POLICY BRIEF

How can coastal wetland restoration mitigate climate change? What we know and what is still unclear

KEY MESSAGES

- **Coastal wetland restoration is a potential Nature-based Solution (NbS) for climate change mitigation**. Restored wetlands act as net carbon sinks by increasing carbon stocks in plant biomass and soils/sediments without a corresponding rise in greenhouse gas (GHG) emissions.
- **The evidence on carbon stocks and GHG emissions is uneven across places and wetland types**. Most of the existing data comes from tropical and subtropical regions; temperate Europe is barely studied. Freshwater wetlands and transitional waters are frequently found in Europe yet underrepresented in providing empirical evidence of the effects of restoration on carbon storage and GHG fluxes. Targeted European monitoring can close these gaps.
- **Many studies focus on carbon stocks, but not on GHG emissions**. GHG net fluxes are important parameters to understand and effectively quantify the benefits of restoration actions, yet there are not many mass balance studies. Prioritisation of GHG flux measurements is important to close evidence gaps and guide funding for restoration actions.
- **Reporting of GHG flux data is not standardised**. Existing data, especially of GHG fluxes are not standardised and results are therefore not comparable. Standardised monitoring, reporting, similarly to what is set for Water Framework Directive (WFD) reporting, and verification is needed to upscale these numbers from local to EU level.

Introduction

Among the ecosystem services provided by coastal wetlands, their capacity to capture and store carbon in soils/sediments over long timescales has gained particular attention. This long-term carbon sequestration potential currently positions coastal wetland protection and restoration as one of the key components of climate change mitigation options at EU and global levels.

What are coastal wetlands?

Coastal wetlands are ecosystems located at the interface between land and sea, characterized by periodic or permanent flooding with salt, brackish, or fresh water. They support hydrophytic or submerged vegetation and include habitats such as saltmarshes, seagrass meadows, tidal flats, and mangroves. Under the Ramsar Convention, wetlands encompass areas of marsh, fen, peatland, or water—whether natural or artificial—with water that is static or flowing, fresh, brackish, or salt, including coastal marine areas shallower than six meters at low tide. These ecosystems provide critical services such as biodiversity support, shoreline protection, and carbon storage, yet mapping their full extent remains challenging, often leading to underestimation of their global coverage.

What are the carbon pathways in coastal wetlands?

Coastal wetlands act as carbon sinks, storing carbon in plant biomass and soils/sediment through processes collectively known as "blue carbon" pathways (Figure 1). Photosynthesis captures atmospheric CO_2, which is then stored in vegetation and sediments. Waterlogged, anoxic conditions slow decomposition, allowing carbon to accumulate over centuries. Microbial processes such as methanogenesis occur under low-oxygen conditions, producing methane (CH_4), although this is often suppressed in saline environments. Wetlands degradation, particularly mediated by increasing organic matter, leads to decreased redox potential in the sediment and results in increased CH_4 emissions. Restoration of degraded wetlands can reactivate the blue carbon pathways, enhance carbon sequestration and contribute to climate mitigation.

What are GHG fluxes in coastal wetlands?

Greenhouse gas (GHG) fluxes in coastal wetlands involve exchanges of CO_2, CH_4, and N_2O between wetlands' soils, water and vegetation, and the atmosphere (Figure 1). While these ecosystems act as strong carbon sinks, they can also emit methane and nitrous oxide, particularly under freshwater or nutrient-rich conditions. Restoration generally improves carbon storage but does not always ensure reductions in CH_4 or N_2O emissions, highlighting the complexity of net GHG fluxes. Therefore, accurate measurements and reporting are paramount to inform climate-actions.

The key policy question is whether restoration actually improves the net greenhouse gas (GHG) balance in coastal wetlands, rather than only in theoretical models. Within RESTORE4Cs we synthesized peer-reviewed studies[1], that compare degraded and restored coastal wetlands to assess their climate change mitigation potential worldwide.

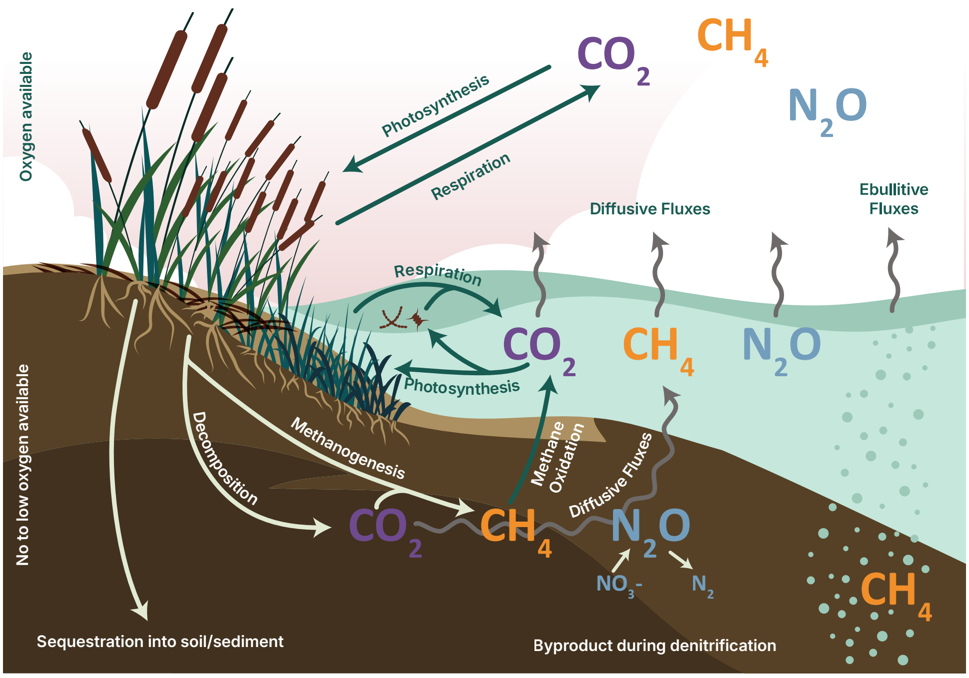

Figure 1. Schematic overview of carbon fluxes and GHG pathways in coastal wetlands.

Lessons learned from a systematic review of coastal wetland restoration knowledge

Coastal wetland restoration is a potential nature-based solution for climate change mitigation

Coastal wetland restoration increases carbon stored in both above- and underground plant biomass and in soils or tidal sediments. Reported GHG emissions of CO_2, CH_4, and N_2O do not show a consistent change after restoration, as it is common in other wetland types. Drawing on current scientific knowledge, we could therefore conclude that, in general, restoration is a potential tool for climate change mitigation (Figure 2).

Current evidence on GHG fluxes is limited and uneven

Existing evidence on greenhouse gas (GHG) net fluxes, which represent the balance between emissions and storage, is limited and inconsistent for coastal wetlands. This makes it challenging to fully assess the climate benefits of restoration efforts in Europe. Most available studies come from tropical regions, while temperate European coasts, and especially freshwater and brackish wetlands common across Europe, are still poorly studied. Research mainly focuses on carbon stocks, with far fewer studies measuring GHG fluxes, even though these fluxes determine whether restoration leads to net climate benefits.

Relevant examples from European coasts, specifically from Mediterranean wetlands[2-5] shows that hydrological management and conservation status strongly influence net carbon fluxes and greenhouse gas emissions. These studies consistently indicate that restoration or adaptive management practices tend to enhance net emission reduction, with methane playing a particular role due to its high sensitivity to environmental factors such as salinity and temperature[4]. They also highlight that adaptive management will only be effective if the hydrological regime and ecosystem structure are maintained.

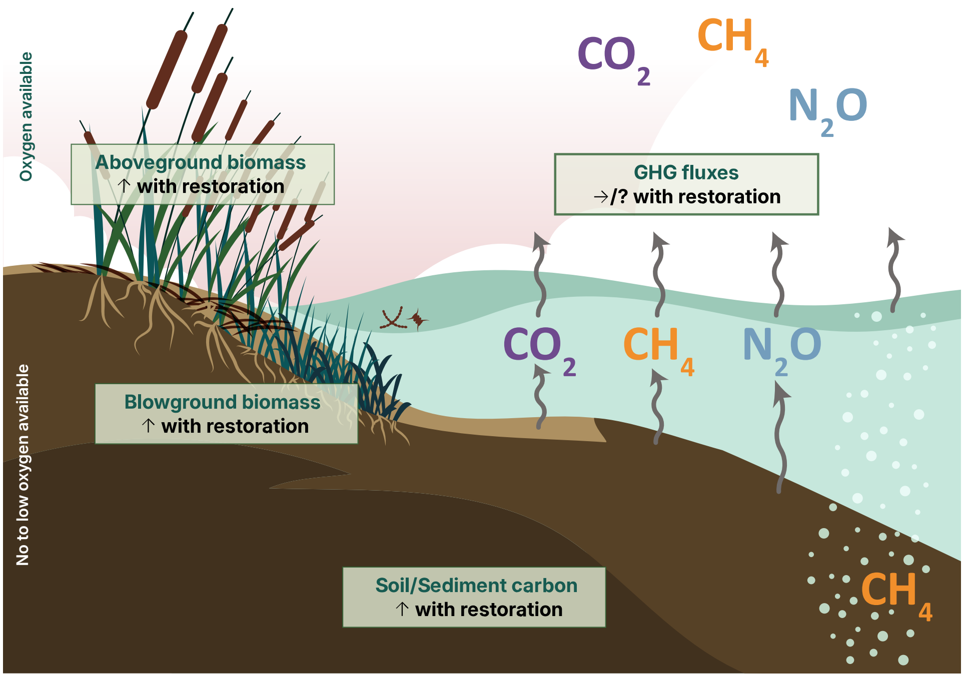

Figure 2: Overview of carbon stocks and GHG fluxes studied in our literature synthesis including key results. © University of Salento / LifeWatch ERIC

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Although this requires further empirical confirmation, it should already serve as a guiding principle for restoration planning and implementation. In more detail, these studies show that good hydrological management and overall healthy ecosystem condition are essential for reducing emissions, particularly methane, which is highly sensitive to environmental change.

Standardised monitoring and reporting of restoration outcomes are missing

Our literature synthesis revealed that restoration outcomes are reported in a highly inconsistent and incomplete way, severely constraining any quantitative synthesis. Many studies lack standardised monitoring protocols, pre-restoration baselines or comparable control sites. Key methodological details—timing and number of measurements, environmental context, and specific restoration actions—are often missing. Data on soil and biomass carbon stocks, and on CO_2, CH_4, and N_2O fluxes, are frequently absent or collected using non-comparable approaches, making continental- or global-scale assessments of climate benefits difficult.

RESTORE4Cs project demonstrates how to ensure methodological consistency across sites, which is critical for reliable data collection. By harmonizing sampling protocols and laboratory procedures beforehand, the project minimizes variability and strengthens comparability of results. This standardized approach underpins the integration of ecological indicators, land-use data, and climate variables into spatially explicit models, enabling assessments of pressures and mitigation potential across wetland types. Such rigour not only enhances scientific validity but also ensures restoration outcomes are scalable and policy relevant.

Relevance of coastal wetland restoration, knowledge about carbon storage and GHG fluxes for legislation, strategic frameworks and related processes

The importance of coastal wetland restoration for carbon storage and GHG mitigation is already recognized in EU and global policies and processes. Insights from this review of existing knowledge can help improve their implementation. These particularly include:

- **Paris Agreement and NDCs**. Restored coastal wetlands can serve as net carbon sinks and be recognised as nature-based mitigation measures within the EU NDC, with explicit accounting of biomass and soil carbon supported by appropriate Measurement, Reporting and Verification (MRV).
- **Ramsar Convention on Wetlands**. Many coastal wetlands are Ramsar sites; their restoration advances habitat conservation, water regulation, and climate-mitigation objectives.
- **EU Climate Law**. The binding 2050 climate-neutrality goal and 2030 reduction target recognise ecosystem restoration—including coastal wetlands—as contributors to EU carbon sinks.
- **EU LULUCF Regulation (2023–2030)**. Restored coastal wetlands can strengthen national land-sector sinks and support delivery of the EU-wide sink target.
- **EU Nature Restoration Regulation & Biodiversity Strategy 2030**. Restoration targets for saltmarshes, seagrass meadows, and other coastal ecosystems support both carbon-sink enhancement and biodiversity objectives.
- **UN Decade on Ecosystem Restoration & UN Ocean Decade**. Both initiatives prioritise scaling up coastal wetland restoration—including salt marshes and mangroves—as key nature-based solutions for climate action, coastal resilience, and progress toward the Sustainable Development Goals (SDG). Projects in these habitats can serve as exemplars by demonstrating measurable carbon sequestration alongside ecological co-benefits, tracked through combined carbon and ecological indicators.
- **Carbon markets and finance**. Blue carbon crediting frameworks are expanding to include coastal wetlands, requiring projects to demonstrate additionality, permanence, and no leakage. Standards increasingly align with EU rules such as the Carbon Farming and Carbon Removal (CRCF) Regulation and updated sustainable-finance frameworks (2025), strengthening MRV and directing capital toward high-integrity climate outcomes—opening new funding streams for restoration.
- **National GHG inventories and models**. National GHG inventories and Earth system models should distinguish restored from degraded wetlands, as restored systems store more biomass and soil carbon and emit minimal methane. Reflecting these differences improves national reporting accuracy and captures the full mitigation value of restoration.

South-West Dutch Delta, Netherlands

Integrating coastal wetland restoration into EU Climate Policy and carbon accounting: policy recommendations

Building on knowledge generated by the RESTORE4Cs project, there is an opportunity to promote the restoration of coastal wetlands and enhance their role in carbon storage and GHG emission reductions within existing policies. However, the climate change mitigation service of these ecosystems cannot compensate for global GHG emissions, so deep decarbonisation of the global economy remains essential. Under these premises, the role of ecosystems and, particularly of coastal wetlands, in climate change mitigation can be enhanced by the following political actions:

Action 1

Establish a harmonized monitoring, reporting and verification (MRV) system with open data (FAIR principles)

A unified MRV framework is essential for credible and comparable climate accounting across the EU. Similar harmonisation has been achieved before for eutrophication, for example through the Protocol Handbook for NICE – Nitrogen Cycling in Estuaries[6], which under the EU MAST III programme in 2000 provided standardised sampling, analysis and calculation methods for nitrogen fluxes in estuaries. This requires several steps:

- **Adopt standardized protocols** aligned with Intergovernmental Panel on Climate Change (IPCC) guidance to measure key carbon pools and GHG fluxes (soil carbon, biomass, fluxes of CO_2, CH_4, N_2O).
- **Include baseline measurements** before restoration and ensure regular, long-term monitoring to track changes over time.
- **Report results with reference comparisons**, presenting outcomes alongside comparable degraded and natural sites.
- **Ensure open and interoperable data**, publishing methods, results, and geospatial information in accessible repositories compatible with national inventory systems.
- **Guarantee data quality and credibility** through quality assurance procedures, uncertainty assessment, and independent verification to support national and EU-level reporting.

Lessons could be learned from the process that underpinned the Protocol handbook for NICE - Nitrogen Cycling in Estuaries[6], to standardize studies on eutrophication in estuaries, and support the implementation of the WFD in transitional waters.

Action 2

Align carbon targets and accounting with climate policy frameworks

Restoration efforts should be guided by clear, measurable, and policy-aligned targets, aligned with climate policies. This entails several key elements:

- **Define measurable carbon targets**, including increases in carbon stored in biomass and soils, and thresholds for acceptable CH_4 and N_2O emissions, accounted as CO_2 -equivalents.
- **Align restoration targets with existing EU and national policy instruments**, including the EU NDC, the European Climate Law, the EU LULUCF Regulation, and the EU Nature Restoration Regulation.
- **Establish consistent baselines for degraded conditions** to ensure comparability across sites and Member States.
- **Apply realistic timelines for ecological recovery**, reflecting the time needed for ecosystems to stabilise and deliver measurable climate benefits, bearing in mind that most coastal wetlands are socio-ecological systems.
- **Support integration into national GHG inventories** by ensuring targets, baselines, and timelines are compatible with reporting requirements.

Action 3

Enable access to carbon finance through credible blue carbon crediting

Coastal wetland restoration can generate carbon finance through voluntary and compliance carbon markets. Ensuring credibility and maximizing impact requires several key actions:

- **Establish clear eligibility criteria** for carbon projects:
  - Demonstrate additionality, long-term carbon storage (permanence), and minimal leakage.
  - Avoid harm to the environment and biodiversity.
  - Use conservative baselines and IPCC-aligned methodologies.
  - Apply recognized standards where available and develop EU-specific guidance to streamline adoption.
  - Rely on the climate effects according to the radiative potential of the different GHG, accounted as CO_2 -equivalents.
- **Build local capacity** to navigate carbon crediting:
  - Support design of MRV systems.
  - Assist with certification processes and market access.
- **Reduce transaction costs and expand participation:**
  - Implement pre-approved funding and crediting pipelines.
  - Where feasible, link carbon credit generation to national GHG inventories while preventing double counting.
- **Adopt adaptive management frameworks:**
  - Align restoration practices with dynamic hydrology, vegetation, and carbon processes.
  - Evidence from European projects (e.g., Interreg Wetlands4Climate) shows that managing water regimes, soils, and vegetation is crucial to sustaining mitigation potential.
- **Maximize co-benefits:**
  - Beyond carbon, restored wetlands provide biodiversity enhancement, flood regulation, and nutrient retention, strengthening overall ecosystem resilience.

Camargue, France © University of Salento-LIFEWatch ERIC

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RESTORE4Cs is a Horizon Europe project that aims to evaluate the effects of restoration actions on wetlands' ability to mitigate climate change and deliver a range of ecosystem services, using an integrative socio-ecological systems approach. More information is available at: https://www.restore4cs.eu/

Authors: Misteli, B.[1], Attermeyer, K.[1,2], Rochera, C.[3], Lillebø, A.I.[4], Camacho, A.[3]

Reviewers: Elkina, E.[5], Štrbenac, A.[6]

[1] WasserCluster Lunz, Austria; [2] University of Vienna, Austria; [3] University of Valencia, Spain; [4] University of Aveiro, Portugal; [5] Ecologic Institute, Germany; [6] MedWet, France

Citation: Misteli, B., Attermeyer, K., Rochera, C., Lillebø, A.I., Camacho, A. 2025. How can coastal wetland restoration mitigate climate change? What we know and what is still unclear. Policy Brief. *Restore4Cs project*.

PARTNERS

Disclaimer: This working paper has been published with financial support from the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.