Carbon Dioxide Removal (CDR): What is Sustainable and Just?

by Duncan McLaren and Olaf Corry

Duncan McLaren is a Climate Intervention Fellow in Environmental Law and Policy at the UCLA School of Law, USA. Olaf Corry is Professor of Global Security Challenges at the University of Leeds, UK.

The Quaker United Nations Office

The Quaker UN Offices in Geneva and New York have supported peace and justice concerns at the United Nations for over 75 years.

We offer both direct advocacy and behind the scenes (quiet) diplomacy to facilitate constructive outcomes to negotiations. We are accredited observers at the UN Framework Convention on Climate Change, the Intergovernmental Panel on Climate Change, the Human Rights Council, the UN Environment Programme, and the World Trade Organization. Past work includes intensive quiet diplomacy support to the Paris Agreement, to the development of the Human Rights Council and the Landmine Ban Treaty, to preparations for the 1992 Earth Summit, and the establishment of the UN Convention to Combat Desertification.

Quaker United Nations Office

13 Avenue du Mervelet
1209 Geneva, Switzerland

Tel: +41 22 748 4800
Fax: +41 22 748 4819
www.quno.org

Introduction

As atmospheric greenhouse gas (GHG) concentrations continue to rise apace and global temperatures and climate impacts accelerate due to insufficient global action, many are placing hopes and expectations in large scale anthropogenic ‘carbon dioxide removal’ (CDR) to balance the global carbon budget.

CDR comprises a range of ideas and schemes that aim to draw down atmospheric carbon dioxide (which is already at harmful levels) and store it safely. In pursuing a maximum of a 1.5°C temperature rise at 2100, the Intergovernmental Panel for Climate Change (IPCC) Reports include many potentially unsustainable scenarios with removal of between 6 and 11 billion tonnes of CO_2 (6-11 Gt-CO_2) *every year* for 50 years[1]. This would be a staggering amount of removal and storage and raises a host of challenging questions not only about ***feasibility and effectiveness***, but also about ***safety, sustainability, legality,***[2] ***justice, ethics and geo-politics.***

---

[1] IPCC, ‘Global Warming of 1.5ºC’ (Switzerland: Intergovernmental Panel on Climate Change, 2018). https://www.ipcc.ch/sr15/

[2] Large-scale CDR schemes with (negative) effects on biodiversity would seem to fall under a *de facto* moratorium established by the United Nations Convention for Biological Diversity (CBD). See CBD, ‘Climate-related Geoengineering and Biodiversity’ https://www.cbd.int/climate/geoengineering. Oceanic CDR schemes may also be restricted by London Convention/London Protocol provisions (not yet in force) to prevent deployment of marine geoengineering techniques beyond legitimate scientific research (see: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/LC-45-LP-18.aspx).

Questions include:

- Are such rates of removal even possible in the face of technical, economic and social limits?[3]
- Whose continued emissions would be counterbalanced with CDR?
- What would a world of large-scale CDR look like in terms of human rights, sustainability and geopolitical risks?
- What do such calculations assume about continual economic growth and global inequalities?
- Can CDR be pursued without deterring urgently needed acceleration of emissions cuts?

This briefing paper offers some answers to these questions, highlighting uncertainties surrounding prospects for CDR, and ***social, environmental and human rights harms*** that may arise if we place too much trust in CDR – especially if CDR is treated as interchangeable with emissions reductions. We outline a pathway that restrains climate change and avoids unsafe, unjust and unsustainable technofixes.

Why CDR?

With continued delays in global action to mitigate emissions, the best estimates of a safe remaining carbon budget for limiting average temperature rise to 1.5°C approach exhaustion within about 5 years[4]. In this context, it is clear that emissions reductions alone will not deliver our desired climate goals.

The IPCC's 6th Assessment Report (AR6) concludes that *"deployment of carbon dioxide removal (CDR) to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO2 or GHG emissions are to be achieved".* At the same time, the IPCC analysis also makes it clear that rapid and equitable emissions reduction at source remains the overriding priority for effective and sustainable action. Moreover, the IPCC makes two further things clear: first, that accelerating emissions reduction would reduce future dependence on CDR, *and* second - ***'large-scale' CDR faces feasibility and sustainability constraints,***[5] ***potentially threatening food and water security for many.*** This applies both to biological forms such as afforestation, and engineered forms such as bioenergy with carbon capture and storage (BECCS).

To support safe and just climate outcomes *some* CDR is needed, but the scale and form it takes will be critical, especially to ensure that pursuit of CDR does not obstruct emissions reduction at source, nor lead to "carbon tunnel vision"[6] harming other essential interests such as human rights, biodiversity and ecological integrity.

Any use of CDR that may affect biodiversity should be in accordance with the precautionary principle and Article 14 of the UN Convention for Biological Diversity (CBD).[7] Climate policy must also be alert to the social, environmental, human rights and security risks that can result from large-scale implementation of emerging CDR technologies and changed land use practices. In the face of climate change driven by growing material consumption, energy use, forest clearance and livestock farming, ***it would be dangerously ineffective, and high risk, as well as unjust, to rely on CDR as a 'technofix', as this approach would avoid the system-wide***

---

[3] Sabine Fuss et al., 'Negative Emissions—Part 2: Costs, Potentials and Side Effects', *Environmental Research Letters* 13, no. 6 (2018): 063002; Pete Smith et al., 'Biophysical and Economic Limits to Negative CO_2 Emissions', *Nature Climate Change* 6 (online 2015): 42, https://doi.org/10.1038/nclimate2870

[4] Robin D. Lamboll et al., 'Assessing the Size and Uncertainty of Remaining Carbon Budgets', *Nature Climate Change* 13, no. 12 (December 2023): 1360–67, https://doi.org/10.1038/s41558-023-01848-5; Piers M. Forster et al., 'Indicators of Global Climate Change 2023: Annual Update of Key Indicators of the State of the Climate System and Human Influence', *Earth System Science Data Discussions*, 8 May 2024, 1–57, https://doi.org/10.5194/essd-2024-149.

[5] IPCC 2023 Summary for Policymakers https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf p. 23.

[6] 'It's Time to Move beyond "Carbon Tunnel Vision"', SEI, accessed 16 May 2024, https://www.sei.org/perspectives/move-beyond-carbon-tunnel-vision/.

[7] Article 14 requires any proposed projects that are likely to have significant adverse effects on biological diversity to be subject to full assessment of threats to biodiversity or ecological functioning, and appropriate efforts to provide restoration or compensation.

transformation of root causes in our energy, economic and social systems seen as essential by both the IPCC and IPBES[8]. In other words, the need for CDR must be minimized, and legitimate 'residual emissions' should only include those that can be justified on grounds of social necessity, not merely the financial cost or technical difficulty of abatement.

How much CDR?

In scenarios and models of future climate pathways, CDR is conceived to play three roles.

1. ***Accelerate:*** Before global 'net-zero' is achieved, additional CDR could hypothetically accelerate action to limit atmospheric accumulation of greenhouse gases.
2. ***Counterbalance:*** At and after net-zero, CDR would counterbalance or compensate for any residual 'hard-to-abate' emissions.
3. ***Reduce:*** In a post net-zero state of global net-negative emissions it could actively reduce atmospheric carbon dioxide levels, theoretically making good any 'overshoot' of the carbon budget.

Yet just and sustainable CDR looks set to be a severely limited resource. There are dozens of different proposed techniques of CDR, most of which remain speculative, experimental, and unproven (see Annex for a brief summary of the status, limitations and potential co-benefits of some of the most widely discussed techniques)[9]. ***There are no demonstrated techniques that can safely deliver large-scale removals without threatening other vital interests or resources***[10].

Given that context, the less CDR required to counterbalance 'hard-to-abate' residuals, the more easily any overshoot of carbon budgets might be limited and corrected with the limited CDR capacity that can realistically and safely be anticipated[11].

With rapid transformation of root causes delivering ***deep emission cuts***, CDR needed for counter-balancing hard-to-abate residual emissions would be dramatically reduced. The difference between 95% emissions cuts and 80% is around 7 Gt-CO_2 annually – a tripling of required CDR capacity. The best way to remove carbon is to leave it in the ground.

With ***rapidly accelerated and equitable emission cuts***, less CDR will be needed to return GHG concentrations to safe levels. The level of overshoot of carbon budgets depends on cumulative emissions between now and net-zero. For purposes of illustration, cutting emissions by 6% per year from now (a pathway to around 80% cuts by 2050), versus 11% per year (reaching around 95% cuts by 2050, and 80% before 2040) increases the aggregate need for CDR (to return atmospheric concentrations of CO_2 to today's levels), by 60% or around 230Gt[12]. Minimizing overshoot is critical, as tipping points and feedbacks in the climate system can result in irreversible harm, even if atmospheric concentrations are subsequently lowered[13].

There are ***huge uncertainties*** over whether such levels and quantities of CDR could ever be delivered, let alone if they are possible without breaching planetary boundaries, exacerbating global

---

[8] IPCC, 'Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change'; Hans-Otto Pörtner et al., 'IPBES-IPCC Co-Sponsored Workshop Report on Biodiversity and Climate Change' (Zenodo, 24 June 2021), https://doi.org/10.5281/zenodo.5101133.

[9] For further discussion of the range of CDR technologies see Duncan McLaren, 'A Comparative Global Assessment of Potential Negative Emissions Technologies', *Special Issue: Negative Emissions Technology* 90, no. 6 (1 November 2012): 489–500, https://doi.org/10.1016/j.psep.2012.10.005; Jan C. Minx et al., 'Negative Emissions—Part 1: Research Landscape and Synthesis', *Environmental Research Letters* 13, no. 6 (2018): 063001; Fuss et al., 'Negative Emissions—Part 2: Costs, Potentials and Side Effects'; Smith S. M. et al., 'The State of Carbon Dioxide Removal - 1st Edition', 2023, Available at: https://www.stateofcdr.org; Smith et al., 'Biophysical and Economic Limits to Negative CO_2 Emissions'.

[10] See Annex, also Fuss et al., 'Negative Emissions—Part 2: Costs, Potentials and Side Effects'; Smith et al., 'Biophysical and Economic Limits to Negative CO2 Emissions'.

[11] This would also mean that CDR capacity could provide some safeguard against worse than anticipated climate sensitivity, or the risk of tipping events.

[12] This is similar to the difference between the lowest and highest estimates from the IPCC – 6Gt-CO_2 pa implies 300 Gt-CO_2 in total; 11 Gt-CO_2 pa implies 550 Gt-CO_2 in total. Other scenarios include even larger scales of removal.

[13] See Tim Lenton et al 2023. The Global Tipping Points Report, at https://global-tipping-points.org/

inequalities or infringing on human rights, or the rights of Indigenous Peoples. What is certain is that ***choices between pathways will have serious consequences, not only for the level of climate risk, but also for sustainability, justice and geopolitics.***

Hyping CDR?

Why are expected levels of CDR so high? In part, this is a product of ***misleading modelling techniques***. Many models 'discount' the costs and limitations of future technological options, while only poorly incorporating the social and environmental benefits of near term behavioural and lifestyle changes[14]. This means ***models treat it as cost-effective to sacrifice near-term mitigation in favour of notionally 'cheaper' (yet highly speculative) future CDR***. Models are also poor at addressing land-use implications, which also makes many CDR techniques appear more feasible in models than in practice.

Political and corporate narratives are also placing undue emphasis on CDR in many parts of the world. ***Fossil fuel companies are investing in and promoting CDR even as they seek to increase production***, with projected levels of fossil fuel production already running at over twice Paris-compatible levels for 2030[15]. The oil and gas company Occidental has recently bought out Carbon Engineering, one of the leading direct air capture (DAC) companies.

Fossil fuel companies and wealthy fossil fuel extraction countries are also promoting a 'carbon management' narrative which misleadingly conflates carbon capture and storage on continued fossil fuel exploitation (CCS) with removing carbon from the atmosphere (CDR) (see Box 1 on CCS vs CDR)[16]. And in wealthy consumer societies in particular, unsustainable levels of aviation and meat-based diets are increasingly included as sources of 'hard-to-abate' emissions, based purely on technical and economic assessments that ignore whether the underlying demands can be socially justified[17].

These narratives justify large funding streams, potentially diverting these from emissions reduction. Governments in wealthy countries – despite falling short on their pledges to deliver climate finance for the Global South – are already investing in substantial infrastructures and policy support for carbon dioxide transport and storage to support the development of carbon removal industries. The USA has allocated $3.5bn to a series of speculative DAC hubs[18]. Both Japan and the UK plan to integrate CDR into their emissions trading schemes[19]. Meanwhile the European Union (EU) is considering a similar approach to build a CDR market predicated on tradeable offsets[20].

Private investment is also flowing: early stage CDR companies accounted for a disproportionate 13% of all climate tech investment in 2023, with over $8bn of capital investment[21]. These investments are

---

[14] Duncan McLaren, 'Quantifying the Potential Scale of Mitigation Deterrence from Greenhouse Gas Removal Techniques', *Climatic Change* 162 (2020): 2411–28, https://doi.org/10.1007/s10584-020-02732-3; Jay Fuhrman et al., 'From Zero to Hero?: Why Integrated Assessment Modeling of Negative Emissions Technologies Is Hard and How We Can Do Better', *Frontiers in Climate* 1, no. 11 (December 2019), https://doi.org/10.3389/fclim.2019.00011.

[15] Stockholm Environment Institute et al., 'The Production Gap: Phasing down or Phasing up? Top Fossil Fuel Producers Plan Even More Extraction despite Climate Promises' (Stockholm Environment Institute, 8 November 2023), https://doi.org/10.51414/sei2023.050.

[16] See for example *The Carbon Management Challenge* involving countries such as the Saudi Arabia, UAE, Norway and the USA, https://www.carbonmanagementchallenge.org/cmc/

[17] See for example Edelenbosch et al, 2022. Mitigating greenhouse gas emissions in hard-to-abate sectors, PBL Netherlands Environmental Assessment Agency, https://www.pbl.nl/sites/default/files/downloads/pbl-2022-mitigating-greenhouse-gas-emissions-in-hard-to-abate-sectors-4901.pdf

[18] Department of Energy, 'Regional Direct Air Capture Hubs', Energy.gov, accessed 16 May 2024, https://www.energy.gov/oced/DACHubs.

[19] Carbon Gap, 'Carbon Removal Policy in the United Kingdom', *Carbon Gap - Policy Tracker* (blog), accessed 16 May 2024, https://tracker.carbongap.org/region/united-kingdom/. *Carbon Herald*, 'Japan To Accept Durable Carbon Removals In Its Emissions Trading Scheme', May 15, 2024 https://carbonherald.com/japan-to-accept-durable-carbon-removals-in-its-emissions-trading-scheme/.

[20] Frédéric Simon, 'EU Commission Wants Captured CO_2 to Become "Tradeable Commodity"', www.euractiv.com, 29 January 2024, https://www.euractiv.com/section/circular-economy/news/eu-commission-wants-captured-co2-to-become-tradeable-commodity/.

[21] Ongeleigh Underwood et al., 'Circular Carbon Market Report: 2023 Analysis' (Circular Carbon Network, 2023),

predicated on projections of markets trading huge volumes of removals at prices per tonne of CO_2 of $200 or more[22]. They have been encouraged by voluntary purchases or advance purchase commitments of high-cost early-stage CDR removals by companies including Microsoft, Airbus and Equinor[23]. In effect, carbon trading businesses and CDR start-ups are increasingly attempting to commoditize forests, oceans and soils as carbon sinks.

Inflated demands for gigaton scale, land-intensive CDR technologies could have serious implications for human rights, justice and sustainability[24]. At the same time, they also maintain existing structures of exploitation, extractivism and domination, sustaining the political power of fossil fuel interests, agribusinesses, and the global North. This goes against increasingly accepted understanding of the urgent need for transformation of economic, social and energy systems to avoid worst harms of climate change[25].

Excessive reliance on CDR also appears to contravene norms and principles of international law including the precautionary approach and necessary due diligence to prevent transboundary harm. It implies failure to comply with expectations regarding nationally determined contributions and low-emissions development plans, while risking harms to human rights through overshooting temperature goals[26]. Pathways that postpone mitigation in favour of CDR likely also breach intergenerational rights[27].

If the current political narratives and proposals for large-scale CDR risk delaying climate action,[28] this exacerbates injustice not only on those already experiencing harmful impacts (especially in the global South), but also on future people who will experience more severe impacts while bearing the costs of action to rectify those harms[29].

Risks and Concerns in reliance on CDR

How might the excessive pursuit of CDR contribute to continued unfair delay in emissions reduction, while sustaining political and economic structures of exploitation and domination? And what are potential direct negative justice and sustainability impacts of existing and proposed CDR techniques?

Delay

Delay in effective climate action perpetuates intergenerational injustice (undermining human

---

https://circularcarbon.org/wp-content/uploads/2024/02/CCN-2023-MarketReport.pdf. This is not to suggest that CDR investment itself is inappropriate or excessive, rather that overall levels of climate tech investment should be much higher, and given the urgent need to rapidly cut emissions much more heavily oriented towards emissions reduction.

[22] K Mistry et al., 'The Time for Carbon Removal Has Come' (Boston Consulting Group, 2023), https://web-assets.bcg.com/67/f7/0f41cd074a66b49cdb8baf5e59c0/bcg-the-time-for-carbon-removal-has-come-sep-2023-r.pdf. A cost of $200/tonne of CO_2 is highly speculative. Current costs for Direct Air Capture are more than double this level, and may never become cost effective: see M. Ma, https://www.bloomberg.com/news/articles/2024-06-05/swiss-carbon-removal-startup-touts-tech-cost-cut-as-industry-eyes-further-saving.

[23] Microsoft has accounted for over 75% of reported purchases so far with more than 8 million tonnes (see https://www.cdr.fyi/). However this number is massively outweighed by increased emissions enabled by Microsoft's sales of digital and AI services to the fossil fuel industry (see Hao, K., Microsoft's hypocrisy on AI. *The Atlantic,* Sept 13th 2024 https://www.theatlantic.com/technology/archive/2024/09/microsoft-ai-oil-contracts/679804.

[24] See 'Negative Impacts' below for details, and the Annex for technique specific risks.

[25] IPCC, 'Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change'. T.M. Lenton et al., eds., 'The Global Tipping Points Report 2023' (University of Exeter, Exeter, UK., 2023), https://global-tipping-points.org/resources/. Tiffany H. Morrison et al., 'Radical Interventions for Climate-Impacted Systems', *Nature Climate Change* 12, no. 12 (1 December 2022): 1100–1106, https://doi.org/10.1038/s41558-022-01542-y.

[26] Rupert F. Stuart-Smith et al., 'Legal Limits to the Use of CO_2 Removal', *Science* 382, no. 6672 (2023): 772–74, https://doi.org/10.1126/science.adi9332.; UN Human Rights Council (2023) 'Impact of new technologies intended for climate protection on the enjoyment of human rights' https://documents.un.org/doc/undoc/gen/g23/141/86/pdf/g2314186.pdf

[27] Stuart-Smith et al. 'Legal Limits to the Use of CO_2 Removal'

[28] See 'Delay' below for details.

[29] Some might argue that delay would sustain economic growth, also passing wealth forward to future generations. However the effects of climate change are already substantially suppressing growth (see Bilal and Kanzig 2024 https://www.nber.org/papers/w32450) and this would be exacerbated by delay.

rights of future people to live in a clean, healthy and sustainable environment) and also undermines the rights of nature[30]. Specifically, delaying steep emission cuts locks-in large CDR dependence in future decades, at scales likely to aggravate transgression of planetary boundaries with potentially irreversible consequences[31], and imposes much higher costs of mitigation if CDR deployment fails to achieve expectations[32].

Concerns that excessive reliance on CDR might result in delay are commonplace, but not widely understood. There are several intersecting problems which combine to trigger what scholars call 'mitigation deterrence' or 'mitigation obstruction'[33]:

Firstly**, *ideological commitments*** to market mechanisms[34] ensure deliberate efforts to make every tonne of carbon appear equivalent and tradeable (or 'fungible') with any other tonne, regardless of its source, destination or associated side effects[35]. This promotes three unhelpful kinds of 'lumping' together of – and therefore substitution between – things that need to be kept separate if CDR is not to deter accelerated mitigation:

i. Most harmfully, ***emissions reduction and carbon removal are treated as equivalent*** in 'net-zero' emissions policies. This creates huge ambiguity about their relative contributions and establishes political opportunities for pathways with high residual emissions and high levels of CDR – so-called 'loose convergence'. Both sides of this equation generate additional harms[36] since sustained residual emissions means sustained harms from fossil fuel extraction and combustion including continued deaths and ill-health from air pollution, currently estimated at 8 million per year[37].

ii. ***Conflating CDR and fossil CCS*** generates a similar ambiguity, but also directly incentivises continued use of fossil fuels (with all other associated harms, and unabated CO_2 emissions of at least 10-15 per cent)[38]. A narrative of 'carbon management' that lumps them together also stokes competition for limited geological storage – filling the most easily available, and most cost-effective underground storage spaces with fossil carbon, rather than reserving them for atmospheric carbon. (Box 1 elaborates the differences between CCS and CDR).

iii. ***Rolling biological and engineered CDR together*** raises further problems – biological sinks have different characteristics to geological stores: they are more easily

---

[30] HRC Advisory Committee, 'Impact of New Technologies Intended for Climate Protection on the Enjoyment of Human Rights. Report of the Human Rights Council Advisory Committee' (UN Human Rights Council, 2023), https://documents.un.org/doc/undoc/gen/g23/141/86/pdf/g2314186.pdf. See also Office of the UN High Commissioner for Human Rights, Maastricht Principles https://www.ohchr.org/sites/default/files/documents/new-york/events/hr75-future-generations/Maastricht-Principles-on-The-Human-Rights-of-Future-Generations.pdf and the Special Rapporteur on human rights and the environment: Human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment https://www.ohchr.org/en/documents/thematic-reports/ahrc3759-report-special-rapporteur-issue-human-rights-obligations

[31] Alexandra Deprez et al., 'Sustainability Limits Needed for CO_2 Removal', *Science* 383, no. 6682 (2 February 2024): 484–86, https://doi.org/10.1126/science.adj6171.

[32] Neil Grant, Adam Hawkes, Shivika Mittal and Ajay Gambhir, 'Confronting Mitigation Deterrence in Low-Carbon Scenarios', *Environmental Research Letters* (2021): doi.org/10.1088/1748-9326/ac0749

[33] Nils Markusson, Duncan McLaren, and David Tyfield, 'Towards a Cultural Political Economy of Mitigation Deterrence by Negative Emissions Technologies (NETs)', *Global Sustainability* 1 (2018): e10, https://doi.org/10.1017/sus.2018.10.

[34] Ryan Gunderson, Diana Stuart, and Brian Petersen, 'Ideological Obstacles to Effective Climate Policy: The Greening of Markets, Technology, and Growth', *Capital & Class* 42, no. 1 (February 2018): 133–60, https://doi.org/10.1177/0309816817692127.

[35] Duncan P. McLaren and Louise Carver, 'Disentangling the "Net" from the "Offset": Learning for Net-Zero Climate Policy from an Analysis of "No-Net-Loss" in Biodiversity', *Frontiers in Climate* 5 (July 2023), https://doi.org/10.3389/fclim.2023.1197608.

[36] Chris Armstrong and Duncan McLaren, 'Which Net Zero? Climate Justice and Net Zero Emissions', *Ethics and International Affairs* 36, no. 4 (2022): 505–26, https://doi.org/10.1017/S0892679422000521.

[37] Jos Lelieveld et al., 'Air Pollution Deaths Attributable to Fossil Fuels: Observational and Modelling Study', *BMJ* 383 (29 November 2023): e077784, https://doi.org/10.1136/bmj-2023-077784.

[38] Demonstrated capture rates in CCS are disappointing. Boundary Dam has a net average capture rate below 60% (https://www.cbc.ca/news/canada/saskatoon/boundary-dam-carbon-capture-missing-emmision-goals-1.7191867), but rates of 85-90% continue to be cited as credible targets. It must be noted that because of the energy penalty involved, the total gross emissions of a fossil-CCS facility rise (by perhaps 25%), and thus even with 90% capture, net emissions would be 12.5% of the pre-CCS level.

saturated (their capacity exhausted), and more easily reversed (by wildfire, drought or pest damage). Forests and soils cannot be relied upon to take up carbon dioxide released from burning fossil fuels[39]. Moreover, biological removals are easily subject to problems of double counting, or additionality, as much biological capture in natural terrestrial and marine ecosystems happens regardless of human interventions.

Policy makers can reduce (but not eliminate) the risk that these elisions will enable delay (or result in reversal of removals) by emphasising their differences and ***by setting separate (appropriately scaled) targets for – and accounting separately for - emissions reductions, and any engineered CDR and biological CDR***[40].

Secondly, ***vested interests.*** These tend to promote market models, not because they are committed to the presumed economic and political benefits of markets, but because they can exert undue influence in markets. For businesses dependent on fossil assets – from oilwells to aircraft – and the financiers heavily invested in them, delay is profitable, enabling continued returns from these investments. By contrast, an accelerated phase-out of fossil fuels would leave many such assets ‘stranded’ and worthless[41].

The industries with vested interests in delay have a history of climate denial and delay. It is no surprise to see businesses like Occidental Petroleum investing in DAC enterprises and describing CDR as protecting their licence to operate for decades to come[42]. Or to see wealthy fossil fuel extraction economies and their national oil and gas corporations as the most vociferous cheerleaders of ‘carbon management’ at COP28. Nor is it a surprise to see CDR playing a similar rhetorical role to CCS, as a promise of future action[43]. However, far from ‘buying time’, the climate cost of ‘pursuing’ CDR could be more than an extra 1°C in peak climate heating[44] if like CCS, CDR promises prolong the fossil economy but, also like CCS, largely fail to materialise due to excessive costs, public opposition and other technical obstacles.

Box 1: Carbon Dioxide Removal vs Carbon Capture and Storage – the differences and why they matter

CDR techniques all remove CO_2 from the atmosphere and move it into some form of (ideally long-term) storage, in plant matter, soils, long-lasting products such as construction materials, oceans or underground. Many CDR methods rely solely on the biological process of photosynthesis to capture carbon, while others deploy chemical reactions in engineered forms.

Some engineered methods have commonalities or overlaps with processes of ‘carbon capture and storage’ (CCS). CCS describes a set of a long promoted, but rarely deployed, methods to capture CO_2 from a mixture of gases, purify, compress and store it away underground. Typically, CCS has been advocated as a means to extract CO_2 from the exhaust gases from fossil fuel combustion (at the cost of using up to a quarter of the energy generated). In this form, CCS does not remove CO_2 from the atmosphere, but merely reduces the proportion of CO_2 emitted when fossil fuels are burned to generate energy.

---

[39] Wim Carton, Jens Friis Lund, and Kate Dooley, ‘Undoing Equivalence: Rethinking Carbon Accounting for Just Carbon Removal’, *Frontiers in Climate* 3, no. 30 (April 2021), https://doi.org/10.3389/fclim.2021.664130.

[40] Duncan P. McLaren et al., ‘Beyond “Net-Zero”: A Case for Separate Targets for Emissions Reduction and Negative Emissions’, *Frontiers in Climate* 1 (2019): 4, https://doi.org/10.3389/fclim.2019.00004; Carton, Lund, and Dooley, ‘Undoing Equivalence’.

[41] Shreekar Pradhan et al., ‘Effects of Direct Air Capture Technology Availability on Stranded Assets and Committed Emissions in the Power Sector’, *Frontiers in Climate* 3 (2021), https://www.frontiersin.org/articles/10.3389/fclim.2021.660787.

[42] Reported in https://grist.org/accountability/occidental-petroleum-net-zero-oil-climate-strategy-carbon-market-watch-dac-capture-removal/

[43] Duncan McLaren and Nils Markusson, ‘The Co-Evolution of Technological Promises, Modelling, Policies and Climate Change Targets’, *Nature Climate Change*, no. 10 (20 April 2020): 392–97, https://doi.org/10.1038/s41558-020-0740-1.

[44] McLaren, ‘Quantifying the Potential Scale of Mitigation Deterrence from Greenhouse Gas Removal Techniques’.

(Box 1 cont.) However, if CCS is applied to biomass energy facilities (BECCS) then the overall process (including the biomass production) can be considered a form of CDR, with at least some of the carbon captured by growing biomass ending up stored underground. The effectiveness of BECCS as CDR is disputed, with significant uncertainties in the accounting of emissions and removals over time. Arguably any CDR effect of such processes only arises as the biomass used regrows, as even if the capture rate is high, it is only preventing emissions from burning carbon already stored by biomass[45].

CCS-like approaches can also be applied to ordinary air (as opposed to exhaust gases). This is called Direct Air Capture, or Direct Air Carbon Capture and Storage (DACCS). The very low concentration of CO_2 in air means these processes are highly energy intensive, and their application at scale relies on availability of additional renewable or zero-carbon energy sources.

Past experience with the overpromising of CCS by fossil fuel businesses is a major reason to be concerned about current narratives of CDR. The promotion of CCS has served as an effective tool to delay transformation of the energy sector and protect otherwise stranded assets from closure[46], resulting in continued emissions and the persistence of severe environmental injustices from fossil extraction and air pollution.

Even though both fossil-CCS and CDR may be false solutions, in the sense of enabling delay in transformative emissions reductions, conflating them exacerbates that risk, as seen in narratives of ‘carbon management’[47].

Thirdly, mitigation deterrence can also materialise in ***rebound effects*** – such as increased oil and gas production achieved by injecting CO_2 into aging oil and gas fields – a process otherwise known as ‘enhanced oil recovery’. This has, so far, been the principal destination of CO_2 captured from US bioenergy plants, as well as that captured by CCS on fossil fuels[48]. Rebounds can also arise where CDR uses biomass for capture or storage potentially causing forest clearance or ploughing up of pastureland for agriculture displaced by biofuel crops. This so-called ‘indirect’ land use change can impose a substantial carbon debt[49]. And if the introduction of enhanced rock weathering or biochar were to make agriculture more productive and profitable in certain situations, it could encourage more clearance of forests for agriculture in the short term[50].

Misleading modelling leads to delay

Fourthly, mitigation deterrence also emerges unintentionally in ***misleading modelling***. Projected future requirements for CDR are typically arrived at using integrated assessment models (IAMs) which combine climate and economic modelling. These allow researchers to explore different future scenarios of climate policy and technology, but they are typically ‘optimising’ models which seek to deliver specified outcomes with the lowest cost of a combination of interventions for which the model has defined parameters. When a new technology is introduced into these models its costs, capabilities and effects must be estimated (or ‘parameterised’). Not only is this hard to do for novel techniques with significant uncertainties, but there are features of how these models work that mean ***speculative future technologies systematically and disproportionately displace near-term emissions cuts***.

---

[45] Timothy D. Searchinger, Tim Beringer, and Asa Strong, ‘Does the World Have Low-Carbon Bioenergy Potential from the Dedicated Use of Land?’, *Energy Policy* 110 (1 November 2017): 434–46, https://doi.org/10.1016/j.enpol.2017.08.016.

[46] Nils Markusson et al., ‘The Political Economy of Technical Fixes: The (Mis)Alignment of Clean Fossil and Political Regimes’, *Energy Research & Social Science* 23 (2017): 1–10.

[47] https://legal-planet.org/2023/12/06/is-carbon-management-just-another-cop-out/

[48] See https://zerocarbon-analytics.org/archives/energy/a-closer-look-at-ccs-problems-and-potential

[49] Vassilis Daioglou et al., ‘Progress and Barriers in Understanding and Preventing Indirect Land-Use Change’, *Biofuels, Bioproducts and Biorefining* 14, no. 5 (2020): 924–34, https://doi.org/10.1002/bbb.2124; Joseph Fargione et al., ‘Land Clearing and the Biofuel Carbon Debt’, *Science* 319, no. 5867 (29 February 2008): 1235–38, https://doi.org/10.1126/science.1152747.

[50] Carsten Paul et al., ‘Rebound Effects in Agricultural Land and Soil Management: Review and Analytical Framework’, *Journal of Cleaner Production* 227 (1 August 2019): 1054–67, https://doi.org/10.1016/j.jclepro.2019.04.115.

Discounting – the economic practice that treats future costs and benefits as of lower value, because of human time-preferences, and the effects of presumed economic growth – is the most serious flaw, especially for CDR. Discounting means that - to the model - CDR in the future appears cheap while having the same effect in balancing carbon budgets as expensive near-term emissions cuts. As a result, the models will deploy as much of the apparently cheap technology as possible[51]. This pushes climate action further into the future, and the models effectively treat the question of what is 'hard to abate' through an economic lens, rather than a social one. Moreover, real limits to such deployment of CDR may not be well accounted for in models because side-effects and sustainability limits of interventions are poorly parameterised[52]. This problem underlies IAMs' apparent appetite for BECCS, which can be so great as to demand completely unrealistic areas of land (e.g. more than 3 times the area of India, or 80% of the world's cropland)[53].

Such scenarios easily get mistaken for policy-advice, despite the side-effects of direct and indirect demands for land being poorly modelled. Compounding this, models tend to overlook co-benefits of mitigation, so – for example - health gains from reduced particulate pollution, more active transport or lower-meat diets are not accounted when the net cost of emissions cuts from structural or behavioural interventions to cut fossil fuel use are estimated. This makes such interventions appear more expensive. Once again we see the results of a misplaced fungibility between CDR and emissions cuts.

A final concern of note with the models used to underpin IPCC and other projections is the underlying ***blanket presumption of continued economic growth***. Although the IPCC recognises the need for energy convergence and reduced global inequality, the scenarios it relies on contain assumptions about growth that increase demand and consumption even in rich countries and exacerbates global energy inequalities. This then 'requires' carbon removals that "appropriate land in the Global South to support, and further boost, the energy privilege of the Global North"[54]. Growth multiplies the overall challenge with an inbuilt demand for novel technological responses.

Delay arising from the above factors is problematic in and of itself. Moreover, if future CDR takes the place of rapid and deep emissions cuts, carbon sinks and ecosystem CDR itself will be impaired by climate impacts such as wildfires or drought. ***In a decade, wildfires in California have already released almost twice as much carbon from forests protected as carbon offsets than had been allowed for over the coming century***[55].

Negative impacts

There are multiple ways in which large scale CDR is likely to impose injustice and lead to harms to human rights, biodiversity, and the environment.

It would generate ***additional demands and competition for resources***: notably land, energy, materials and water. Different CDR techniques place different demands on resources, but none could be scaled without significant resource requirements[56], exacerbating stresses on planetary boundaries[57]. In some cases, the demands are so great as to impose serious limits on the practical potential of the technique. In others they suggest critical social

---

[51] McLaren, 'Quantifying the Potential Scale of Mitigation Deterrence from Greenhouse Gas Removal Techniques'.

[52] The IPCC provides 'technical mitigation potentials' for various CDR techniques, but these are in some cases vastly over-optimistic about sustainable levels. See: Deprez et al., 'Sustainability Limits Needed for CO_2 Removal', and Perkins et al., Toward quantification of the feasible potential of land-based carbon dioxide removal. *One Earth* 6(12) 2023 https://doi.org/10.1016/j.oneear.2023.11.011.

[53] Mathilde Fajardy et al., 'BECCS Deployment: A Reality Check', vol. No 28, Grantham Institute Briefing Paper (London: Imperial College, January 2019), https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/BECCS-deployment---a-reality-check.pdf.

[54] Jason Hickel and Aljosa Slamersak, 'Existing Climate Mitigation Scenarios Perpetuate Colonial Inequalities', *The Lancet Planetary Health* 6, no. 7 (1 July 2022): e628–31, https://doi.org/10.1016/S2542-5196(22)00092-4.

[55] Reported by Badgley, G at https://carbonplan.org/research/buffer-pool-burning.

[56] Smith et al., 'Biophysical and Economic Limits to Negative CO_2 Emissions'.

[57] Deprez et al, 'Sustainability Limits Needed for CO_2 Removal'; also see Rockstrom et al 'Safe and just Earth system boundaries', *Nature* volume 619, pp102–111 (2023).

limits, threatening food and water security for millions of people. In extreme cases such demands could exacerbate risks of conflict (see Box 2).

CDR interventions also threaten ***local impacts and side-effects which could exacerbate environmental injustice, especially in the Global South***. These include problems such as exclusion from land, local pollution and disturbance from biomass energy, industrial plant or mining operations, impacts of pipeline construction and routing, and particulate pollution from distribution of rock dust or biochar (a particular health hazard for workers in such industries). Engineered CDR at industrial scales is potentially as environmentally and socially damaging as any other industry. ***Biological CDR at scale is likely as harmful as industrial agriculture.*** In such sectors there is a long record of distributional injustice, in which poor and vulnerable communities suffer the worst harms[58].

Large-scale CDR development would also add disproportionately to the burdens faced by the poorest countries. Offsetting schemes where wealthy countries, corporations and consumers can claim emissions cuts made in poorer countries (typically through forest-protection) have long drawn accusations of 'carbon colonialism'[59]: a continuation of extractive global relations, imposing additional burdens on countries and people who have contributed least to the problems of climate change. CDR can also be exploited in such ways, especially when dependent on the availability of cheap land adding another motivation for further violent dispossession, land-grabbing, and enclosure[60]. This disproportionately affects Indigenous Peoples, as it also disrupts subsistence and spiritual uses of land and oceans.

In many rich countries, BECCS would also likely be reliant on imported biomass – imposing a double or treble injustice: the burden of land-use (and competition for food) is imposed on poor populations in the Global South; the 'negative emissions' are accounted in the Global North; and the 'renewable' energy fed into Northern energy grids. The ways in which different forms of CDR would be accounted for in international settings are not yet clear. For example, biomass might be grown, burned in a BECCS plant, and the carbon dioxide stored in three different countries. Or minerals for rock weathering mined in one country might be used in international waters by another country. In each case harmful side-effects might be experienced in a country unable to claim the carbon accounting benefits.

Box 2: Excessive land and energy demands from large scale CDR

High demands for land or energy from large scale BECCS and DACCS for example, would aggravate the biodiversity loss crisis and threaten food and energy security especially for the poorest everywhere in the world. Dedicating land to CDR techniques poses particular risks to Indigenous Peoples already harmed by loss of territory[61]. Researchers highlight land-use constraints to CDR, and particularly BECCS which suggests feasible capacities significantly below those anticipated in IPCC pathways[62].

Assessment of the land requirements for carbon removal included in national climate plans has shown that countries are already banking on using around 1 billion hectares of land for carbon removal (equivalent to two-thirds of global cropland) – mainly to service the climate plans of richer nations[63].

Another recent report concludes that any further expansion of biomass production for BECCS would threaten the integrity of planetary boundaries[64].

---

[58] J. Agyeman, R.D. Bullard, and B Evans, eds., *Just Sustainabilities: Development in an Unequal World Edited by Julian Agyeman, Robert D. Bullard and Bob Evans*, Urban and Industrial Environments (Cambridge, MA: MIT Press, 2003).

[59] E.g. Heidi Bachram, 'Climate Fraud and Carbon Colonialism: The New Trade in Greenhouse Gases', *Capitalism Nature Socialism* 15, no. 4 (1 December 2004): 5–20, https://doi.org/10.1080/1045575042000287299.

[60] James Fairhead, Melissa Leach, and Ian Scoones, *Green Grabbing: A New Appropriation of Nature* (London: Routledge, 2014).

[61] HRC Advisory Committee, 'Impact of New Technologies Intended for Climate Protection on the Enjoyment of Human Rights. Report of the Human Rights Council Advisory Committee'.

[62] Alexandra Deprez et al., 'Sustainability Limits Needed for CO_2 Removal', *Science* 383, no. 6682 (2 February 2024): 484–86, https://doi.org/10.1126/science.adj6171.

[63] See The Land Gap Report at https://landgap.org/

[64] NEGEM https://www.negemproject.eu/wp-content/uploads/2023/12/D3

(Box 2 cont.) Even if dietary change were to free up productive agricultural land, the only sustainable form of CDR in this analysis would be reforestation. In some locations even this would have unacceptable social impacts, for example through displacement of marginal communities with a cultural attachment to the land.

If utilising additional land, BECCS could provide additional energy supply, but adding CCS to existing bioenergy facilities would impose an energy penalty. But DACCS relies entirely on additional energy consumption: delivering 10Gt-CO_2 pa of DAC might require around 470EJ (exajoules)[65]. For comparison, total global primary energy production is currently around 620EJ. Techniques such as ocean alkalinization and enhanced weathering are also energy and/or material intensive.

An assessment of the climate pathways modelled in IPCC finds that that the burden of land-based interventions falls disproportionately on the Global South with adverse impacts on food security[66]. Shifting demand to DACCS would significantly raise costs and increase energy requirements to the extent that energy poverty and insecurity could be expected to intensify. Likewise, modelling of international carbon trading under Article 6 of the Paris Agreement would see roughly half of all national reductions before 2030 being bought in other countries, with biological storage in non-OECD countries replacing cuts in fossil emissions in OECD countries[67]. Instead of ‘increasing ambition’ by lowering costs of mitigation, combined with excessive CDR, carbon markets could thus facilitate huge substitution of mitigation of fossil emissions for uncertain biological storage.

Finally, ***CDR could threaten peace***. In as much as CDR stands to slow the phase-out of fossil fuels, it also maintains the existing geopolitics of fossil energy and related conflicts[68]. Furthermore, if land-grabbing displaces or impoverishes disadvantaged populations, this could fuel grievances and social conflict.

Campaigners and others are trying to push the emerging CDR sector to attend to such concerns[69], but despite some efforts to offer local community benefits[70] it is hard to imagine a responsible CDR sector successfully emerging within the current extractive global economy: transformative system change is essential here too.

What role(s) *can* CDR play in climate justice?

Serious harms can arise from excessive reliance on CDR – but there are circumstances in which the inclusion of certain CDR approaches at appropriate scales could contribute to delivering climate justice.

After achievement of net-zero, CDR offers potential to reduce what are already excessive and harmful atmospheric concentrations of GHGs. This could reduce climate impacts on future generations and potentially help avoid triggering irreversible climate tipping points[71]. However, to permit this ***the amount of CDR dedicated to counterbalancing remaining or residual emissions must be minimised***, and rapid

---

.10-Report-on-synoptic-assessment-of-global-theoretical-NETP-potentials.pdf

[65] Based on Smith et al., ‘Biophysical and Economic Limits to Negative CO_2 Emissions’.

[66] Sreeja Jaiswal, Aravindhan Nagarajan, and Akhil Mythri, ‘Projecting a Food Insecure World: Equity Implications of Land-Based Mitigation in IPCC Mitigation Pathways’, *Environmental Science & Policy* 155 (1 May 2024): 103724, https://doi.org/10.1016/j.envsci.2024.103724.

[67] Jae Edmonds et al., *The Economic Potential of Article 6 of the Paris Agreement and Implementation Challenges* (International Emissions Trading Association, University of Maryland, and Carbon Pricing Leadership Coalition, Washington, D.C., 2019), https://doi.org/10.1596/33523.

[68] Daniel Scholten et al., ‘The Geopolitics of Renewables: New Board, New Game’, *Energy Policy* 138 (1 March 2020): 111059, https://doi.org/10.1016/j.enpol.2019.111059.

[69] Sara Nawaz et al., ‘Agenda for a Progressive Political Economy of Carbon Removal’ (Washington DC: Institute for Responsible Carbon Removal, 2024), https://www.american.edu/sis/centers/carbon-removal/upload/agenda-for-a-progressive-political-economy-of-carbon-removal.pdf.

[70] L Aronowsky et al., ‘From the Ground Up: Recommendations for Building an Environmentally Just Carbon Removal Industry’ (XPrize Foundation and Carbon180, 2023), https://www.xprize.org/prizes/carbonremoval/articles/from-the-ground-up.

[71] Lenton et al., ‘The Global Tipping Points Report 2023’.

and just emissions reductions maximised in pursuit of real zero[72].

Nonetheless sustainable, small-scale CDR can also support justice and equity in the short term, by helping manage socially necessary or socially beneficial sources of emissions. Net benefits can be maximised by focusing on appropriate scales, forms and locations for CDR that offer social or environmental co-benefits.

- *Dealing with socially necessary emissions*: There are emissions now and in the transition to real zero that are not only technically hard-to-abate, but also *socially necessary* – in other words 'legitimate' residual emissions that justify counterbalancing if appropriate scale sustainable CDR can be realised. Even if zero CO_2 emissions can be achieved, it may prove less just to seek to eliminate *all* other GHG emissions: counterbalancing residual emissions of methane from rice growing – for example – seems likely to merit deployment of CDR. But the assessment of what should be seen as legitimate residual emissions must not simply be left to market demand and ability to pay, nor purely to technical difficulty. For instance, emissions associated with space tourism might be very difficult to eliminate technically, and the activity might remain in high demand from extremely wealthy individuals. But in no way could such emissions be considered socially necessary.
- *Socially beneficial emissions*: By contrast, some emissions supporting good quality jobs, access to education or other critical services, or underpinning economic development in the poorest parts of the world – might well be considered legitimate for longer than might otherwise seem reasonable, if sustainable and just CDR can compensate for them. In this way CDR deployed and paid for by the rich, historic excess polluters, might contribute (alongside accelerated emissions reductions in the rich world) to creating additional 'headroom' for essential development.

  Doing CDR simply where it would be economically cheapest would impose unfair and harmful demands for land and water in the Global South, and however much CDR is needed globally, the rich world should bear the brunt of any costs and harms involved. Researchers have calculated that the fair shares that major emitters (basically the rich countries) should supply are two to three times greater than those implied by least-cost modelling[73]. But supporting development 'headroom' should not be an excuse for expanded reliance on fossil fuels offset by CDR: there are multiple social, health and sustainability benefits in 'leapfrogging' to development based on renewable energy – enabled by effective climate finance and technology transfer from richer countries.

- *Co-benefits of removals.* At small scales, several CDR techniques can offer potential co-benefits for biodiversity, sustainable agriculture and food security[74]. Utilising genuine waste biomass, or existing mining residues in biochar or enhanced rock weathering approaches may enhance agricultural productivity if applied appropriately. While maintaining old-growth forests and ocean health is critical for both biodiversity and carbon management, well-managed reforestation or ecosystem restoration can deliver benefits for biodiversity as well as higher levels of secure carbon storage[75]. Localized ocean alkalinization might help protect coral reefs. But in all these cases it would be preferable that states regulate for, or fund and incentivise the benefit directly, rather than trying to incorporate these approaches into carbon markets. While

---

[72] Armstrong and McLaren, 'Which Net Zero? Climate Justice and Net Zero Emissions'; Sam Fankhauser et al., 'The Meaning of Net Zero and How to Get It Right', *Nature Climate Change* 12, no. 1 (1 January 2022): 15–21, https://doi.org/10.1038/s41558-021-01245-w; Fuhrman et al., 'Ambitious Efforts on Residual Emissions Can Reduce CO_2 Removal and Lower Peak Temperatures in a Net-Zero Future'. See also https://www.realzeroeurope.org/

[73] Claire L. Fyson et al., 'Fair-Share Carbon Dioxide Removal Increases Major Emitter Responsibility', *Nature Climate Change* 10, no. 9 (1 September 2020): 836–41, https://doi.org/10.1038/s41558-020-0857-2.

[74] M.J. Mace et al., 'Large-Scale Carbon Dioxide Removal to Meet the 1.5°C Limit: Key Governance Gaps, Challenges and Priority Responses', *Global Policy* 12, no. S1 (2021): 67–81, https://doi.org/10.1111/1758-5899.12921.

[75] See summary at Institute for Agriculture and Trade Policy, https://www.iatp.org/documents/missing-pathways-15degc

unlikely to prove the rule, there may also be specific cases where deployment of engineered CDR could facilitate the development of previously untapped renewable energy resources, supporting carbon removal and increased access to clean energy at the same time. This has been suggested for geothermal resources in the Kenyan rift valley[76]. However, if adequate climate finance were available to develop those renewable resources regardless, this would do more for the availability of reliable clean energy in Kenya, while avoiding the risk that the CDR removals would be sold as offsets for otherwise abatable emissions in the rich world. Once again, we see that the role of CDR would be minimised in just and equitable climate policy.

Inadequate governance hitherto

Policy makers around the world have yet to get to grips with the novel dimensions of climate policy that come with consideration of CDR. In most cases policy is unclear about the extent of and implications of reliance on CDR, in part because the IPCC defines CDR as a part of 'mitigation'. Because emissions reduction plans remain inadequate to meet Paris Agreement compliance, they risk reliance on unsustainable and unjust levels of CDR. These policies and investment in CDR are often unspecified, or similarly inadequate[77] (see Box 3). Carbon markets lack coordination, agreed principles, and credibility[78]. Negotiations at COP28 on rules for trading carbon reductions failed to agree on transparency and governance of projects sold as carbon reduction or removals.

And whether markets are part of the governance framework or not, consistent rigorous accounting and verification methods will be necessary to ensure that CDR activities are actually additional, and not double counted. Some efforts are emerging to improve carbon accounting to effectively measure CDR contributions and to prevent the misleading deployment of corporate claims about CDR and net-zero or climate neutrality[79].

Box 3: Inadequate plans

Research assessing countries' long-term low-emission development (LED) plans reveals that CDR plans and aspirations (for less than 2 Gt-CO_2 pa) fall far short of the levels that would be needed. Given existing mitigation plans, countries' plans for realizing CDR capacity that would be needed to deliver Paris Agreement commitments (even if understood as achieving only 'well below 2°C') are not in train[80].

If these countries planned to cut emissions more rapidly this would not be a problem. Levels of

---

[76] Payton, B. Kenya gears up for direct air capture push in 'Great Carbon Valley' 13th Nov 2023. Reuters News. https://www.reuters.com/sustainability/climate-energy/kenya-gears-up-direct-air-capture-push-great-carbon-valley-2023-11-13/

[77] Holly Jean Buck et al., 'Why Residual Emissions Matter Right Now', *Nature Climate Change* 13, no. 4 (April 2023): 351–58, https://doi.org/10.1038/s41558-022-01592-2; Jens Friis Lund et al., 'Net Zero and the Unexplored Politics of Residual Emissions', *Energy Research & Social Science* 98 (1 April 2023): 103035, https://doi.org/10.1016/j.erss.2023.103035; William F. Lamb et al., 'The Carbon Dioxide Removal Gap', *Nature Climate Change*, 3 May 2024, 1–8, https://doi.org/10.1038/s41558-024-01984-6; Stuart-Smith et al., 'Legal Limits to the Use of CO_2 Removal'.

[78] Axel Michaelowa et al., 'International Carbon Markets for Carbon Dioxide Removal', *PLOS Climate* 2, no. 5 (8 May 2023): e0000118, https://doi.org/10.1371/journal.pclm.0000118.

[79] J. Burke and F. Schenuit, 'Governing Permanence of Carbon Dioxide Removal: A Typology of Policy Measures' (CO_2RE: the Greenhouse Gas Removal Hub, 2023), https://co2re.org/wp-content/uploads/2023/11/CO_2RE_Report_CDR_Permanence-FINAL-v7.pdf; Lindsay Otis, 'Green Claims Directive: European Parliament Votes to Ban Carbon Neutrality for Products but Not Companies', Carbon Market Watch, 12 March 2024, https://carbonmarketwatch.org/2024/03/12/green-claims-directive-european-parliament-votes-to-ban-carbon-neutrality-for-products-but-not-companies/; United Nations' High-Level Expert Group on the Net Zero Emissions Commitments of Non-State Entities, 'Integrity Matters: Net Zero Commitments by Businesses, Financial Institutions, Cities and Regions', 2022, https://www.un.org/sites/un2.un.org/files/high-levelexpertgroupupdate7.pdf.

[80] Lamb et al., 'The Carbon Dioxide Removal Gap'. This study assesses LEDs from 68 countries submitted as of November 2023.

additional CDR anticipated in country-LEDs are not that far short of what ‘demand-reduction’ focused scenarios estimate would be needed (around 2.3Gt pa). But in practice, countries are not following demand reduction scenario priorities. Real-world plans more closely match scenarios with high demand and high reliance on low carbon energy or on carbon removal. Then the removal gap becomes much more alarming, estimated at 5.1-7.4Gt pa)[81], and CDR requirements collectively may more than quadruple, landing in the order of 10GtCO_2 pa[82].

Even if such large-scale CDR proved technically feasible to deliver (which currently seems unlikely), the environmental and social harms associated with excessive CDR reliance would make this highly unsafe.

But these positive initial steps expose the black hole at the heart of climate policy. ***It is entirely ineffective to leave the governance of CDR to markets and pricing, whether in compliance or voluntary trading and offsetting schemes.*** Proposals to include CDR in existing or planned carbon markets would mean making it tradeable with emissions reductions, triggering substitution and delay. Research demonstrates that simplistic price-based approaches relying on such tradability would leave twice as much ‘need’ for CDR as dedicated targeting of gross emissions[83]. To avoid such problems, ***CDR needs to be kept separate from emissions reduction***. Market-based approaches to CDR allocations guided by ‘ability to pay’, not social necessity, would also relieve pressure on the richest to contribute to social transformation. Moreover, commodifying carbon in ecosystems undermines respect for the inherent rights of nature, increasingly recognised by nation states as well as Indigenous peoples[84].

Conclusions

Insufficient action to rapidly reduce GHG emissions poses a major threat to peace, justice and sustainability. There is a critical need to prioritize effective responses that rely on urgent, healthy, rights-based and transformative radical action in tackling root causes [[85]] with deep transformations in economic and social systems, eliminating unsustainable energy use, land-use, lifestyles and patterns of consumption and production[86].

Measures which could hinder the rapid social and political transformation of root causes must be avoided so that climate action is delivered in just and sustainable ways. Rapid emissions reduction underpins just climate policy, but still needs good governance to ensure it also leads to more equitable access to energy, mobility and healthy food, for example, rather than exacerbating inequality, creating environmental sacrifice zones or undermining human rights. While CDR involves similar opportunities and challenges, the risks are greater.

Large scale CDR is currently being pursued by key vested interests in ways that enlist it into resistance to transformative change, as the latest in a string of promissory technologies helping delay real climate action[87]. Only with mobilization and effective governance can this pattern be broken. Otherwise a failure to deliver promised CDR could lead to a worse result than had CDR not been entertained as

---

[81] Lamb et al., ‘The Carbon Dioxide Removal Gap’.

[82] Harry B. Smith, Naomi E. Vaughan, and Johanna Forster, ‘Residual Emissions in Long-Term National Climate Strategies Show Limited Climate Ambition’, *One Earth* 0, no. 0 (9 May 2024), https://doi.org/10.1016/j.oneear.2024.04.009; Buck et al., ‘Why Residual Emissions Matter Right Now’.

[83] Jay Fuhrman et al., ‘Ambitious Efforts on Residual Emissions Can Reduce CO_2 Removal and Lower Peak Temperatures in a Net-Zero Future’, *Environmental Research Letters* 19, no. 6 (May 2024): 064012, https://doi.org/10.1088/1748-9326/ad456d.

[84] Guillaume Chapron, Yaffa Epstein, and José Vicente López-Bao, ‘A Rights Revolution for Nature’, *Science* 363, no. 6434 (29 March 2019): 1392–93, https://doi.org/10.1126/science.aav5601.

[85] Morrison et al., ‘Radical Interventions for Climate-Impacted Systems’.

[86] IPCC, Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK and New York, NY, USA. p. 40, https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

[87] McLaren and Markusson, ‘The Co-Evolution of Technological Promises, Modelling, Policies and Climate Change Targets’.

an option in the first place. A double failure of emissions cuts and CDR could lead the world further down a solutionist slippery slope towards even riskier scenarios, including novel risks of unproven solar geoengineering in an overheating world.

In the face of already harmful climate change, ***CDR cannot be ignored. But, if it is to avoid intensifying wider risks, it must be developed soberly and safely***, in line with sustainability, justice, ecological integrity and human rights. There are no demonstrated techniques that can safely deliver large-scale removals without threatening other vital interests or resources. At appropriate scale, CDR could form *part* of a just transition, but only with strong safeguards to avoid contributing to delay to urgently needed emissions cuts, social transformations and respect for Indigenous peoples' rights and environmental integrity.

Recommendations

All options for climate action come with challenges and risks to safety, justice and sustainability. The tools we choose, and how we deploy them both matter in minimizing these risks and addressing those challenges. Reliance on large-scale CDR as a technofix is amongst the most risky and inappropriate options.

Here we suggest five key take-aways for just climate policy focused on potential state and intergovernmental measures[88].

1. ***Minimise the need for CDR by maximizing emissions reduction and accelerating equitable fossil-fuel phase out, increasing renewable energy, and energy use minimisation.*** In particular, focus on transforming the root causes driving anthropogenic climate change, minimising energy demand and reorienting energy, economic and social systems towards the delivery of wellbeing rather than economic growth or development per se.
2. ***Develop explicit policy on sustainable and just CDR, which avoids excessive reliance on CDR. Establish clear separate targets and accounting mechanisms***, keeping CDR separate from emissions reduction to avoid substitution, and distinguishing aspirations for biological and engineered CDR.
3. ***Ensure that CDR is allocated only to counterbalancing 'legitimate' residual emissions*** that are both technically hard to abate ***and*** socially necessary, and subsequently prioritizing active drawdown of atmospheric GHGs. In particular, this means not giving industry and current emitters a license to define, by themselves, what qualifies as 'legitimate residuals'.
4. ***Actively support sustainable, fair and rights-based small-scale deployment of CDR, through dedicated conditional support***, especially for deployment in the global South, with community involvement, shared intellectual property (IP), knowledge transfer and fair terms of finance.
5. ***Orient incentives for sustainable CDR towards co-benefits,*** avoiding carbon tunnel vision or aggregate cost fixation. ***Avoid offsetting mechanisms,*** which leave both quantities and qualities of CDR under the control of elites or vested interests, mediated by market forces.

Further Reading

Institute for Responsible Carbon Removal, 2024. *Agenda for a Progressive Political Economy of Carbon Removal*.

The state of carbon dioxide removal (Second Edition) 2024.

Report of the Human Rights Council Advisory Committee 2023. *Impact of new technologies intended for climate protection on the enjoyment of human rights.*

Sustainability limits needed for CO_2 removal, Deprez et al. *Science,* 2024.

Convention on Biological Diversity (*de facto* moratorium on geoengineering since 2010, reaffirmed 2016): Decisions X/33 and XI/20.

---

[88] Several of these draw on Nawaz et al., 'Agenda for a Progressive Political Economy of Carbon Removal'.

Annex: Summary of CDR techniques, status, limitations and potential co-benefits[89d]

CDR is considered to be anthropogenic removal of CO_2 from the atmosphere (or ocean) by geo-engineered methods, or through intentional enhancement of natural sinks generating additional removals. Removals by terrestrial and marine ecosystems happening naturally are not included. Despite some similarities, CDR does not include technologies that capture CO_2 from emissions generated in fossil fuel combustion or production (known as 'carbon capture and storage' - CCS).

Technique	***Status and accounting***	***Limitations***	***Co-benefits***
Biological techniques			
Afforestation/ Reforestation Planting trees (or supporting natural regeneration) on land that had previously been cleared of forests, or that had not previously supported forests. Forest growth builds carbon stores in both biomass and soils.	- Established techniques. - Forests account for most of all current CDR (estimated at around 2Gt-CO_2 pa – although not all of this can necessarily be accounted as additional). - Accounting is complicated by the need to distinguish existing and new forests. The carbon balance of afforestation depends on the prior land-use and soil type, and may be negative.	- Converting agricultural land could undermine food security, whilst monoculture plantations are bad for biodiversity. Rebound effects such as clearance of forest or ploughing of pastures elsewhere (indirect land use change (ILUC)) would reduce benefits. Forest CDR removal rates slow as the store becomes saturated. Forest stores – especially monoculture plantations - are not reliably permanent, subject to losses through wildfire, disease, or changes in management. - The darkening albedo effect of forests, especially in high latitudes, could offset some climate benefit. - At large-scale, possibly covered by CBD geoengineering decisions.	- Well managed forests with appropriate species mix can bring co-benefits for water management, and biodiversity. Co-benefits are greatest from natural reforestation as opposed to any form of plantation.

---

[89] See notes 6 and 7 above for main sources and further information on specific techniques.

Biomass burial Burying biomass in anaerobic locations underground or sinking it in the deep ocean.	- Experimental and start-up operations under development. - Major governance and accounting challenges and unknowns regarding ocean storage.	- Using terrestrial biomass could generate competition for land or ILUC. - Durability, and levels of leakage of stored carbon are uncertain, and may be difficult to monitor (especially in oceans). - At large-scale, possibly covered by CBD geoengineering decisions.	- Use of existing biomass wastes or residues could provide synergies with waste management, but only at limited scale.
Biochar Partially combusting biomass, producing a mix of gas, oil and carbon-rich char. Char buried in soils can store carbon for centuries.	- Widespread experimental and some commercial operations (all at small scale). Accounts for over 90% of traded carbon removal offsets[90] delivered. - Accurate accounting is challenging regarding share and duration of carbon storage.	- Using terrestrial biomass could generate competition for land or ILUC. Human health impacts may arise from particulate char and possible contaminants in waste feedstocks. Durability, and levels of leakage of stored carbon are uncertain, and may be difficult to monitor. At large-scale, possibly covered by CBD decisions on geoengineering.	- Char in soils can have agricultural benefits, e.g. promoting water and nutrient retention. Use of existing biomass wastes or residues at limited scale may have synergies with waste management.
Ecosystem restoration Some ecosystems form dense carbon stores, notably peatlands, salt-marshes and sea-grass meadows.	- Suitable locations are geographically limited. Multiple projects exist. - Carbon accounting is difficult in these relatively open systems.	- Like forests, such ecosystems reach saturation and are subject to rapid reversibility if affected by drought, damage or fire. - Active peatlands also generate emissions of methane which grow as the bogs age.	- Significant co-benefits for biodiversity, coastal protection and water management.
Ocean Iron fertilisation Adding iron to nutrient poor waters can cause algal blooms. If the dying algae fall to the ocean bed, the carbon sequestered in photosynthesis can be stored long-term in deep ocean sediments.	- Trials with mixed results. Large scale is theoretically possible and sometimes claimed. - Effectiveness and 'downstream' effects on adjacent ocean regions remain unclear. Accounting is hugely difficult as final destinations of carbon are impossible to track.	- Potential impacts on marine biology and food web. Possible anoxia in surface ocean. Increased emissions of methane and nitrous oxide partially offsetting climate benefit. - Permanence of sequestration unclear. - Covered by London Convention provisions permitting only research (as	- Claimed benefits to fisheries (although this may well reduce carbon transport to the deep ocean).

---

[90] https://www.cdr.fyi/blog/2023-year-in-review

		yet not in force), and CBD decisions on geoengineering.	
Soil carbon sequestration Managing soils in crop & pastureland to maximise carbon sequestration through techniques such as no-till, organic matter additions, and rotational grazing management.	- Many such techniques are widely practiced for agricultural reasons. Some projects selling credits in carbon markets. - Accounting accurately for carbon gains is difficult. Carbon benefits of rotational grazing are still uncertain.	- Soil carbon levels reach saturation in years or decades. Require continued management to maintain carbon stores, with high risks of reversibility in drought or changed agricultural practices. - May require additional fertilizer applications.	- Possible co-benefits for agriculture, and improved soil resilience, water retention and resistance to erosion.
Hybrid techniques			
Bioenergy with CCS (BECCS) Using biomass to produce energy in ways that allow the capture and subsequent storage of carbon dioxide from combustion or fermentation processes. Because biomass energy is seen as carbon neutral, the capture and storage creates a ‘negative emission’.	- Existing commercial BECCS facilities (aggregating just 2Mt-CO_2 pa) are largely on biofuel fermentation, achieve only partial capture, and largely send the CO_2 to enhanced oil recovery (EOR) not dedicated storage. The presumption that biomass energy is carbon neutral is contested. BECCS on biomass combustion would still need to account for emissions arising in harvesting and transport of biomass, as well as for the delay in regrowth of biomass.	- Biomass production could compete with other land use including ecosystem conservation, and threaten food security, or trigger ILUC. - The addition of CCS imposes a significant energy penalty on the biomass energy facility, requiring more fuel to generate the same outputs. - The costs of CCS have proved prohibitive on fossil energy plants, and commercial viability of large-scale BECCS is uncertain. - At scale BECCS would need CO_2 transmission pipelines (often controversial). Using CO_2 in EOR creates additional emissions. - At large-scale, likely covered by CBD geoengineering decisions.	- Use of existing biomass wastes or residues in BECCS facilities could provide synergies with waste management, but only at limited scale.
Engineered techniques			
Direct Air Capture (DAC / DACCS)	- Pilot plants in operation and under development	- All forms of DAC have a high energy demand (for moving air, regenerating	- Possible benefits to indoor air quality.

Using chemical processes and energy to separate CO_2 from ambient air, typically with some form of sorbent, with captured CO_2 subsequently purified, compressed and stored.	at scale of thousands to millions of tons. - Relatively simple to measure and account quantities captured and stored, although system leakage and supply chain emissions can be in the order of 10-25%.	chemical sorbents, purifying and compressing CO_2). At large scale DAC could contribute to energy insecurity and energy poverty. Projected costs per ton are very high, creating substantial uncertainty about practical levels of capacity. At large scale, chemical needs might exceed supply. Potential harmful wastes. - At scale would need CO_2 transmission pipelines (often controversial). Leakage to temporary 'carbon utilisation' in e.g. synthetic fuel could be significant. Using CO_2 in EOR would create additional emissions.	
Enhanced Rock Weathering Exposing ground-up reactive rock or mine waste to water by spreading it on soils, beaches or oceans	- Some pilot projects in progress. Large potential claimed. Accounting will be challenging, as both location and timing of capture are variable	- Suitable rock is widely available, but impacts of quarrying could be severe, while capture rates depend on how finely ground the rock is, with energy costs increasing with fineness (and likely limiting potential). - Possible health impacts from particulate dust and mineral contaminants.	- Rock dusts can support agricultural productivity and may substitute for some emission intensive fertilizer applications. Use in ERW could help management of existing quarry and mining wastes.
Ocean Alkalinity enhancement Diverse methods that increase the alkalinity of ocean waters (including by addition of lime, or direct electro-chemical treatments)	- Early-stage research and experimentation. - Outstanding questions regarding governance, and accounting. 'Downstream' effects of such interventions outside the target areas are still unclear.	- Both liming and electrochemical approaches have high energy demands (with liming also requiring the addition of effective CCS to the lime production process). - Likely to be covered by future extension of London Convention provisions restricting deployment.	- Possible co-benefits for biodiversity if targeted for reef protection. - Possible (energy intensive) combination with treatment of desalination brines.