Quantifying and Deploying Responsible Negative Emissions

Science-policy brief

About NEGEM

NEGEM is an EU Horizon 2020 research project. The aim of NEGEM is to 'filter' the maximum theoretical deployment potential of CDR often portrayed in models (such as those of the IPCC) through a set of constraints to reduce the uncertainties associated with CDR and identify more realistic deployment potentials. These constraints include techno-economic and commercial barriers, environmental limits, and socio-political acceptance.
The project seeks to identify the EU-wide potential of CDR deployment, along with the relevant governance frameworks to accommodate it in a Paris-compatible manner. The aim is to produce a more granular knowledge base to inform ongoing policymaking processes.
This science-policy brief presents the current key findings of NEGEM.

NEGEM - Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways is a Research and Innovation Action started on 1 June 2020 that will continue through 31 May 2024. The project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 869192.

To what extent is carbon dioxide removal (CDR) required to achieve climate neutrality?

To reach the 1.5C target for global warming, **immediate and significant greenhouse gas (GHG) emission reductions are needed**. The current and expected pathways of emission reductions are not in line with the Paris Agreement target and emission reductions need to be accelerated during this decade (IPCC AR6).

Carbon dioxide removals (CDR) technologies and practices cannot replace emission reductions. However, CDR is also needed according to IPCC's newest scenarios: One of the key messages of AR6 WGIII is that deploying Carbon Dioxide Removal (CDR) will be essential to globally reach net-zero.

Based on the economically optimized climate stabilization scenarios included in IPCC's AR6 that limit warming to 1.5°C, the cumulative global net-negative emissions including CDR are 20–660 $GtCO_2$ by 2100 (of which the share from the AFOLU sector is 20-400 $GtCO_2$). Obviously, the need for CDR varies enormously depending on the speed and rate of emissions reductions accomplished.

The IPCC outlines three complementary roles for CDR:

1. To supplement emission reductions and accelerate climate change mitigation;
2. To achieve net-zero by balancing out residual CO_2 and non-CO_2 greenhouse gas emissions;
3. To exceed annual GHG emissions and achieve 'net-negative' emissions globally to draw down global temperatures.

To what extent is CDR needed in the EU?

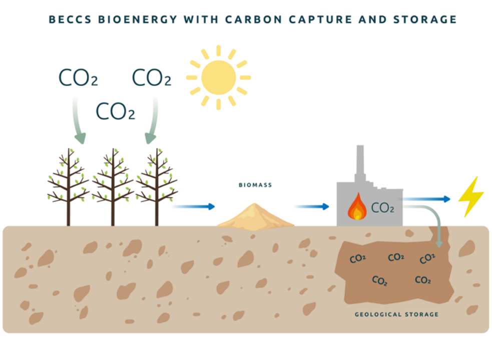
In 2020, the European Commission published an impact assessment accompanying the document "Stepping up Europe's 2030 climate ambition" SWD (2020) 176 final. It concludes that in the EU the total negative emissions (including the LULUCF sector and other CDR options) need to be around 0.5 $GtCO_2$/year by 2050, in order to enable climate neutrality.

A study by Pilli et al. (2022) states that to become carbon neutral by 2050, the EU27 net carbon sink from forests should increase from the current level of around −360 to the level of −450 Mt CO_2eq/yr by 2050. However, their study shows that according to recent developments, the EU27 + UK forest carbon sink would instead decrease to about −250 Mt CO_2eq/yr in 2050 and to −80 Mt CO_2eq/yr by 2100. This could significantly increase the need for emission cuts and for other types of CDR.

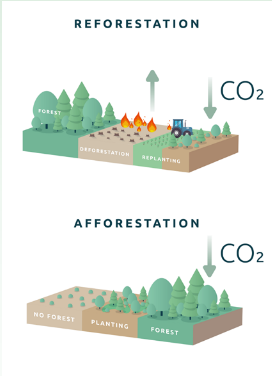
NEGEM has studied possible CDR targets for Europe based on a cumulative need for 687 Gt of global CDR by 2100 in IPCC 1.5°C scenarios. Different effort-sharing principles were tested to allocate the global target for CDR to different regions. The cumulative target for EU28 varied from 32 Gt by 2100 (based on the Equity principle) to 325 Gt by 2100 (Capacity principle) (see Deliverable 4.3).

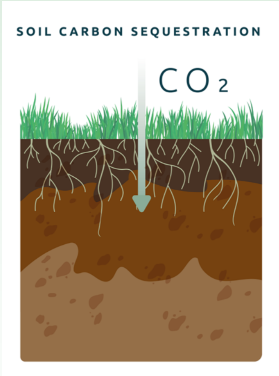
Currently, only 5 EU countries + UK have set a separate target for emission reductions and CDR in their climate policies, and only Switzerland has a comprehensive CDR target[1]. However, many countries have included vague plans for CDR in their climate policies[2].

Nature-based vs. technical solutions for CDR



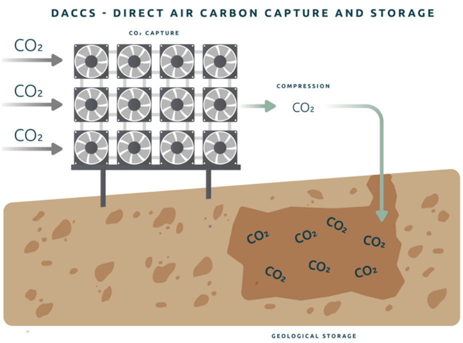
CDR can be accomplished by various **technical and nature-based solutions**. Technical solutions include, for example, direct air capture and CO_2 storage (DACCS), bioenergy or other biomass-based process combined with CO_2 capture and storage (BECCS and Bio-CCS), enhanced weathering (EW), and ocean-based solutions, such as ocean liming. Nature-based solutions include e.g., afforestation, reforestation, biochar, soil carbon sequestration, and seaweed cultivation and sinking. The separation of the CDR solutions in nature-based and technical solutions is rather unclear, and classification based on the permanence of CO_2 storage (geological vs. temporary) would be more useful.

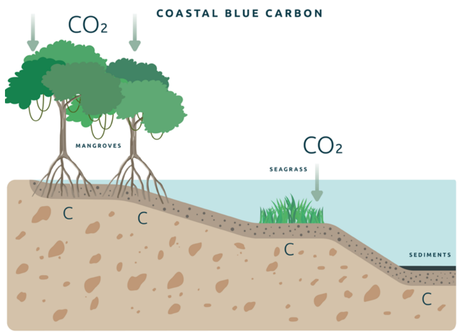




Nature-based solutions can provide immediate and cost-effective opportunities for reducing net CO_2 emissions with substantial co-benefits, e.g. for soil quality and biodiversity (Allen et al. 2022). Thus, they potentially provide strong synergies between climate change mitigation and international targets for nature restoration (i.e. the Kunming-Montreal Global Biodiversity Framework) and broader sustainable development goals. However, nature-based solutions **mostly provide storage solutions with high risk of intentional or unintentional CO_2 leakage**, e.g., due to forest fires, pests, discontinuous land management, etc.
In addition, nature-based solutions will likely be needed in the future to compensate for biogenic emissions and the release of carbon from the biosphere due to global warming itself. **It is unlikely, therefore, that nature-based solutions could compensate for residual fossil fuel emissions**. If net zero is to be durable, any remaining CO_2 generation from fossil fuel use would be balanced by **active CO_2 removal to geological-timescale storage**. (Allen et al. 2022).

NEGEM has also studied **non-CO_2 GHG removal** solutions for methane (CH_4) and nitrous oxide (N_2O) through metal-catalytic oxidation, photocatalytic oxidation and biological oxidation. The low concentration of CH_4 and N_2O may limit these approaches on the basis of cost and energy requirements. For example, more emissions could be generated from energy use than could be removed at certain concentrations of GHGs. It remains an open question if non-CO_2 removal techniques will prove commercially viable at scale; all the options studied require further research and development.





At what scale is it feasible to implement CDR methods, given their technical, environmental, economic, and socio-political aspects?

Environmental impacts

To understand the realistic potential of CDR methods, NEGEM utilises several approaches to study their environmental impacts.

First, NEGEM has accomplished a comprehensive life cycle assessment (LCA) study of altogether 36 different CDR configurations. The results show that none of them comes without side-effects and trade-offs. On the other hand, also low risk options with co-benefits can be recognized. Cobo et al. (2023) recognized six especially promising CDR options:

1. https://tracker.carbongap.org/country-data-summary/
2. https://www.ecologic.eu/sites/default/files/publication/2022/50084-ECF-CDR-report-web.pdf

- **Forestation, soil carbon sequestration**: co-benefits, lower costs and high maturity levels, thus allowing for rapid deployment. However, continuous monitoring is needed to reduce unintended side-effects and release of the stored carbon.
- **Enhanced weathering with olivine**: overall good performance and substantial co-benefits. However, risks concerning human health and mining should be further investigated prior to deployment.
- **Three modalities of DACCS**[3]: involves few side-effects, however, requires substantial energy demand. Early investments could reduce costs and accelerate scale-up. More research is needed e.g. on the absorbent materials used in DACCS.

Second, **environmentally-constrained global biomass potentials for BECCS** have been studied with the biosphere model LPJmL5-NEGEM. In climate stabilization scenarios from Integrated Assessment Models included in IPCC's AR6, the need for CDR is largely covered by BECCS from dedicated bioenergy crops, the medium demand for BECCS being around 9 $GtCO_2$/yr in 2050. However, these rates result from economic optimization balancing emission reductions and CDR, yet with limited representation of environmental constraints.

In NEGEM, a "**supply-driven**" assessment of the global BECCS potential is done **by excluding further transgression of terrestrial planetary boundaries** and ensuring that forest ecosystems are not converted to biomass plantations. The study focuses on **energy-crops outside current agricultural land.** (Deliverable 3.2)

Significant limitations to BECCS potential on other than agricultural land is recognised when planetary boundaries other than climate stabilization are included in the assessments. The planetary boundaries evaluated here are freshwater use, nitrogen flows, land-system change and biosphere integrity.

The main conclusion is that to free land area for BECCS, **significant transformations of the agricultural sector** would be needed, for example, as a result of dietary changes (reduced meat consumption). In addition, the current agricultural land should be more efficiently yet sustainably used, including **crop yield increases, innovative farming practices** (e.g., intercropping, double cropping, cover cropping, agroforestry), and the use of waste and **residue streams** across all agricultural value chains for BECCS.

Global dietary changes, e.g., by following the EAT-Lancet planetary health diet, **could free up substantial amounts of land from pastures for BECCS or reforestation purposes**. Depending on the level of global shift to the new diet regime (25, 50 or 100% change), the intensity of land management, and the carbon removal efficiency, the additional BECCS potentials could range from 1.7 to 18.5 $GtCO_2$/yr – yet, this would severely increase pressures on water stress and environmental boundaries for nitrogen, water and biosphere integrity. By contrast, reforestation on pastures is simulated to remove 1.5 to 4.3 $GtCO_2$/yr while serving both climate stabilization and nature restoration, thereby synergistically contributing to getting back into a safe operating space with regard to multiple planetary boundaries.

Solutions for Bio-CCS can be found from application of CCS in existing and future **point sources of biogenic CO_2** emissions, e.g. from pulp and paper industry; bio-CHP plants and biorefineries. In addition, Bio-CCS with use of residual **raw materials, such as agricultural and forestry residues with sustainable harvest rates**, is recommended.

Scenarios on BECCS potential have been studied in NEGEM also with "demand-driven" models (MONET and TIMES-VTT), including Bio-CCS from both residual biomass and point-sources. Although the results vary depending on the baseline assumptions and models used, they **all indicate more conservative figures for BECCS than those expressed by IPCC scenarios. Only with substantial changes in the agricultural sector, could the potential be increased.**

(A separate NEGEM factsheet on Bio-CCS can be found https://www.negemproject.eu/results/#factsheets)

3. Low temperature solid sorbent DAC (LTSS-DAC) with temperature swing adsorption (TSA) or moisture swing adsorption (MSA);
High temperature liquid sorbent DAC (HTLS-DAC)

Third, NEGEM has made a preliminary assessment of the **key non-renewable resource chains** (rare metals and minerals) in the context of large-scale deployment of CDR. (Deliverable 3.9) The results showed that the clean energy transition may be constrained by a supply of cobalt and neodymium, which are important metals in batteries and wind power installations. In addition, copper and silver are used in significant amounts. These metals could potentially limit long-term investments in clean energy technologies.

Social licence to operate

NEGEM results find that the **social license to operate** for different CDR methods varies across sectors and geographies (Deliverable 5.1). For example, NGOs and companies can have varying/opposing views on the acceptability of different CDR solutions. Most firms tend to favor technological solutions such as BECCS and DACCS, whereas NGOs more commonly favor nature-based solutions. However, **interaction between different stakeholders has an effect in changing perceptions**. (Deliverable 5.3)

There are tensions between the goals of carbon dioxide removal and other high-priority social or environmental goals, thus a **systems perspective** needs to be adapted when designing the legislation or regulations. (Deliverable 5.2)

Socio-economic impacts associated with deploying CDR at the national scale differ greatly from a CDR method to another. Nature-based CDR methods are expected to increase gross value added (GVA) in the agricultural and forestry sectors, whereas technical CDR methods are more likely to increase GVA in economic sectors such as machinery & equipment, maintenance, construction, utilities, or even R&D. (Deliverable 7.3)

To respond to the environmental and social challenges, a portfolio of CDR methods is needed to balance the impacts. NEGEM findings suggest that climate change mitigation scenarios, which mostly rely on BECCS and af-/reforestation, should consider a wider range of CDR methods.

How to formulate policies and governance structures to optimise the deployment of CDR within the overall climate architecture?

In the short- to medium-term **separate targets and governance frameworks for emission reductions and CDR** are required to ensure that net-emissions are more quickly reduced (Reiner et al, 2021). In EU climate policy, such a separation is included in the European Climate Law, where the contribution of the land-sink towards the net emission reduction target of 55% by 2030 is capped to 225 $MtCO_2e$.

To be able to invest in CDR, stakeholders need **clear, long-term regulation and greater certainty**. (Deliverable 5.2) There is also an urgent need for clear CDR definitions and accounting frameworks internationally. No comprehensive accounting framework for CDR exists, but, as a start, there are relevant parts in UNFCCC and EU frameworks (Deliverable 6.3). These frameworks should be developed to recognize specific features of different CDR methods.

Accounting frameworks must account for storage durability (Mac Dowell et al. 2022). Separate policy instruments are needed for nature-based CDR and permanent CDR, recognising e.g. different permanence of storage and vulnerabilities to intended and/or unintended releases of carbon.

Regulations should **guarantee compliance of CDR with planetary boundaries**. Large scale CDR measures can put pressures on several planetary boundaries, such as fresh water, land system change, and biosphere integrity.

NEGEM has studied the market-based, public procurement, and fiscal policy mechanisms for CDR (Hickey et al. 2023). The **current mechanisms are under-resourced** and provide too little incentive to enable a CDR portfolio that could support achievement of net zero. The current mechanisms mainly support paying modest sums for established afforestation and soil carbon sequestration methods, while **mechanisms to support geological CDR remain largely underdeveloped.**

Chiquier et al. (2022) have shown that **international cooperation is a key for deploying the most cost-optimal CDR pathway** to deliver the Paris Agreement 1.5 °C ambition. This cooperation could be implemented via an international market for negative emissions trading. This way the regions with most CDR potential could generate a "CDR surplus".

(A separate NEGEM factsheet on CDR accounting and regulation can be found https://www.negemproject.eu/results/#factsheets)

Key messages on the role of CDR for EU's 2040 climate policy:

- **Establish separate targets for GHG reduction and CDR for 2040**
  - By 2040 emissions should be close to zero in many sectors, including the energy sector. In addition to targets for deep and sustained emissions reductions, a target for CDR may be needed for 2040.
  - Establish **separate targets for GHG reduction, the LULUCF sector, and technical CDR that leads to geological storage.**
  - An "equitable and fair" allocation of emission reduction and carbon dioxide removal targets between EU Member States is needed, while also considering the EU's responsibilities at a global level.
- **For the 2050 climate neutrality target the role of CDR is likely important**, especially considering the possibility for a degrading forest carbon sink in the EU.
  - Industrial level deployment of CDR methods should start latest in 2030's in order to provide CDR at scale in 2050.
  - However, dependence on CDR should be kept to a minimum.
- **Recognize the different roles of nature-based and technical solutions.** The CO_2 storage time and vulnerability to intended and/or unintended release of CO_2 is essential.
  - Technical solutions with geological-timescale storages provide permanent CDR and are needed to reach climate neutrality.
  - Nature-based methods are needed as they provide strong synergies between climate change mitigation and international targets for nature restoration (i.e. the Kunming-Montreal Global Biodiversity Framework), and broader sustainable development goals given their benefits e.g. for biodiversity and soil quality.
- **Enable co-operation** between Member States and outside EU for CDR (e.g. CO_2 transport & CO_2 storage).
- **Agreement on CDR regulation** is needed as soon as possible, in order to establish a clear investment horizon for stakeholders.

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NEGEM deliverables

- Deliverable 3.2 Report on global NETP biogeochemical potential and impact analysis constrained by interacting planetary boundaries
- Deliverable 3.9 Report on assessment of selected impacts on key non-renewable resource chains
- Deliverable 4.3 Member States Targets
- Deliverable 5.1 NETP analogues and Social License to Operate
- Deliverable 5.2 Stakeholder views on the business case for NETPs
- Deliverable 5.3 Stakeholder views on NETP governance
- Deliverable 6.3 Global governance of NETPs - global supply chains and coherent accounting
- Deliverable 7.3 Link MONET-EU and JEDI
- NEGEM Briefing on the role of CDR in IPCC AR6 WGIII. 2022

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