This is a preproof accepted article for *Global Sustainability*
This version may be subject to change during the production process
DOI: 10.1017/sus.2025.10017

Editorial Introduction to the Collection: 'Ethics of Carbon Dioxide Removal'

By Hanna Schübel, Clare Heyward, Dominic Lenzi, and Ivo Wallimann-Hellmar

The role of Carbon Dioxide Removal (CDR) technologies in achieving the Paris Agreement goal of reaching net zero carbon dioxide emissions by 2050 is increasingly recognised in scientific and public debate.[1] For example, the IPCC writes '[t]he deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero carbon dioxide or greenhouse gas emissions are to be achieved' (IPCC 2022, 36). It seems that CDR technologies could be a key part of the effort to keep global temperature increases to a manageable level. Accelerated by the Paris Agreement's affirmation of the 2-degree temperature target and acknowledgement of an aspirational 1.5-degree target, the possibility of removing carbon and thereby producing 'negative emissions' gained significant traction. There is increasing academic research into the technical feasibility of various CDR technologies, as well as some attempts to develop CDR techniques by private companies. Some of the latter have already caused controversy.[2] Accordingly, governance of CDR technologies is an increasing area of research and debate, and it is ethical questions that are at the heart of many governance issues (see Honegger et al 2023 for discussion).

Among the many ethical objections that can be levelled against CDRs, three concerns have become the most prominent in scientific discussions.[3] First, CDR may create a 'moral hazard', undermining climate mitigation (Shue 2017, following Anderson and Peters 2016; for an in-depth review of research on CDR and moral hazard see Carton et al 2023). The

[1] CDR technologies have also been called "negative emissions technologies" or NETS but the Intergovernmental Panel on Climate Change (IPCC) and most other participants in the debate now use the term CDR. During the production of this special issue, *Frontiers in Climate: Negative Emissions Technologies* changed its name to *Frontiers in Climate: Carbon Dioxide Removal* (for editors' explanation, see Renforth et al., 2023). The papers in this collection themselves use different terminologies but we will refer to CDR technologies throughout this introduction.

[2] See, for example, the recent controversies surrounding the now-defunct US company Running Tide and the Canadian company Planetary Technologies Other CDR controversies have included Russ George's Haida Gwaii "Salmon Restoration project" (for discussion see Buck 2014, Kyle Powys White 2017) and the LOHAFEX project (for discussion see Kintisch 2010).

[3] Other possible concerns include issues of procedural justice and hubris. Literature on these issues specifically in relation to CDRs (as opposed to solar radiation modification proposals or 'geoengineering' in general) is scant, but regarding the former, see (Wallimann-Helmer 2021) and the latter, see Lawford Smith and Currie (2017).

This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (http://creativecommons.org/licenses/by/4.0), which permits unrestricted re- use, distribution and reproduction, provided the original article is properly cited.

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/sus.2025.10017

introduction of CDR within economic models of climate mitigation obstructs near-term mitigation because CDR lowers the aggregate costs of mitigation over the century, while the availability of CDR in models may provide policymakers with an excuse for slower mitigation (Lenzi 2018, see also Hollnaicher, this volume).

The second concern is that planning to rely upon the ability to scale up CDR to the levels seen in many modelled mitigation scenarios risks a catastrophic policy failure of not stabilising global temperature at 2°C or below. (Fuss et al. 2014; Shue 2017). Some commentators therefore regard "betting on NETS" (Fuss et al. 2014) as an "unjust gamble" with the welfare of future generations (Shue 2017). Others regard the development of CDRs as a prudent measure that could be a useful part of the fight against climate change, whilst acknowledging that emissions reductions is the preferred strategy (Moellendorf 2022).

One potential reason for any such policy failure is connected to the third set of ethical concerns. There are potential harmful side-effects of CDR, particularly in the case of very large-scale implementation. The main worry here is that such side-effects could be severely unjust (Shue 2017, 2021; Lenzi 2018, 2021; Minx et al. 2018). Most attention has been paid to the biomass-based BECCS technique. Typical mitigation scenarios featuring BECCS have been alleged to require a land area the size of India, while earlier climate models predicted the expansion of biomass to occur predominantly in tropical regions (Anderson and Peters 2016). Such possibilities for implementation could create serious threats of injustice related to local food security, water availability, and biodiversity, (Shue 2017). Accordingly, "justice in siting" (Rayner et al, 2013) and navigating trade-offs between space and resources (Low et al, 2024) are increasingly important issues.

This collection aims to contribute to the discussion about the permissible use and governance of CDR technologies by both analysing some of the ethical challenges of modelling CDR technologies and discussing the fairness of potential implementations in practice. All of them go beyond the overwhelming focus on "moral hazard" which characterised the earliest interventions on the ethics of CDR. The first two articles both challenge the common idea that the development of CDRs is "necessary" to meet the Paris Agreement goals, by challenging common assumptions made in economic modelling. The third and fourth articles each consider a problem that could arise if CDR technologies are used.

Accepted Manuscript

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/sus.2025.10017

Simon Hollnaicher asks how CDRs should be modelled to serve as a good scientific basis for policy advice. He identifies a bias towards CDR in integrated assessment models (IAMs). He first distinguishes between 'false positives', where the potential of large-scale CDR is overestimated and 'false negatives' where it is underestimated. The consequences of overestimating the potential of CDR are far more serious, from an ethical perspective, than the consequences of underestimating it and so, he argues optimistic assumptions about the potential of large-scale CDR demand a greater burden of proof. IAMs, he argues, include a great deal of CDR and therefore contain a "normative bias" in that certain results are systematically favoured over others, in this case, a bias in favour of market-based measures and technological measures such as CDRs. He identifies three elements in IAMs that play an especially influential role in creating this systemic bias: idealised implementation, perfect foresight, and high intertemporal discount rates. Hollnaicher concludes by supporting Carrrier's (2021) two strategies for dealing with values in policy-relevant science. The first is transparency: of making value judgements explicit. Whilst there have been some high-profile cases which have highlighted this need (e.g. in discounting), Hollnaicher argues that there is much work to be done when it comes to IAMs. In particular, discount rates are rarely varied in IAMs and it can be difficult even to identify certain value judgements. The second strategy would be to embrace plurality concerning values, and to observe their implications for a wider range of technological, institutional and behavioural changes. Hollnaicher suggests that this approach goes beyond plugging in different value positions into existing modelling scenarios and instead involves much more dedicated interdisciplinary work in the development of alternative scenarios.

Given the modelling bias in favour of CDR technologies, it is even more important to consider alternative scenarios, and the values underlying the selection of these scenarios. Lieske Voget-Kleschin, Christian Baatz, Clare Heyward, Detlef Van Vuuren, and Nadine Mengis (2024) explore the commonly supposed choice between large-scale CDR and technologically intense mitigation pathways and argue that this obscures other viable alternatives. They argue that pathways involving lifestyle changes or population policies rarely feature in conversations about climate change mitigation, as if there were a self-imposed "taboo" against discussing such options. They undertake an ethical analysis of four "alternative mitigation pathways proposed by Van Vuren et al (2018), namely: "life-style changes" (i.e. reduced carbon dioxide consumption by consumers), "low population", "low non-CO2" (replacing meat products with alternatives) and "agricultural intensification"

Accepted Manuscript

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/sus.2025.10017

(increasing livestock yields in lower-income countries). Their overarching conclusion is that the moral permissibility of each pathway depends on the precise implementation of measures rather than the kind of measures highlighted. A corollary of this is that the scenarios that are commonly seen as most morally problematic, that is “life-style changes” and “low-population”) could be implemented in morally permissible ways. By contrast, the less controversial “low non-CO2” and “agricultural intensification” pathways actually deserve more ethical scrutiny. Therefore, scenarios involving lifestyle changes and population measures should not be prematurely dismissed. Nor should even the most commonly accepted strategies escape closer ethical scrutiny.

Whilst the first two papers address issues regarding the modelling and the assumptions surrounding CDR technologies, the next two papers discuss the responsibilities of the actors who could potentially implement CDR technologies, and the question of how the costs and benefits of CDR technologies should be distributed. Kian Mintz-Woo (2023) identifies what he calls a “needs-efficiency trade-off”. There are two possible reasons to develop CDR, Minz-Woo argues. The first justification is the potential contribution that CDR technologies can make to global mitigation goals. The second is that investment in these technologies can contribute to development in the region where they are located. However, as Minz-Woo points out, these two justifications lead to different conclusions about where CDR measures should be implemented. If contribution to mitigation (efficiency) is taken as the primary concern, then implementation should be done in countries with the best prospect of success. Minz-Woo contends that successful deployment is most likely in Western industrialised nations, due to greater human capital and scientific understanding. However, if developmental concerns are primary (need) then CDR should be developed and deployed in developing regions of the world. This is because where developing countries are dependent on carbon-intensive industry and infrastructure, requiring them to simply reduce emissions could deepen socio-economic injustices. Using CDRs, Minz-Woo argues, offers the opportunity to “offset” GHG emissions that are needed for economic development. Policy-makers should carefully consider whether they wish to pursue “efficiency” or “need” as the practical implications are very different.

Another conflict between efficiency and fairness is addressed by Dominic Lenzi, Hanna Schübel and Ivo Wallimann-Helmer (2023). They outline moral dilemma between holding carbon majors responsible for their historical contributions to climate change, and the prospect of their being among the best placed to offer certain forms of CDR (i.e. BECCs and

Accepted Manuscript

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/sus.2025.10017

DACCs). As the storage of carbon dioxide is likely to be very profitable, carbon majors thus stand to benefit from supplying fossil fuels and offsetting or cleaning up the carbon dioxide that results from their use. Accordingly, Lenzi et al. argue that from the perspective of ideal theory, carbon majors are not entitled to keep the profits from CDR usage until they have addressed their historical responsibility for causing climate change. This conclusion may be resisted under non-ideal circumstances, where it might be permissible to allow carbon majors to profit from CDR, if no other agents have the technical or institutional capacity to develop or use it. However, they argue that in more favourable circumstances, including those of most OECD countries, it remains impermissible to reward carbon majors for undertaking CDR until they compensate for their historical climate responsibilities. Additionally, Lenzi et al echo the arguments of the first two papers: that assumptions about the feasibility of development and deployment must be made explicit.

The papers in this collection thus present arguments showing how the development and use of CDR technologies may - or may not - be in line with climate justice and present conclusions addressing both policymakers and modellers. The discussion of these questions addressed here – and others – is crucial in navigating the balance between technological possibilities, political demands, and moral requirements.

Acknowledgments. The authors thank the editor for his useful comments.

Author contributions. All authors contributed equally to the conceptualisation and planning of the text. Hanna Schuebel and Clare Heyward drafted the text, with comments and input from Dominic Lenzi and Ivo Walliman Hellmer.

Financial support. Clare Heyward's contribution was supported by both CEMICS2 (Contextualising Climate Engineering, Mitigation, Illusion, Complement or Substitute) SPP 1689, German Research Foundation, and the Institute for Future Studies project: 'Climate Ethics and Future Generations', funded by Riksbankens Jubileumsfond (grant number M17-0372:1).

Dominic Lenzi's research on this piece was supported by

the RIVET project (grant number: 2020-00202), funded by FORMAS Sweden;

and by the research program Ethics of Socially Disruptive Technologies

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms.
https://doi.org/10.1017/sus.2025.10017

Accepted Manuscript

(ESDiT), funded through the Gravitation program of the Dutch Ministry of Education, Culture, and Science and the Netherlands Organization for Scientific Research (NWO grant number 024.004.031).

Competing interests. None.

Research transparency and reproducibility. This research does not produce any empirical results.

Bibliography

Anderson, Kevin, and Glen Peters. 2016. "The Trouble with Negative Emissions: Reliance on Negative-Emission Concepts Locks in Humankind's Carbon Addiction." Science 354 (6309): 182–83. https://doi.org/10.1126/science.aah4567.

Buck, Holly Jean. 2014. Village science meets global discourse: The Haida Salmon restoration corporation's ocean iron fertilization experiment. *Case Study, Engineering Our Climate Working Paper and Opinion Article Series*. Available at: http://wp.me/p2zsRk-9M

Carton, Wim, Inge-Merete Hougaard, Nils Markusson,and Jens Friis Lund, 2023. "Is carbon removal delaying emission reductions?" *WIREs Climate Change*, 14(4), e826. https://doi.org/10.1002/wcc.826

Carrier, Martin. 2022. M. What Does Good Science-Based Advice to Politics Look Like? Journal for General Philosophy of Science, 53. https://doi-org.mime.uit.no/10.1007/s10838-021-09574-2

Fuss, Sabine, Josep G. Canadell, Glen P. Peters, Massimo Tavoni, Robbie M. Andrew, Philippe Ciais, Robert B. Jackson, et al. 2014. 'Betting on Negative Emissions'. *Nature Climate Change* 4 (10): 850–53. https://doi.org/10.1038/nclimate2392.

Honegger, Matthias, Christian Baatz, Samuel Eberenz, Antonia Holland-Cruz, Axel Michaelowa, Benno Pokorny, Matthias Poralla and Malte Winkler. 2022. The ABCof Governance Principles of Carbon Dioxide Removal Policy. Frontiers in Climate 4. https://doi.org/10.3389/fclim.2022.884163

Hollnaicher, Simon. 2022. "On Economic Modeling of Carbon Dioxide Removal: Values, Bias, and Norms for Good Policy-Advising Modelling." Global Sustainability 5: e18. https://doi.org/10.1017/sus.2022.16.

Accepted Manuscript

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/sus.2025.10017

IPCC, ed. 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. https://doi.org/10.1017/9781009325844.

Lawford-Smith, Holly and Adrian Currie, 2017. "Accelerating the Carbon Cycle: The Ethics of Enhanced Weathering." Biology Letters 13. 20160859 http://dx.doi.org/10.1098/rsbl.2016.0859

Lenzi, Dominic. 2018. "The Ethics of Negative Emissions." Global Sustainability 1: 23. https://doi.org/10.1017/sus.2018.5.

Lenzi, Dominic, Hanna Schübel, and Ivo Wallimann-Helmer. 2023. "Justice in Benefitting from Carbon Removal." Global Sustainability 6. https://doi.org/10.1017/sus.2023.22.

Low, Sean, Miranda Boettcher, Shinichiro Asayama, Chad Baum, Amanda Borth, Calum Brown, Forrest Clingerman, et al. 2024. 'An Earth System Governance Research Agenda for Carbon Removal'. Earth System Governance 19 (January): 100204. https://doi.org/10.1016/j.esg.2024.100204.

Mintz-Woo, Kian. 2023. "The NET Effect: Negative Emissions Technologies and the Need–Efficiency Trade-Off." Global Sustainability 6: e5. https://doi.org/10.1017/sus.2023.3.

Moellendorf, Darrel. 2022. Mobilizing Hope: Climate Change and Global Poverty. New York: Oxford University Press.

Renforth et al. 2023. "Speciality Grand Challenge: Renaming our Section to Carbon Dioxide Removal" Frontiers in Climate 5. https://doi.org/10.3389/fclim.2023.1279109

Shue, Henry. 2017. "Climate Dreaming: Negative Emissions, Risk Transfer, and Irreversibility." Journal of Human Rights and the Environment 8 (2): 203–16. https://doi.org/10.4337/jhre.2017.02.02.

The Royal Society. 2009. "Geoengineering the Climate." London. https://royalsociety.org/~/media/royal_society_content/policy/publications/2009/8693.pdf.

Voget-Kleschin, Lieske, Christian Baatz, Clare Heyward, Detlef Van Vuuren, and Nadine Mengis. 2024. "Reassessing the Need for Carbon Dioxide Removal: Moral

Accepted Manuscript

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/sus.2025.10017

Implications of Alternative Climate Target Pathways." Global Sustainability 7: e1. https://doi.org/10.1017/sus.2023.21.

Wallimann-Helmer, Ivo. 2021. "Feasibility and Justice in Decarbonizing Transitions" edited by C. Katz and S. Kenehan, 191–210. Lanham: Rowman & Littlefield.

White, Kyle Powys. 2018. "Indigeneity in Geoengineering Discourses: Some Considerations." Ethics, Policy and Environment 21. https://doi-org.mime.uit.no/10.1080/21550085.2018.1562529.

Accepted Manuscript

Downloaded from https://www.cambridge.org/core. IP address: 13.201.136.108, on 02 Oct 2025 at 05:02:59, subject to the Cambridge Core terms of use, available at https://www.cambridge.org/core/terms. https://doi.org/10.1017/sus.2025.10017