Carbon Dioxide Removal Strategy for the EU

Discussion paper

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Executive summary

The EU's debate on carbon dioxide removals (CDRs) is gaining momentum, **but in important parts it is still a mystery**. Basics of an EU framework for CDR remain unclear. The overall contributions of CDRs to achieving climate neutrality by 2050 and net negative emissions thereafter are undecided and obscure. The contributions of different CDR options to the EU's overall removal efforts remain unclear. The EU has fairly developed policies for nature-based CDR options – unlike a hardly existing framework for technology-based CDR options – but even this framework has gaps, in particular for the time after 2030. **An EU CDR Strategy could demystify CDRs and help trigger the necessary political debate on CDRs.**

To help close gaps in the existing framework and to support the achievement of climate neutrality in the next 30 years in a credible manner, **the EU CDR Strategy should contain the following elements**:

- **CDRs are the smaller sibling of emission reductions:** No CDR option is as safe as gas, coal and oil in the ground, the world's best "sinks". For this reason, the EU CDR Strategy should strengthen the reductions-first principle, as already enshrined in the EU Climate Law. Accordingly, emission reductions must be the EU's priority, while removals are only an auxiliary means of climate action. This might change slightly as CDR options mature, but at this point it would be an irresponsible bet to assume that CDR will become a major element of EU climate action.

- **Quantified and separate CDR targets for the EU:** As its backbone, the CDR Strategy should contain quantified CDR targets, either set in tonnes or in percentage shares of the EU's overall climate efforts. These CDR targets must be clearly distinct from reduction targets and should aim to include quantified ranges for nature and technology-based CDR concepts. Currently, the EU lacks such a framework. The amount of residual emissions and CDRs for the time after 2030 is unclear. In an ambiguous way, the EU's 2050 climate neutrality target treats reductions and CDR the same. This ambiguity weakens verification, accountability and – ultimately – the environmental integrity of EU climate policies. A CDR Strategy containing quantified targets for CDRs and ranges for CDR options would bring an end to this ambiguity.

- **Pave the way to legally binding targets for the EU and Member States:** For a community of law such as the EU, legally binding targets are the highest possible commitment. They are subject to infringement procedures and are taken seriously by Member States and other players. For this reason, the EU should adopt legally binding CDR targets. As a political document, the CDR Strategy cannot set such targets, but it can commit the Commission to propose a legally binding CDR target for the EU. It should also start the debate on distributing this EU target among Member States.

- **Quantifying the CDR in a context of uncertainties:** Estimates of overall removal needs, removal potentials of different CDR options, and their costs vary drastically. Research has yet to develop clear answers but is unlikely to give them soon or at all. In turn, uncertainties will continue, and they appear so large that the quantification of CDR targets seems impossible. These uncertainties, however, are not an argument against quantifying targets, but for an open political debate on them. It is a common

feature of EU climate policies that it is for the democratic processes – not for science – to make decisions in a context of significant uncertainties.

- **Not all CDRs are created equal:** There are many CDR options – nature- and technology-based concepts. Each option has its distinct advantages and disadvantages. To implement successful CDR policies, the EU needs an informed debate on the pros and cons of each option. It is a critical task of the EU CDR Strategy to trigger this debate, and to inform it through outlining criteria for decision-making. Criteria include co-benefits for ecosystems, permanence, removal potentials, costs or innovation potential. Because the EU's framework on technology-based CDR options is still rudimentary, these criteria are particularly relevant for informing the debate on establishing required laws and policies.

- **Restoration of degraded ecosystems first:** The restoration of degraded ecosystems is a no-regret option. It offers many co-benefits for nature, strengthens climate resilience of ecosystems, is immediately available at low costs, and does not require large areas of additional land. It has the potential to remove and store large amounts of CO_2. Building on the EU's new restoration target and other relevant EU policies, the EU CDR Strategy should put the restoration and protection of forests, peatland, and other ecosystems at its heart.

- **Innovation and research:** Available CDR options still have many shortcomings. Research and innovation can address some of them. As another no-regret option, the EU CDR Strategy should strengthen research and innovation in CDR.

- **Afforestation, reforestation and Bioenergy Carbon Capture and Storage (BECCS):** In many scenarios, afforestation, reforestation and BECCS are central options for removing and storing large amounts of CO_2. However, the EU CDR Strategy should treat these options with caution because their removal potentials are uncertain while negative impacts on biodiversity, water, soil, and land are likely to occur. The CDR Strategy should help ensure that the EU does not repeat past mistakes in EU bioenergy support – a genuine risk of BECCS deployment at large scales.

- **Direct Air Carbon Capture and Storage (DACCS) and Enhanced Weathering (EW):** The EU lacks a framework governing DACCS and EW. Estimates of their removal capacities vary significantly. Against this backdrop, the EU CDR Strategy should help define criteria for establishing a legal framework that would make these CDR options a viable pillar of the EU's efforts to remove CO_2 in a cost effective, energy efficient and sustainable manner. While stressing the innovation potential of these solutions, the CDR Strategy should also be realistic about additional energy demand from renewable energy sources (RES) – in the context of a decarbonised economy which will consume considerably more electricity from RES.

- **Investment needs and incentives:** Removing CO_2 from the atmosphere can be very costly. Technological solutions in particular require large investments. The EU CDR Strategy should specify investment needs and stress the necessity for direct funding. At this point, trading systems for CDR – another idea for incentivizing CDR generation – seem problematic. Depending on their design, they treat reduction and removals alike, although their environmental integrity can be inherently different. Separate sys-

tems that trade only CDRs could address problems of insufficient environmental integrity, but they struggle to reconcile the significant differences of available CDR option.

The EU already has a developed framework for nature-based CDR options – at least until 2030. With the Commission's proposal to revise the LULUCF Regulation, this framework is set to establish a number of new relevant rules for the time after 2030. There is no similar EU framework for technology-based CDR options, and no concrete efforts are underway to develop such a framework in the near future. Against this backdrop, the CDR Strategy would be **complementary to the EU's existing rules – similar to other EU Strategies that complement other EU laws and policies.** The place of the EU CDR Strategy in the EU's climate architecture would be as outlined in the following graphic.

Figure 1: CDR Architecture of the EU.

1 Introduction

To keep increases in temperature to well below 2°C or below 1.5°C compared to pre-industrial levels, drastic and immediate reductions of greenhouse gas emissions are essential, but probably not sufficient. Effectively all emission reduction pathways that stay below temperature goals **assume that CO_2 is removed from the atmosphere**.

The amounts of required removals vary significantly but are large in most scenarios. According to the IPCC, the required scale of net CDRs can vary from 1–2 $GtCO_2$ per year from 2050 onwards to as much as 20 $GtCO_2$ per year.[1] In total, necessary amounts of CDR range between 100 and 1000 $GtCO_2$ cumulatively over the century.[2] The median of CO_2 removals across all scenarios is **730 $GtCO_2$ in the 21st century**.[3] This means that the world could be required to remove and store as much as the equivalent of about 18 years of global CO_2 emissions – based on current global emissions of around 40 Gt. **To contribute to these global removal efforts, the EU long-term climate strategy assumes CDRs of up to 606 $MtCO_2$ in 2050.**[4] According to other estimates, the EU could be required to remove around 50 $GtCO_2$ until 2100 – roughly equivalent to the amount the EU has emitted over the last 10 years.[5]

As such, various **EU policies and laws recognise the importance of CDRs**:

- **Climate neutrality target 2050:** The new European Climate Law (ECL) establishes a legally binding target for the EU to become climate neutral by 2050. By then, greenhouse gas emissions *and* removals regulated in the EU must be balanced (Article 2.1).

- **Net greenhouse gas target for 2030:** The ECL sets an EU *net* greenhouse gas emissions target for 2030. Accordingly, emissions after deduction of removals must be at least 55% below 1990 levels. The contribution of net removals to target achievement is limited to 225 million tonnes of CO_{2eq}.

- **Net negative emissions after 2050:** According to Article 2.2 of the ECL, the EU shall aim to remove more greenhouse gas emissions than it emits after 2050 – which would result in the net negative emissions.

- **LULUCF Regulation:** The LULUCF Regulation sets the no debit rule, stipulating that accounted emissions do not exceed removals from the LULUCF sectors (Article 4). If the Commission's proposal on a revised LULUCF Regulation would be adopted, the Regulation would also establish CDR rules for the time after 2030.

- **Long-term climate strategies:** According to Article 15.4 of the Governance Regulation, Climate Strategies of the EU and Member States should contribute to achieving a balance between emissions and removals.

- **EU Biodiversity Strategy:** The EU Biodiversity Strategy states that the Commission will propose legally binding EU targets to restore degraded ecosystems, *in particular*

[1] IPCC, 2021.
[2] IPCC, 2018.
[3] IPCC, 2021, 4-81; Rogelj et al., 2018b; Rickels et al., 2018.
[4] COM (2018) 773, p. 198.
[5] Lee et all, 2021, see also Geden Oliver and Felix Schenuit, 2020.

> *those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters*.[6]

In light of the scientific discourse and the EU's framework, the **CDR debate in the EU is gaining momentum**. Member States discuss the role of CDRs in more detail – partly in response to the net climate targets for 2030 and the 2050 climate neutrality target. As a frontrunner, Sweden has developed a relatively detailed roadmap to remove quantified amounts of CO_2 from the atmosphere.[7] A few companies have set themselves targets to achieve negative emissions.[8] These developments are likely to gain additional momentum if other major players, such as the US or China, would engage more actively in the debate on CDRs and would adopt new policies.

Despite this new momentum, **discussions in the EU are still deficient.** The political debate in the EU has not addressed the strategic role of CDRs in EU climate policies in detail. The contributions of CDRs to achieving the 2050 climate neutrality target remain unaddressed. With the exception of the LULUCF Regulation, the discussions on regulating CDRs are still in an early phase. The broader public seems largely unaware of the need for CDRs and negative emissions. **International discussions** are also underdeveloped; the political economy of CDR and net negative emissions has received little attention in the post-Paris negotiations[9], and the concept of 'carbon debt' has not gained traction yet. NDCs from developed countries hardly contain CDR commitments.[10]

In this context and based on previous work[11], this **paper** discusses a CDR strategy for the EU. It examines why the EU should have a CDR strategy (Chapter 2) and explores the main elements of a CDR strategy (Chapter 3). As a discussion paper, the paper does not explore available CDR options in detail nor their possible roles in an EU CDR Strategy.

What are CDRs?

The IPCC defines CDRs as "the withdrawal of greenhouse gases from the atmosphere as a result of deliberate human activities".[12] In broad terms, these activities can be grouped into (1) nature-based removals ("enhancing biological sinks of CO_2") and (2) technology-based removals ("using chemical engineering to achieve long-term removal and storage"). Nature-based CDRs include, for example, restoring degraded ecosystems, afforestation and reforestation, rewetting of peatland, ocean fertilization (OF), or soil carbon sequestration (SCS). Technology-based ideas are, for example, BECCS, DACCS or EW. BECCS combines nature-based options with technical storage. Storage options have varying degrees of permanence.

[6] COM (2020) 380 final. The EUs Farm to Fork Strategy and the Circular Economy Action Plan also mention CDRs as a tool to achieve climate neutrality.
[7] See https://www.regeringen.se/48ec20/contentassets/1c43bca1d0e74d44af84a0e2387bfbcc/vagen-till-en-klimatpositiv-framtid-sou-20204.
[8] Microsoft wants to achieve negative emissions by 2050, offsetting all its emission since 1975, https://www.bbc.com/news/technology-51133811.
[9] Aniruddh et al., 2021
[10] Mace et al. 2021a
[11] Meyer-Ohlendorf, Nils, 2020.
[12] See https://www.ipcc.ch/sr15/chapter/glossary/.

2 Why the EU should have a CDR strategy

Although the EU has a range of policies relevant for CDRs – probably more than any other world region - its **framework for CDRs is deficient**:

- **Lack of a strategic approach:** The EU framework lacks a strategic approach to CDRs, and there exists no comprehensive framework regulating *all* CDRs. The EU has policies for some CDR options – in particular nature-based CDR options (LU-LUCF Regulation) – but lacks a framework that addresses CDRs and their contribution to EU climate action in a holistic manner.

  This causes problems. First, the contribution of CDRs to EU climate policies and target achievement remains unclear, particularly for the time after 2030. Second, the EU CDR discussion is largely a debate in silos. Specific stakeholders discuss CDRs through the lens of their specific interests and circumstances, which makes an informed debate on the role of each CDR option harder.

- **Important CDR questions unanswered:** Many questions important for CDRs are unanswered:

  - **No pretext to delay reductions:** How can the EU avoid CDRs leading to a delay in emission reductions? What is the relationship between reductions and removals?
  - **Required CDR amounts:** How much CO_2 should the EU remove from the atmosphere until 2050 and 2100? Should the EU have quantified CDR targets?
  - **Which CDR options:** There are many different CDR options, each featuring distinct advantages and disadvantages. Which CDR options should the EU prefer, and which should it not pursue?
  - **Restoring degraded ecosystems:** Should restoring degraded ecosystems be the priority of the EU's removal efforts?
  - **Innovation and research:** Many CDR options are not yet fully developed. Could innovation and research solve these problems? How can the EU support innovation?
  - **Incentives for investments:** Many CDR options are expensive. How could the EU incentivise investments in their development and deployment?
  - **When:** Many scenarios assume that CDRs will only start playing an important role in the second half of the century, but this does not mean CDRs are a futurist debate decades away from today. As CDR's capabilities do not exist at the required scale, but need long timespans to develop, the EU needs to have an informed debate on CDRs now. Which CDR options should become available, and when?

- **Lack of public awareness and debate:** Although CDRs have received growing attention in recent years – probably more than ever before – public awareness is still low. The importance of CDRs in the near term is not well understood, and the need for net negative emissions in the long term is not an item of the political debate. This is a problem because CDR deployment is not a futuristic prospect but already a real issue with many important implications for societies today. A CDR Strategy could help trigger the debate required to increase public awareness.

An **EU CDR Strategy** is an opportunity to help answer these questions, and to facilitate political consensus on the roles of CDRs in the EU, among its Member States and citizens. It is also an established way to address a new policy area that has lacked strategic orientation, well-defined objectives, an agreed narrative, and normative benchmarks.

The EU CDR Strategy could feature as a **Communication by the Commission**. Alternatively, it could be a full **EU Strategy endorsed by the Council of Ministers and Parliament** – similar to the EU Environmental Action Programme. A Communication by the Commission promises higher political feasibility and quicker adoption. A full EU Strategy has more political weight, but its adoption can be slow. The Strategy could build on Member States' long-term strategies which already address CDRs but, for the most part, only in a descriptive manner.

3 Relationship with other EU policies

A CDR Strategy would not start from scratch but would take account of other EU-relevant policies significant for CDRs. **Concerning nature-based CDR options, the EU has a developed framework**. The LULUCF Regulation contains detailed rules until 2030. It sets the so-called no debit rule and contains accounting rules. The Biodiversity Strategy and Forest Strategy complement this Regulation.

If adopted as proposed by the Commission, **the revised LULUCF Regulation** would enhance this framework, introducing news rules for the time after 2030. The revised Regulation would include an enhanced EU 2030 target of net removals of 310 million tonnes CO_{2eq} and would distribute this target among Member States. For this purpose, the Regulation would set legally binding targets for Member States, which would be enforced by a new compliance system that resembles the Climate Action Regulation. After 2030, the Regulation would also expand its scope to non-CO_2 emissions from the agriculture sector and would set an EU commitment aiming to achieve climate neutrality in the land sector by 2035. For the time after 2036, the Regulation would require covered sectors to generate CDRs to balance remaining emissions in other sectors.

The EU has **no similarly detailed framework for technology-based CDR options**. The CCS Directive only includes rules on the storage of CO_2 from installations covered but is not applicable to technology-based CDR options. The Emissions Trading Directive stipulates that there is no obligation to surrender allowances if the respective emissions are verified as captured and permanently stored – in accordance with the requirements of the CCS Directive (Article 12 (3a)).

The CDR Strategy would not replace this framework but complement it. Performing its complementary role, the CDR Strategy **would help close gaps in the existing framework**, such as setting CDR targets for the EU, establishing an agreed CDR narrative for the EU, and prioritizing CDR options with the greatest co-benefits for society and nature. In this sense, the CDR Strategy would be similar to many other EU Strategies that complement laws and policies.

4 What should the EU CDR Strategy contain?

The CDR Strategy of the EU should include the following elements:

4.1 Reductions first, removals second

As one of its core elements, the EU CDR Strategy should state and reinforce the **reductions-first principle as already stipulated implicitly in Article 2.1 of the ECL**. For the following reasons, emission reductions must be the priority, while removals are only an auxiliary means of climate action:

- **Insufficient capacities:** Although the world's geological storage capacities are large[13], the technological, economic, and political limitations of each CDR option make it clear that necessary removal and storage capacities are not available at a scale that could largely substitute emission reductions.

- **Comparing apples and oranges:** CDRs cannot substitute emission reductions. They are an inherently weaker way of climate protection than emission reductions – all CDR concepts face challenges that reductions do not have, ranging from permanence to sustainability. Removed and stored CO_2 can leak, while emission reductions cannot. Technology-based CDR options might be able to address problems of permanent storage but they struggle with unsustainable levels of energy consumption and land use or other sustainability issues (see below).

- **Tipping points:** Emission reductions foregone in the present cannot simply be substituted by future emission reductions because emissions accumulate in the atmosphere, leading to greenhouse gas concentrations that are much more likely to set in motion tipping points of the climate systems, which – in turn – can lead to additional emissions.[14]

- **Monitoring and verification:** Monitoring and enforcement of CDRs is fundamentally more difficult than the monitoring and enforcing of emission reductions.[15]

- **Until 2050 and beyond:** The ECL already sets the reductions-first principle but only until 2030. It makes no provision for the time after 2030.[16] The CDR Strategy should help fill this gap.

[13] The IEA estimates global storage capacities between 8 000 to 55 000 GtCO2; IEA, 2021.
[14] Meyer-Ohlendorf, Nils, 2020.
[15] Ibid.
[16] Article 2.1 stipulates that the EU and the Member States "shall prioritise swift and predictable emission reductions and, at the same time, enhance removals by natural sinks". Article 2.1 limits the contribution of net removals to achieve the 2030 target to 225 million tonnes of CO_2 equivalent - to ensure sufficient mitigation efforts. The ECL makes no similar provision for the time after 2030.

4.2 Quantified CDR targets

As another core element, the EU CDR Strategy should establish a quantified target for the removal of CO_2 – for the **following reasons**:

- **Backbone of any strong strategy:** Clear and robust targets are a core element of any strategy. Clear quantification of targets provides for a robust verification basis, which in turn supports accountability.

- **Clarify the role of CDRs in EU climate policy:** The exact role of CDRs in EU climate policies after 2030 is still unclear.[17] Neither the EU's 2050 climate neutrality target nor any other EU rule specify the permissible amounts of residual emissions and the contributions of CDRs to target achievement. In consequence, the climate neutrality target could be achieved in many different ways. It could be met through 100% reductions and no CDRs, but it could also be reached through significantly smaller reductions, for example 80%, and – correspondingly – higher CDR shares. This ambiguity has important implications for the environmental integrity of the EU's climate framework after 2030, its investment environment, and research needs. A quantified CDR target would end this ambiguity.

- **An established and proven way of EU policy making:** Targets have driven EU climate and energy policies – practically since its inception. They have been an essential reference point of the political debate and have heavily influenced the choice and design of measures. This lesson also applies to CDRs.

- **Assigning responsibilities for CDRs:** With the exception of the LULUCF, the EU does not assign responsibility for the development or deployment of CDRs.[18] Targets for the EU and Member States are a proven way to assign responsibilities to them in a transparent and politically meaningful way.

Design options of a quantified CDR target

The EU CDR Strategy could quantify the CDR target in various ways.

As one option, the Strategy could set specific amounts in tonnes of CO_2 emissions to be removed from the atmosphere by activities within EU territory. In this design option, the CDR target would specify CDRs in Mt or Gt.

As an alternative, the target could specify a percentage share of the overall EU climate efforts, e.g., reductions of 95% by 2050 and CDRs of 5% compared to 1990 levels. Both options could be combined.

The CDR target could include a quantified target for the EU and / or targets for Member States. The CDR target could also set quantified ranges for sectors or specific CDR options – similar to Sweden's CDR system.

[17] For a general discussion on net zero targets: Rogelj, Joeri et al., 2021.
[18] Mace, M.J., et al., 2021.

4.3 Paving the way towards legally binding targets for the EU and Member States

Experiences in other fields of EU policy support the **case for legally binding targets**. Progress in emission reductions or expanding renewable energies, for example, has been driven by legally binding targets. For a community of law such as the EU, legally binding targets represent the highest possible commitment. They are subject to infringement procedures – the EU's strongest means of enforcement – and are taken seriously by Member States and other players. The CDR strategy should acknowledge the value of legally binding targets for the EU and **should help pave the way towards a legally binding CDR target**.

To this end, the Strategy should **commit the Commission to propose a legally binding CDR target** for the EU. The Strategy should contain a specific timeframe for the Commission to make the required legislative proposal. As a political document with no legal force, the CDR Strategy cannot set a legally binding target.

In addition to this EU target, the CDR Strategy should also **start a process to set targets for Member States** – a critical element for ensuring the implementation of the EU target. For this purpose, the Commission should propose provisions for distributing the new EU target among Member States. If the LULUCF Regulation is revised as proposed by the Commission, the Commission's proposal would necessarily build on the national targets set out in the Regulation. In addition to these targets under the LULUCF Regulation, the Strategy would address the contributions of technology-based CDR options (see below).

If it is politically unfeasible to establish such targets in the CDR Strategy, weaker alternatives include:

- **Qualitative targets:** Qualitative targets do not contain numeric commitments. This weakens verification and – in consequence – accountability. A qualitative CDR target could include, for example, an EU commitment to enhance sinks and to engage in CDR activities, including research and provision of funding.

- **Describing scenarios and options:** As another alternative, the CDR Strategy could contain scenarios outlining possible roles for CDR in achieving the EU's climate targets.

4.4 How much CDRs for the EU?

Although there are clear benefits of including a quantified CDR target in an EU Strategy, its **exact quantification is difficult**. Science does not provide one specific number, but many. Depending on the scenarios and assumed emission reductions, the overall amounts of required CDR vary significantly. The 1,5Tech of the 2018 LTS, for example, assumes carbon captured in the range of 606 $MtCO_2eq$ in 2050, while the 1,5 Life scenario estimates 281 $MtCo_2eq$ and the 1,5Life-LB takes 385 $MtCO_2eq$ CDR.[19]

In consequence, ranges appear so large that the quantification of CDR targets seems impossible. It is true that there is no magic number[20] or formula quantifying CDR targets, but this is not

[19] European Commission, 2018.
[20] A similar argument is relevant for estimating emission budgets: Peters, Glen, 2018.

an argument against CDR targets.[21] It is an **argument for having a political debate on targets**, and underlining scenarios and assumptions. Uncertainties are also a powerful argument to make political decisions on underlying assumptions.

Because each CDR options has distinct pros and cons (see below), the EU CDR target could be further specified along CDR options. Accordingly, the EU target would not only be distributed among Member States but would also differentiate between CDR options, stating that each option contributes quantified ranges of CDRs. Sweden's framework on negative emissions could inform this discussion. Sweden's government report on negative emissions – a non-binding document – allocates CDR contributions to specific CDR options.[22] As another illustration, the EU Long-Term Climate Strategy contains scenarios that allocate specific amounts of carbon capture to biomass and DACCS.[23]

While this option has various benefits – clarity of the contributions of each CDR option, verification and accountability, and possibly preference for CDR options – **it struggles with significant uncertainties.** Circumstances in Member States seem to vary too much to assign specific contributions of CDR options to national targets. In addition, the removal potentials of each CDR option also vary drastically, making allocation of removal contributions difficult. Because of these uncertainties, the Swedish government report includes wide ranges of CDR contributions or no estimates at all.[24]

4.5 Criteria for an informed debate on CDR options

There is not one single CDR option capable of removing required amounts of CO_2. A mix of different CDR options will be necessary.[25] As each CDR option has specific advantages and disadvantages, the EU needs an informed debate on the pros and cons of each option. It is **one of the main tasks of the EU CDR Strategy to facilitate this debate and to help balance trade-offs and benefits of CDR options**. The Strategy should make the weighing of pros and cons transparent and help explain the reasoning of choices made.

To this end, the EU CDR Strategy should specify the **criteria that should inform the debate and support decision making**:

- **Biodiversity, water quality and soil protection:** In the face of the many pressures on nature, it is essential that the EU CDR Strategy prioritizes removal concepts that have strong co-benefits for biodiversity, climate resilience of ecosystems, prevention of water runoff and erosion, improving water quality and soil protection. The CDR Strategy should avoid concepts that harm biodiversity, undermine water quality or damage soils.

- **Permanence of storage:** Permanent storage of CDRs is a key aspect of any CDR strategy.

[21] Meyer-Ohlendorf, Nils, 2020a.
[22] According to this report, Sweden's CDR options for 2045 are distributed as follows: (1) increased carbon sinks in forests and land by 2,7 - ? Mt CO_2 equiv. / year, (2) BECCS by 3-10 Mt CO_2 equiv. / year, (3) other removal technologies with unknown quantities, and (4) verified emission reductions in other countries by 0 to very great Mt CO_2 equiv. / year.: the policy framework also quantifies CDR target for 2030, using the same categories for the 2045 target. Report available online at: https://www.regeringen.se/48ec20/contentassets/1c43bca1d0e74d44af84a0e2387bfbcc/vagen-till-en-klimatpositiv-framtid-sou-20204.
[23] European Commission, 2018.
[24] See previous footnote.
[25] Mace, M.J., et al., 2021.

- **Capable of removing large quantities of CO_2:** Given the required amounts of CDR, CDR concepts should ideally be capable of removing and storing large quantities of CO_2 or should at least promise to develop such capacities in the future.[26]

- **More removals than emissions – in balance:** To be a meaningful tool of climate protection, any CDR option must remove more CO_2 than it emits, including life cycle emissions.[27]

- **Available now, soon or in the future?** Some CDR options are available now, others are still a distant and futuristic prospect. While immediate availability is an important criterion, CDR options that could gain importance as they mature should not be excluded.

- **Verification and accountability:** Verification of CDRs is essential, not only to understand the amount and permanence of CDRs, but also to ensure accountability. Verification and accounting are particularly challenging for CDR options that cannot ensure permanent storage but remove CO_2 only for comparatively short periods.[28] Accounting for life-cycle emissions is another difficult accounting issue that needs to be addressed to ensure that negative emissions are achieved in balance. [29]

- **Innovation, competitiveness and new markets:** Some CDR options offer considerable innovation potential and opportunities for creating new markets and industries. In principle, this is true for technological solutions such as DACCS, but it also applies to ecosystems' restoration and management. As the need for large amounts of CDR is likely to grow, research into new CDR options might become more important (see below).

- **Cost effectiveness:** Cost effectiveness is another important criterion. However, this criterion should clearly differentiate between long-term and short-term cost developments. Some removal policies might be costly today but might offer required removal capacities in the long term, possibly at lower cost as they mature.

- **Intergenerational equity**: To avoid future generations having to bear the implementation of CDR[30], the Strategy should state that the development and deployment of CDR capacities needs time and should start promptly.

- **Only in the EU:** According to Article 2.1 of the ECL, the EU has domestic climate targets for 2030 and 2050. Only reductions and removals generated within the EU are eligible for target achievements. International offsets are not a possible means of target achievement. The CDR Strategy should underline these requirements.

- **Public acceptance:** With its many implications for societies, public acceptance is another essential criterion. To be feasible, specific CDR options must be politically accepted.

[26] Fajardy, Mathilde et al., 2019.
[27] Ibid.
[28] Elkerbout, Milan and Julie Bryhn, 2021.
[29] Ibid.
[30] Bednar, Johannes et al., 2021

4.6 Restoring degraded ecosystems

The restoration of degraded ecosystems is already the centerpiece of several EU policies and laws, in particular the relevant EU Directives on nature protection and the Biodiversity Strategy. The Commission is set to link these rules with CDRs when it proposes **legally binding EU nature restoration targets in late 2021**. These targets should include the restoration of degraded ecosystems, "in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters".[31]

These policies and laws will continue to be central for nature protection and restoration, but the CDR Strategy should strengthen the links between nature protection and climate action as inseparable policies. It should solve the existing tension between these two policy fields, by clearly stating that **the restoration of degraded ecosystems[32] should be a priority**[33] - for the following reasons:

- **Co-benefits for biodiversity, water and soils:** The EU has many rules to protect nature and restore habitats and species. But protection has been incomplete, restoration has been small-scale, and the implementation and enforcement of legislation has been insufficient.[34] Biodiversity continues to decline at a faster rate than at any point in human history. Water and soils in the EU are under stress, often severely. To help address these challenges, restoration of degraded ecosystems must be at the heart of the EU's CDR efforts.

- **Climate resilience:** The capacity of natural sinks to sequester and store CO_2 for long periods depends heavily on its resilience against the consequences of changing climates. Resilience against climate change is a key issue. The impact of climate change on natural sinks is not straightforward, but it is well-established that healthy and diverse ecosystems are more resilient to many of the consequences of the climate crisis than degraded ecosystems. Monoculture forests, for example, are more prone to fall victim to storms, pests, diseases and droughts than diverse close-to-nature forests.

- **Large CDR amounts:** The restoration of degraded ecosystems has the potential to remove large amounts of CO_2.[35] According to the European Commission[36], 500 $MtCO_2e$ could be removed annually by 2050 through forest management and afforestation. Other studies project up to 1,000[37] or even 1,200 $MtCO_2e$.[38] Restoring degraded wetland and peatland through rewetting halts emissions quickly, but its potential to sequester CO_2 is relatively small (globally 0.15-0.8 Gt CO_{2e} per year)[39] and occurs only over long periods.

[31] COM (2020) 380 final.
[32] Pursuant to the definition of the Commission's Biodiversity Strategy Impact Assessment, restoration of degraded ecosystems means: "In many cases full restoration would require measures to overcome the long-term impacts of some pressures, [...]."European Commission, Impact Assessment Biodiversity Strategy, 3.5.2011 SEC(2011) 540 final. According to other definitions, restoring means that a degraded area moves up one level to a better ecological status, or the restoration of the key species, properties and processes of ecosystems and their functions. Lammerant, Johan et al., 2013.
[33] IPCC AR 6, p. 107 and 109.
[34] COM (2020) 380 final, p. 3.
[35] Studies show that old forests continue to provide significant carbon sequestration. Young forests, in contrast, are often sources of CO_2 because their creation frequently follows disturbance to soil resulting in CO_2 emissions that can exceed the CO_2 reabsorbed through the growth of young trees. du Bus de Warnaffe, Gaëtan and Sylvain Anger, 2020.
[36] European Commission, 2018.
[37] Lange, Markus; Nico Eisenhauer.; Carlos Sierra et al., 2015.
[38] Roe, Stephanie; Charlotte Streck; Michael Obersteiner et al., 2019.
[39] IPCC, 2019.

- **Advantages compared to afforestation and reforestation:** With much of Europe's land already taken up by agriculture, urban areas and other infrastructure, the area available for afforestation or reforestation in Europe is small. Restoration of degraded ecosystems, in contrast, does not require much additional land, if any.

4.7 Afforestation, reforestation and Bioenergy with Carbon Capture and Storage (BECCS)

As another important issue, the EU CDR Strategy must address afforestation, reforestation and BECCS – in many scenarios the **main options for removing and storing large amounts of CO_2**. According to the IPCC, afforestation and reforestation could remove between 0.5 and 10 $GtCO_2eq$- per year in the coming decades.[40] Others estimate annual removals of 1 to 12 $GtCO_2$ by 2100.[41] Regarding BECCS, IPCC scenarios (1.5°C) assume removals between 0-1, 0-8, and 0-16 $GtCO_2$ annually in 2030, 2050 and 2100 respectively, and cumulative removals by 2100 between 151 and 1,191 $GtCO_2$.[42] For the EU, the Long-Term Climate Strategy assumes removals from BECCS in a range of 5 to 276 $MtCO_2$ annually by 2050.[43]

In short, very **significant amounts of CDR seem possible but uncertainties are large** – estimates differ by a factor of 10 or more. Uncertainties grow if implementation on the ground, competition for land, or local circumstances are fully considered. In light of these uncertainties, the EU CDR Strategy should treat these CDR options with caution. Taking a cautious approach, the CDR should include only indicative estimates of possible contributions to the EU's overall removal efforts. In addition, it should outline the disadvantages of reforestation and afforestation combined with BECCS:

- **Negative impacts on biodiversity, water and soils:** BECSS at large scale is likely to be based on monocultures, which damage biodiversity, water and soils. In this sense, BECCS holds the risk of repeating past mistakes in EU bioenergy support.

- **Use of land:** At large scales, BECCS uses very large areas of land, competing with food production, nature protection and built infrastructure. According to the IEA, BECCS could require as much as 0.03-0.16 ha to remove a single ton of CO_2 annually.[44]

- **Climate resilience:** Afforested and reforested areas are often monocultures which not only have negative implications for nature but are also considerably less resilient against the impacts of climate change.

[40] Ibid.
[41] Fuss et al., 2018.
[42] IPCC, 2018.
[43] European Commission (2018).
[44] IEA Greenhouse Gas R&D Programme (IEAGHG) (2021), IEAGHG Technical Report: 2021-01 Biorefineies with CCS.

4.8 Direct Air Carbon Capture and Storage (DACCS) and Enhanced Weathering (EW)

The removal potentials of DACCS and EW – two frequently discussed technological CDRs – are similarly uncertain. For DACCS, the IEA projects about 10 $MtCO_2$ per year in 2030 [45], but developers hope for drastically higher capacities of around 1% of global emissions or 225 $MtCO_2$ annually by 2025. [46] For the EU, estimated DACCS removal potentials range between 83 and 264 $MtCO_2$ per year by 2050. [47] At this point, only 15 small-scale DACCS installations operate in Europe, the US and Canada; one large-scale plant with a capture capacity of 1 Mt per year is planned to become operational in 2023. [48] The potential of EW ranges between 0,5-4 $GtCO_2$/year by 2050, with a total cumulative potential of around 100 Gt by 2100. [49]

Because of these uncertainties, the EU CDR Strategy cannot include quantified targets for these two CDR options. Instead, the CDR should include indicative estimates of possible contributions to the EU's overall removal efforts. The Strategy should be **descriptive**, outlining the disadvantages and advantages of each technological CDR option. As a contribution to the debate and in view of developing a legally binding and robust EU CDR framework, it should also help define criteria that would help make DACCS a viable pillar of the EU's efforts to remove CO_2 permanently in a cost effective, energy efficient and sustainable manner.

As **possible advantages** of DACCS, the Strategy should discuss limited land requirements, low environmental impacts and the possibility of locating plants close to suitable storage or utilization sites, eliminating the need for long-distance CO_2 transport[50]. Higher soil fertility, possibly higher crop yields and high permanence of storage should be addressed as possible co-benefits of EW.[51] The Strategy should also explore innovation potentials, and the ability to create new markets and jobs.

As **possible disadvantages**, the Strategy should discuss costs, typically ranging anywhere from USD 100/t to USD 1 000/t.[52] The Strategy should clearly state that both DACCS and EW depend on the availability of renewable energy if they are to serve their purpose of generating negative emissions. In this context, the Strategy should specify the renewable energy needs of DACCS and EW, and – importantly – should put them in the context of increased demand for renewable energy in a decarbonised economy where transport, building and industry need to be fully electrified and will consume considerably more electricity. The Strategy should explain whether this additional demand of energy from RES is economically and technically feasible. Last but not least, it should specify infrastructure needs and their impacts on land use, nature protection and the life-cycle emissions of these infrastructures. Regarding EW, the Strategy should address the implications of rock mining and amounts of required lands.

4.9 Soil carbon sequestration

As another CDR option, the EU CDR Strategy should address **sequestration of carbon in agricultural soils through management**. With ranges between 0.5 and 7 t CO_2 per hectare per year or between 2,000 to 5,000 $GtCO_2$ per year globally, the potential of this CDR option is

[45] IEA, 2021.
[46] https://www.carbonbrief.org/swiss-company-hoping-capture-1-global-co2-emissions-2025
[47] NEGEM, 2021.
[48] IEA, 2021.
[49] The Royal Society and Royal Academy of Engineering, 2018.
[50] IEA , 2021.
[51] The Royal Society and Royal Academy of Engineering, 2018.
[52] IEA , 2021.

highly variable.[53] For the EU, the estimates range from 9 Mt to 58 $MtCO_2eq$ per year.[54] Removal potentials of soil carbon sequestration depend highly on regional circumstances and specifics of the soil types.

Permanence of storage also varies considerably, depending on management practices, climate and soil conditions. Storage can be as short as 5 to 10 years, although long time spans are also possible. At the same time, carbon leakage is a concern as management practices need to be maintained to avoid reversal and climate change affecting biomass growth.

With these considerable uncertainties in mind, the CDR Strategy should **discuss the co-benefits of soil carbon sequestration**. Co-benefits include better soil structure and soil fertility, better water retention capacity, greater resilience to climate change, reduced soil erosion and lower soil compaction risks. Soil carbon sequestration can be implemented at a larger scale within short timeframes. Low costs or even negative costs are other advantages.[55] As a possible disadvantage, the Strategy should help avoid that soil sequestration leads to additional environmental pressures through intensified farming.

4.10 Research and innovation

Available CDR options still have specific shortcomings that research and innovation might be able to solve. DACCS, for example, is still very costly and energy-intensive. At large scale, it requires massive infrastructure. Scaling up EW requires solutions regarding mining and availability of land. Soil carbon sequestration, afforestation and the restoration of degraded ecosystems also raise specific questions which research might be able to address. In light of these research needs, the CDR strategy should stress the central role of research. **Research and innovation are the other no-regret options.**

4.11 Incentives for CDR deployment and research

Technological CDR options are expensive and require large investments. Investment needs for DACCS, for example, range between 100-1000 USD/tCO_2. [56] For BECCS, cost estimates range between 140-270 USD/tCO_2. [57] Costs for nature-based options are considerably cheaper but still require substantial investments. They range between USD 15 to USD 30 per tCO_2 for afforestation and reforestation for the year 2100, and USD10 to USD 100 per tCO_2 for peatland restoration.[58]

In light of significant investment needs, the **EU needs an informed political debate on incentives**. Which incentives and policies are needed to unleash investment at required scale? How should the EU design support for CDRs to avoid perverse incentives? What is the role of government support and private investors? Should there be a market for CDRs? Should incentives include grants, tax deductions or scheme hatching investment risks?

[53] Smith, Pete, 2016.
[54] Lugato, Emanuele; Francesca Bampa, et al., 2014.
[55] Jeffery, Louise et al., 2020.
[56] IEA, 2021.
[57] The Royal Society and Royal Academy of Engineering, 2018.
[58] Ibid.

The **EU CDR Strategy should help answer these questions**. It should specify investment needs, and outline concrete measures:

- **Direct funding:** Public funding is critical in particular for the development and pilot testing of new systems.[59] According to the IEA, large-scale demonstration of DACCS will require targeted government support, in particular in the near term.[60] As BECCS, DACCS and EW have no other benefit than generating CDRs, they are likely to need continuous support, even if the costs decrease.[61] In this context, it should be discussed whether subsidies could be paid through a fund that is replenished by a levy paid by companies covered by the Emission Trading System or the Common Agricultural Policy.[62] In Norway, the carbon tax supports CCS projects directly.[63]

- **Tax breaks:** Although not directly in the competency of the EU, the CDR Strategy could outline the benefits of tax breaks to incentivise investment from the private sector.[64]

- **Inclusion in EU ETS:** The inclusion of CDRs in the existing EU ETS is another idea to incentivise the deployment of CDRs. Accordingly, installations covered by the ETS would be entitled to generate new allowances through CDR.[65] This proposal would require important changes of the ETS Directive which currently is based on emissions, and excludes installations solely using biomass

  This proposal, however, has problems. For three reasons, the CDR Strategy should not advance it. First, the proposal treats CDRs and reductions alike although they are inherently different ways of climate action (see above). Second, it would weaken the environmental integrity of the ETS because it would introduce a second and weaker "currency" for compliance. Third, it would be incompatible with CDR targets that are separate from reduction targets.

  Discount factors, whereby a reduction unit would be worth a multiple number of CDRs, cannot address the inherent differences between reductions and removals. Such discount factors make a complicated system even more complex. Poor experiences with temporary CDM units argue against the mixing of reductions and removals in trading systems.

- **Separate trading system for CDRs:** As another proposal, trading of CDR could be established in a separate system exclusively for CDRs. Such system could, for example, establish requirements for installations and activities covered to generate specific amounts of CDRs, and would allow them to trade CDRs. This system could address the problems of environmental integrity that a combined system has.

  However, such system needs to take account of the differences between the various CDR options. Because of their inherent differences, nature-based solutions and technology-based CDR options cannot be treated alike. Even nature-based CDR options differ significantly and need to be treated differently. A discount factor, whereby CDR

[59] Mulligan, James et al., 2020.
[60] IEA, 2021.
[61] Jeffery, Louise et al., 2020.
[62] Ibid.
[63] Zapantis, Alex; Alex Townsend and Dominic Rassool, 2019.
[64] Mulligan, James et al., 2020.
[65] Rickels Wilfred et al., 2021.

options such as nature restoration are preferred, could address this issue but it would lead to more complexity. It would also need to make tradeoffs between sustainability and permanence.

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