elter-ri.eu eLTER @elter-ri.eu eLTER

eLTER

INTEGRATED EUROPEAN
LONG-TERM ECOSYSTEM, CRITICAL ZONE AND
SOCIO-ECOLOGICAL
RESEARCH INFRASTRUCTURE

Scaling Carbon Removal: Integrating Nature-Based and Technological Solutions for Climate Neutrality

The Message in Brief

To meet Paris Agreement goals, it is imperative to exponentially increase both anthropogenic and biogenic carbon dioxide removal (CDR) efforts. This entails halting deforestation, enhancing land-based CDR methods like afforestation, and rapidly deploying novel technologies such as direct air capture and bioenergy with carbon capture and storage. Achieving this requires robust CO_2 pricing, transparent carbon sink measurements, and comprehensive regulatory frameworks. Immediate action is essential to offset emissions and stabilise global temperatures.

Challenges and Current Status

Global temperatures have risen significantly, with recent data indicating a 1.63°C increase above pre-industrial levels [1]. The carbon budget for limiting warming to 1.5°C is rapidly depleting [2], emphasising the urgent need for effective CDR strategies [3] to sequester and permanently store anthropogenic CO2 emissions, and to enable a return to the +1.5°C level following a now inevitable overshoot. However, effective CDR is hampered by:

Diminishing Carbon Sinks

The activity of terrestrial carbon sinks is slowing [4], calling into question sink magnitude and sustainability under future climatic conditions. In addition, land use reduces sink capacity: In Finland, forest land carbon sink capacity decreased by 4.6% between 2021 and 2022, primarily due to intensive harvesting [5] and increased CO_2 emissions from drained peatland forests [6]. Similar trends are observed in Sweden and Norway.

Insufficient Current Measures

Existing efforts in afforestation and reforestation are inadequate. Without scaling up these initiatives and integrating technological solutions, achieving net-zero emissions by 2050 remains unlikely (see Fig. 1).

Policy and Regulatory Gaps

There's a lack of comprehensive policies that incorporate CDR into Nationally Determined Contributions (NDCs). Moreover, the absence of standardised carbon sink measurements hinders progress.

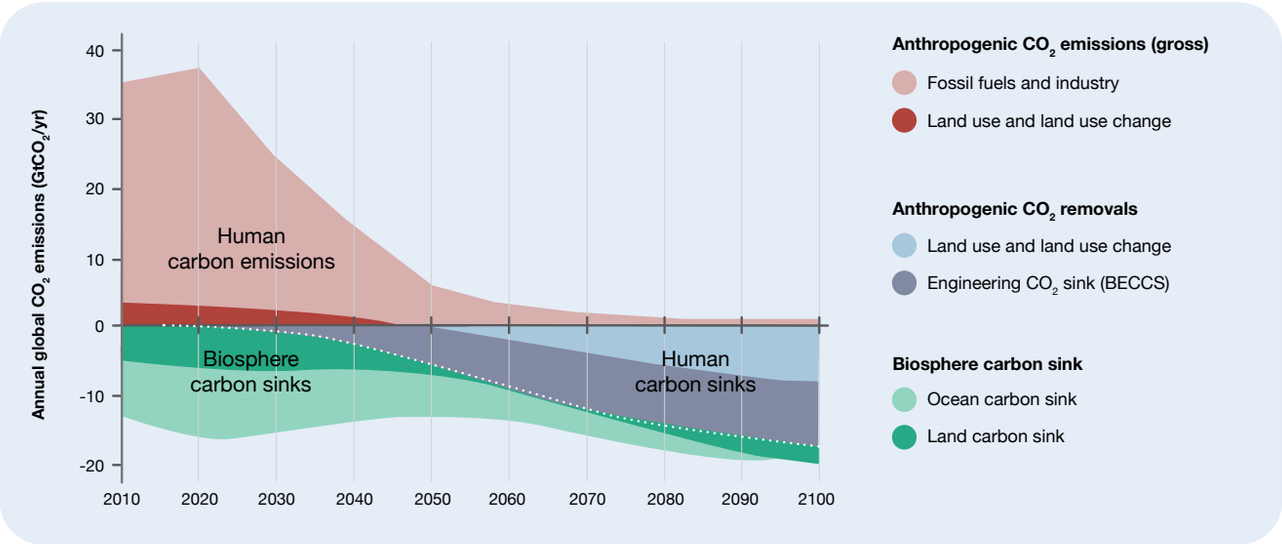


Figure 1. To achieve Paris agreement goals, significant reductions in CO2 emissions need to be accompanied and followed up by massive scale-up of CO2 capture using nature-based and technical solutions (adapted from [7])

Solutions and Opportunities

To effectively meet net-zero climate targets, Europe must rapidly scale up carbon dioxide removal (CDR) by combining **nature-based** and **technological solutions** ([7-10], see Fig. 1). These efforts present several clear opportunities:

Strengthen Land-Based CDR

Nature-based solutions such as **afforestation**, **reforestation**, and improved **forest management** remain cost-effective and scalable. Restoring degraded ecosystems, halting deforestation, and promoting biodiversity-positive land use can significantly enhance natural carbon sinks while providing co-benefits for water quality, biodiversity, and livelihoods.

Deploy Technological Innovations

Emerging technologies such as **bioenergy with carbon capture and storage (BECCS), direct air carbon capture and storage (DACCS)**, and **enhanced weathering** can supplement natural approaches, especially in hard-to-abate sectors. Investment in pilot projects, testing, and scaling is needed to bring these options to maturity and market viability.

Integrate CDR into Climate Policy

Few national climate plans currently include meaningful CDR components. This presents an opportunity to **embed CDR into Nationally Determined Contributions (NDCs)**, long-term climate strategies, and land use planning. Policy alignment at EU and national levels can provide clarity and certainty for private and public stakeholders.

Mobilise Finance and Markets

Robust **CO_2 pricing mechanisms**, performance-based incentives, and carbon credit markets can accelerate private sector investment. Certification systems for carbon removal are also being developed (e.g. EU Carbon Removal Certification Framework), offering transparent, high-integrity pathways for CDR to scale responsibly.

Strengthen Monitoring, Reporting, and Verification (MRV)

Accurate and consistent MRV systems are essential for all CDR methods. Advances in **satellite technology, in situ observations**, and **ecosystem modeling** present an opportunity to standardise and harmonise data across Europe, ensuring that progress is real, measurable, and transparent.

Foster Research and Collaboration

Interdisciplinary, long-term research infrastructures like **eLTER** can serve as neutral platforms for evaluating the environmental, social, and economic impacts of different CDR approaches. Shared data and joint initiatives across countries will help identify best practices and avoid unintended consequences.

How eLTER can help

- Provide long-term ecosystem monitoring data to assess CDR effectiveness.
- Facilitate interdisciplinary research on land-based CDR methods.
- Support policy development through evidence-based insights.
- Enhance stakeholder engagement across sectors.
- Promote data standardisation for carbon sink measurements.

Ways Forward and Recommendations

To enable large-scale carbon dioxide removal in line with climate neutrality goals, coordinated, science-based, and inclusive strategies are required.

Policymakers must urgently **integrate CDR into national and EU climate legislation** and long-term planning. Nature-based approaches must be protected and expanded, while **emerging CDR technologies should be supported through public-private partnerships** and strategic R&D investments. A comprehensive and **transparent CO_2 pricing framework** is needed to make carbon removals economically viable, especially in sectors where mitigation is not feasible.

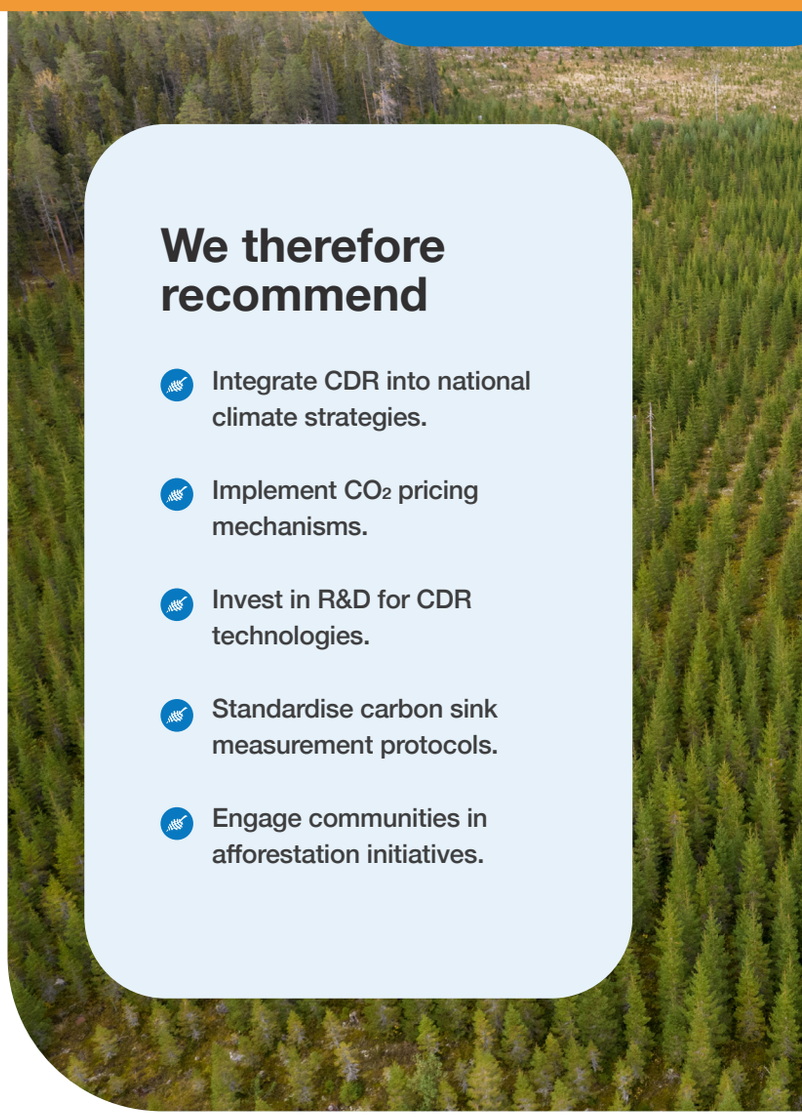
Effective implementation depends on **robust MRV systems**, using consistent and transparent methods to track carbon sinks and avoid double counting. Efforts must also ensure **social acceptance and local engagement**, particularly in regions where land-use changes or infrastructure deployment are required.

Strong **collaboration between scientists, industry, policymakers, and civil society** will be critical to ensure CDR methods are environmentally sound, cost-effective, and contribute to just climate transitions.

By combining regulatory clarity, financial tools, technological innovation, and ecosystem stewardship, Europe can lead the way in responsibly scaling carbon removals to meet climate targets.

Key Messages

- Immediate action is required to scale up CDR efforts.
- Combining nature-based and technological solutions offers the most effective path forward.
- Robust policies and financial mechanisms are essential to drive adoption.
- Standardised monitoring ensures transparency and effectiveness.
- Collaborative research and stakeholder engagement are key to success.



We therefore recommend

- Integrate CDR into national climate strategies.
- Implement CO_2 pricing mechanisms.
- Invest in R&D for CDR technologies.
- Standardise carbon sink measurement protocols.
- Engage communities in afforestation initiatives.

Literature cited

1. Copernicus Climate Change Service (2024). Hottest May on record spurs call for climate action
2. Lamboll, Robin, D., et al. (2023) Assessing the size and uncertainty of remaining carbon budgets | Nature Climate Change
3. Hausfather, Z. (2021), Explainer: Will global warming 'stop' as soon as net-zero emissions are reached? ≠ Carbon Brief
4. Penuelas, J. (2023) Decreasing efficiency and slowdown of the increase in terrestrial carbon-sink activity – ScienceDirect
5. Natural Resources Institute of Finland (2025) Preliminary greenhouse gas inventory results for 2023: Forest land has turned into an emission source because the carbon sink of trees no longer cover emissions from forest soil.
6. Natural Resources Institute of Finland (2023) According to preliminary GHG inventory data, emissions from the land use sector increased in 2022
7. Rockström, J., et al. (2017) A roadmap for rapid decarbonization | Science
8. Geden, O., et al. (2023) The State of Carbon Dioxide Removal – 1st Edition
9. Geden, O., et al. (2024) The State of Carbon Dioxide Removal – 2nd Edition
10. Mannion, P., et al. (2023) Carbon removals: How to scale a new gigaton industry – McKinsey

Contact and acknowledgements

For inquiries: Prof. Jaana Bäck, University of Helsinki, jaana.back@helsinki.fi

eLTER gratefully acknowledges the scientific inputs by Jouni Keronen, Markku Kulmala, Jaana Bäck, Anneli Pauli, Hanna Lappalainen (all University of Helsinki), Antti-Ilari Partanen (Finnish Meteorological Institute) Antti Arasto (VTT Technical Research Centre of Finland) Juha Turkki (Climate Leadership Coalition), and the Atmosphere and Climate Competence Center (ACCC).

Funded by the European Union

eLTER receives funding from the European Union's Horizon 2020 research and innovation programme under GA No 871126 (eLTER PPP) and GA No 871128 (eLTER PLUS), and the European Union's Horizon Europe research and innovation programme under GA No 101131751 (eLTER EnRich).