axiological plurality of cultural ecosystem 'services'. *Ecosyst Serv* **21**, 218–229 (2016).
14. Ye, C. & Sun, F. Development of a social value evaluation model for coastal wetlands. *Ecol Inform* **65**, 101417 (2021).
15. Dobbie, M. & Green, R. Public perceptions of freshwater wetlands in Victoria, Australia. *Landsc Urban Plan* **110**, 143–154 (2013).
16. Papapanagou, E., Tiniakou, A. & Georgiadis, T. Environmental education in wetland ecosystems. *J Biol Educ* **40**, 25–30 (2005).
17. Villa, J. A. *et al.* Carbon sequestration and nitrogen and phosphorus accumulation in a freshwater, estuarine marsh: Effects of microtopography and nutrient loads. *Geoderma* **430**, 116349 (2023).
18. Brailsford, F. L. *et al.* Microbial uptake kinetics of dissolved organic carbon (DOC) compound groups from river water and sediments. *Sci Rep* **9**, 11229 (2019).
19. Everard, M. Nutrient Cycling in Wetlands: Supporting Services. *The Wetland Book* 1–4 (2016) doi:10.1007/978-94-007-6172-8\_256-1.
20. Davidson, N. C. *et al.* Trends in the ecological character of the world's wetlands. *Mar Freshw Res* **71**, 127–138 (2019).

21. Junk, W. J. *et al.* Current state of knowledge regarding the world's wetlands and their future under global climate change: A synthesis. *Aquat Sci* **75**, 151–167 (2013).
22. Craft, C. B., Seneca, E. D. & Broome, S. W. Loss on ignition and kjeldahl digestion for estimating organic carbon and total nitrogen in estuarine marsh soils: Calibration with dry combustion. *Estuaries* **14**, 175–179 (1991).
23. Kayranli, B., Scholz, M., Mustafa, A. & Hedmark, Å. Carbon Storage and Fluxes within Freshwater Wetlands: a Critical Review. *Wetlands 2009 30:1* **30**, 111–124 (2009).
24. Finlayson, C. M., Milton, G. R., Prentice, R. C. & Davidson, N. C. The Wetland Book II: Distribution, description, and conservation. *The Wetland Book II: Distribution, Description, and Conservation 1–3*, 1–2142 (2018).
25. Carpenter, S. R. *et al.* Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. *Ecological Applications* **8**, 559 (1998).
26. Wetzel, R. G. *Limnology Lake and River Ecosystems Estimates of the Nitrogen in Various Compartments in Lake Wingra, Wisconsin, Midsummer*. Academic Press (2001).
27. Keddy, P. A. Wetland Ecology: Principles and Conservation. *Wetland Ecology: Principles and Conservation 1–497* (2010) doi:10.1017/CBO9780511778179.
28. Costanza, R. *et al.* The value of the world's ecosystem services and natural capital. *Nature 1997 387:6630* **387**, 253–260 (1997).
29. Simberloff, D. Invasive Species. (2013) doi:10.1093/WENTK/9780199922017.001.0001.
30. Bonada, N., Prat, N., Resh, V. H. & Statzner, B. Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annu Rev Entomol* **51**, 495–523 (2006).
31. Groot, D. Valuing wetlands Guidance for valuing the benefits derived from wetland ecosystem services Ramsar Technical Reports.
32. Carson, R. T. Contingent valuation: A comprehensive bibliography and history. *Contingent Valuation: A Comprehensive Bibliography and History* (2011).
33. Freeman III, A. M., Herriges, J. A. & Kling, C. L. The Measurement of Environmental and Resource Values : Theory and Methods. *The Measurement of Environmental and Resource Values* (2014) doi:10.4324/9781315780917.
34. A Primer on Nonmarket Valuation. **3**, (2003).
35. Parsons, G. R. The Travel Cost Model. 269–329 (2003) doi:10.1007/978-94-007-0826-6\_9.
36. Rosen, S., Rosen & Sherwin. Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy* **82**, 34–55 (1974).
37. Benefit Transfer of Environmental and Resource Values. **14**, (2015).
38. De Groot, R. *et al.* Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst Serv* **1**, 50–61 (2012).
39. London, W. C. MILLENNIUM ECOSYSTEM ASSESSMENT. (7815).
40. THE 17 GOALS | Sustainable Development. <https://sdgs.un.org/goals>.
41. Costanza, R. *et al.* The Value of Coastal Wetlands for Hurricane Protection. [https://doi.org/10.1579/0044-7447\(2008\)37\[241:TVOCWF\]2.0.CO;2](https://doi.org/10.1579/0044-7447(2008)37[241:TVOCWF]2.0.CO;2) **37**, 241–248 (2008).

42. Mitsch, W. J. & Gossilink, J. G. The value of wetlands: importance of scale and landscape setting. *Ecological Economics* **35**, 25–33 (2000).
43. Gedan, K. B., Silliman, B. R. & Bertness, M. D. Centuries of human-driven change in salt marsh ecosystems. *Ann Rev Mar Sci* **1**, 117–141 (2009).
44. Ricke, K., Drouet, L., Caldeira, K. & Tavoni, M. Country-level social cost of carbon. *Nature Climate Change* **2018 8:10 8**, 895–900 (2018).
45. Turner, R. K. *et al.* Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics* **35**, 7–23 (2000).
46. Bowler, D. E., Buyung-Ali, L. M., Knight, T. M. & Pullin, A. S. A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health* **10**, 1–10 (2010).
47. Heide, C. M. van der, Hendriks, C. M. A. & Borgstein, M. H. Financiering van bestaande natuur: praktijkcasus 'Weerribben-Wieden'. (2016) doi:10.18174/380665.
48. Landsberg, F. *et al.* *Ecosystem Services Review for Impact Assessment Ecosystem Services Review for Impact Assessment Introduction and Guide to Scoping*. <http://www.wri.org/publication/ecosystem-> (2011).
49. Bennett, N. J. *et al.* Environmental Stewardship: A Conceptual Review and Analytical Framework. *Environmental Management* **2018 61:4 61**, 597–614 (2018).
50. Ardoin, N. M., Bowers, A. W. & Gaillard, E. Environmental education outcomes for conservation: A systematic review. *Biol Conserv* **241**, (2020).
51. Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S. & Spreeuwenberg, P. Green space, urbanity, and health: how strong is the relation? *J Epidemiol Community Health* (1978) **60**, 587–592 (2006).
52. Brander, L. *et al.* *The Economics of Valuing Ecosystem Services and Biodiversity. The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations* (Routledge, 2010).
53. Daniel, T. C. *et al.* Contributions of cultural services to the ecosystem services agenda. *Proc Natl Acad Sci U S A* **109**, 8812–8819 (2012).
54. Raymond, C. M., Brown, G. & Weber, D. The measurement of place attachment: Personal, community, and environmental connections. *J Environ Psychol* **30**, 422–434 (2010).
55. Putnam, R. D. Bowling alone. *Proceedings of the 2000 ACM conference on Computer supported cooperative work* 357 (2000) doi:10.1145/358916.361990.
56. Twohig-Bennett, C. & Jones, A. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environ Res* **166**, 628–637 (2018).
57. Hungerford, H. R. & Volk, T. L. Changing learner behavior through environmental education. *Journal of Environmental Education* **21**, 8–21 (1990).
58. Kuo, F. E. & Sullivan, W. C. Environment and crime in the inner city does vegetation reduce crime? *Environ Behav* **33**, 343–367 (2001).
59. Bi, A., Luo, Z., Kong, Y. & Zhao, L. Comprehensive weighted matter-element extension method for the safety evaluation of underground gas storage. *R Soc Open Sci* **7**, (2020).
60. Mirchooli, F., Sadeghi, S. H., Khaledi Darvishan, A. & Strobl, J. Multi-dimensional assessment of watershed condition using a newly developed barometer of sustainability. *Science of the Total Environment* **791**, (2021).

61. Wang, Q., Li, S. & Li, R. Evaluating water resource sustainability in Beijing, China: Combining PSR model and matter-element extension method. *J Clean Prod* **206**, 171–179 (2019).
62. Kumar, R. *et al.* Revealing the benefits of entropy weights method for multi-objective optimization in machining operations: A critical review. *Journal of Materials Research and Technology* vol. 10 1471–1492 Preprint at <https://doi.org/10.1016/j.jmrt.2020.12.114> (2021).
63. ZOU, Z., YUN, Y. & SUN, J. Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment. *Journal of Environmental Sciences* **18**, 1020–1023 (2006).
64. Wang, Q., Li, S., He, G., Li, R. & Wang, X. Evaluating sustainability of water-energy-food (WEF) nexus using an improved matter-element extension model: A case study of China. *J Clean Prod* **202**, 1097–1106 (2018).

