The Duality of Carbon Dioxide Removal: Climate Solution and the Reproduction of Structural Inequalities

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Abstract

Carbon Dioxide Removal (CDR) technologies have transitioned from a marginal concept to a central pillar of international climate mitigation scenarios, most notably those of the Intergovernmental Panel on Climate Change (IPCC) that limit global warming to 1.5°C. While these technologies promise to counterbalance hard-to-abate emissions and potentially restore atmospheric CO_2 levels, their rapid ascendancy warrants critical social scientific scrutiny. This article argues that CDR possesses a fundamental duality: it is simultaneously a potentially indispensable *climate solution* and a powerful vector for the *reproduction of structural inequalities*. Through a systematic, interdisciplinary analysis bridging energy justice and political ecology frameworks, we deconstruct this duality. The article first provides a typology of CDR approaches, from nature-based solutions like Afforestation/Reforestation (AR) to more technologically complex methods like Direct Air Capture with Carbon Storage (DACCS) and Bioenergy with Carbon Capture and Storage (BECCS). It then analyzes the socio-political dimensions of CDR deployment, focusing on three core axes of potential injustice: (1) the *distributional* inequities in the siting of projects and their localized environmental, land, and resource impacts; (2) the *procedural* injustices in decision-making processes that often exclude marginalized communities; and (3) the *recognitional* injustices that arise when CDR overlooks diverse forms of knowledge, values, and worldviews. The analysis reveals that without deliberate and transformative governance, the large-scale deployment of CDR risks reinforcing existing global and local power hierarchies, creating new "sacrifice zones," and diverting attention and resources from urgent decarbonization of energy systems. The article concludes that a just CDR pathway is not inevitable but must be actively constructed through anticipatory, participatory, and equity-centered policies that prioritize frontline communities, address root causes of inequality, and subordinate CDR to a overarching strategy of rapid emissions reduction.

Keywords

Carbon Dioxide Removal (CDR), Climate Justice, Energy Justice, Structural Inequality, Political Ecology, DACCS, BECCS, Net-Zero

1. Introduction

The escalating climate crisis, underscored by increasingly frequent and severe extreme weather events, biodiversity loss, and the relentless rise in atmospheric greenhouse gas concentrations, has precipitated a profound reckoning with the limits of conventional mitigation strategies [1]. In this context, Carbon Dioxide Removal (CDR)-a suite of technologies and processes aimed at removing CO_2 directly from the atmosphere and durably storing it-has emerged as a critical component of climate policy discourse. The IPCC's Special Report on Global Warming of 1.5°C starkly illustrated that pathways to meet this ambitious target are heavily dependent on the large-scale deployment of CDR, often on the order of hundreds of gigatons of CO_2 removal over the 21st century [2].

This "techno-optimistic" narrative frames CDR as a necessary corrective, a tool to counterbalance residual emissions from sectors like aviation, agriculture, and industry, and even to achieve "net-negative" emissions in the latter half of the century. Proponents argue that CDR offers a pragmatic and essential buffer, buying precious time for the energy transition and providing a potential safety net in the event of climate tipping points. This perspective has fueled significant investment in CDR research and development, with both governments and private corporations championing its potential.

However, this rapid and often uncritical embrace of CDR demands a rigorous, interdisciplinary examination that moves beyond technical feasibility and cost curves. A growing body of critical social science literature warns that the promise of CDR is shadowed by a perilous duality. While it may offer a partial technical solution to a geophysical problem, its socio-political implementation risks exacerbating the very structural inequalities that underpin both the climate crisis and unsustainable development pathways [3]. This article posits that CDR is not a neutral tool but a socio-technical system embedded within existing power relations, economic structures, and colonial legacies. As such, it can function as a mechanism for the *reproduction of structural inequalities* across geographic scales-from the global North-South divide to local community disparities.

The objective of this article is to systematically unpack this duality. Drawing on theoretical frameworks from energy justice and political ecology, we will analyze how the pursuit of CDR could lead to inequitable outcomes in the distribution of risks and benefits, the exclusion of marginalized voices from decision-making, and the non-recognition of alternative epistemologies and values. The central research question is: How does the development and prospective deployment of CDR technologies interact with and potentially reinforce structural inequalities, and what governance principles are necessary to navigate this duality towards a just climate future?

The article proceeds as follows. Section 2 outlines the methodological and theoretical foundations. Section 3 provides a typology of major CDR approaches, highlighting their distinct technical and socio-ecological profiles. Section 4 constitutes the core analytical contribution, examining the three dimensions of justice-distributional, procedural, and recognitional-as they pertain to CDR. Section 5 discusses the risk of CDR being used as a justification for delaying fossil fuel phase-out, a phenomenon known as "mitigation deterrence." Finally, Section 6 proposes a framework for just CDR governance and offers concluding reflections [4].

2. Theoretical Framework and Methodology

This research adopts an interdisciplinary approach, synthesizing insights from Science and Technology Studies (STS), political ecology, and energy justice scholarship. It is primarily conceptual and analytical, aiming to build a coherent framework for understanding the socio-political dimensions of CDR.

2.1 Energy Justice and the Tripartite Framework

The energy justice framework provides a robust normative and analytical tool for evaluating energy systems. It is typically structured around three core tenets:

- Distributional Justice: Concerns the equitable allocation of the benefits and burdens (e.g., pollution, resource access, economic opportunities) associated with energy systems across space, time, and social groups.
- Procedural Justice: Refers to the fairness of the decision-making processes, emphasizing inclusive, transparent, and participatory governance where all affected parties have a voice [5].
- Recognition Justice: Involves the respectful acknowledgment and consideration of diverse perspectives, values, cultures, and forms of knowledge. Injustice occurs through the misrecognition or disrespect of particular social groups.

Applying this tripartite framework to CDR allows for a systematic diagnosis of potential injustice across its entire life cycle, from research funding and siting to operation and long-term liability.

2.2 Political Ecology and the Question of Power

Political ecology complements energy justice by foregrounding the role of power, political economy, and historical context in shaping socio-environmental outcomes. It asks *cui bono?*-who benefits?-from particular environmental interventions. A political ecology lens views CDR not merely as a set of apolitical tools but as "socio-technical imaginaries" that are shaped by and, in turn, shape social orders. This perspective is crucial for understanding how CDR might:

- Reinforce Neocolonial Dynamics: By enabling continued high levels of consumption in the Global North while imposing land-use and resource demands on the Global South [6].
- Create New Accumulation Frontiers: Turning the atmosphere's waste absorption capacity into a commodifiable and financially tradable asset.
- Produce Socio-Ecological Sacrifice Zones: Areas deemed expendable for the "greater good" of global climate stabilization [7].

By integrating energy justice's normative focus with political ecology's critical analysis of power, this article provides a comprehensive critique of the CDR paradigm and charts a path for its more equitable governance.

3. A Typology of Carbon Dioxide Removal Technologies

CDR encompasses a diverse portfolio of approaches with vastly different technological readiness levels, costs, scalability, and, crucially, socio-ecological implications. A basic understanding of these technologies is a prerequisite for analyzing their justice dimensions. They can be broadly categorized as follows (see Figure 1):

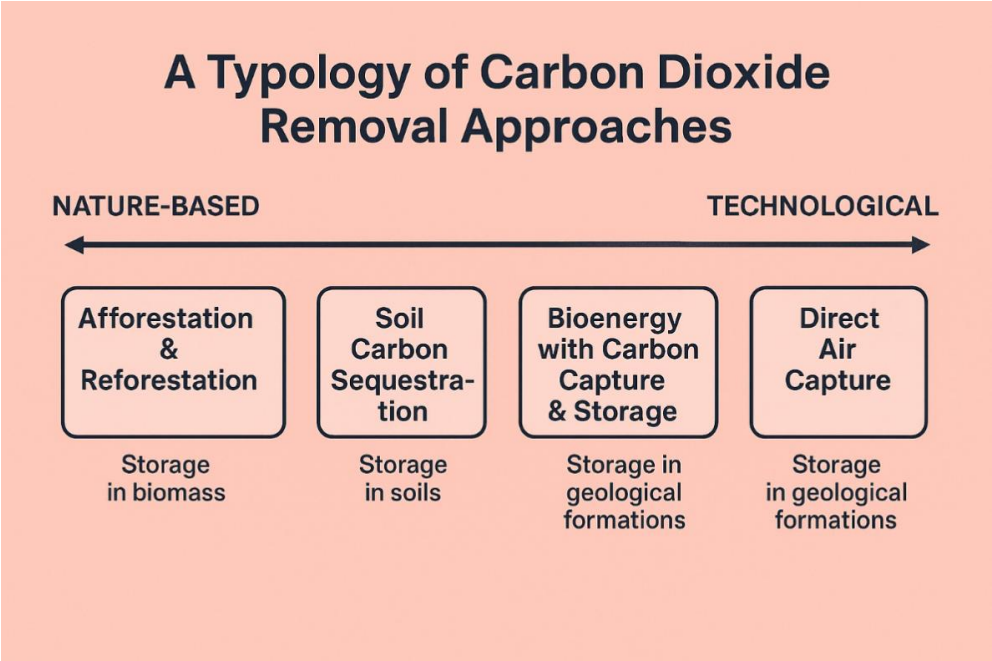

Figure 1. A Typology of Carbon Dioxide Removal Approaches, Categorized by Technological Intervention and Primary Storage Medium

Figure 1 show a two-axis chart. The Y-axis represents a continuum from "Nature-Based" to "Technological" approaches. The X-axis represents the primary storage medium, from "Terrestrial/Biological" to "Geological." Key CDR methods are plotted:

- Afforestation/Reforestation (AR): Nature-Based, Terrestrial storage.
- Soil Carbon Sequestration: Nature-Based, Terrestrial storage.
- Biochar: Hybrid, leaning towards Technological, Terrestrial storage.
- Enhanced Weathering: Hybrid, Geological/Terrestrial storage.
- Bioenergy with Carbon Capture and Storage (BECCS): Technological, Geological storage.
- Direct Air Capture with Carbon Storage (DACCS): Technological, Geological storage.
- Ocean Alkalinity Enhancement: Technological, Ocean storage.

The figure highlights the varying socio-ecological footprints and governance challenges associated with different positions on this spectrum.)

3.1 Nature-Based CDR (Nb-CDR)

These approaches leverage and enhance natural biological processes.

Afforestation/Reforestation (AR): Involves planting trees on non-forested land or reforesting previously cleared areas. It is a well-understood and relatively low-cost method. However, its justice implications are profound, as large-scale monoculture plantations can lead to land grabs, displacement of indigenous and local communities, loss of biodiversity, and reduced albedo (light reflection) in certain regions, potentially undermining the climate benefit [8].

Soil Carbon Sequestration: Involves agricultural practices (e.g., no-till farming, cover cropping) that increase the organic carbon content in soils. While potentially beneficial for soil health, its permanence is vulnerable to changes in land management, and it may not address deeper structural issues in industrial agriculture [9].

Blue Carbon: Refers to carbon sequestration in coastal and marine ecosystems like mangroves, salt marshes, and seagrasses. While highly efficient per unit area, the total potential is limited, and these ecosystems are highly threatened by coastal development, raising issues of conservation justice and displacement.

3.2 Hybrid and Technological CDR

These methods involve more significant engineering and industrial processes.

Biochar: Produced by pyrolyzing biomass in a low-oxygen environment, creating a stable form of carbon that can be added to soils. Its impacts depend on feedstock sourcing (which competes with other land uses) and the effects on soil ecosystems and local communities where it is applied [10].

Enhanced Weathering: Involves spreading finely ground silicate rocks (e.g., basalt) on land or in the ocean to accelerate natural chemical weathering processes that consume CO_2. This requires large-scale mining operations, with associated local environmental and social impacts, and questions about downstream effects on aquatic ecosystems.

Bioenergy with Carbon Capture and Storage (BECCS): This is a hybrid system where biomass is grown, burned for energy, and the resulting CO_2 emissions are captured and stored geologically. BECCS is a cornerstone of many IPCC 1.5°C pathways. Its justice risks are immense, stemming from its colossal land, water, and nutrient demands, which could trigger massive land-use change, threaten food security, and exacerbate water scarcity, disproportionately affecting vulnerable populations in the Global South [11].

Direct Air Capture with Carbon Storage (DACCS): This technology uses chemical processes to capture CO_2 directly from the ambient air, which is then compressed and stored underground. DACCS has a much smaller physical land footprint than BECCS but is extremely energy-intensive. Its justice implications are tied to its energy source (which must be clean to be net-negative), the siting of facilities and pipeline infrastructure, and its potential to be controlled by wealthy corporate actors, potentially creating a "moral hazard".

4. The Justice Deficit: Analyzing the Three Dimensions of CDR-Induced Inequality

The technical promise of CDR obscures a complex landscape of potential socio-ecological harm. This section analyzes these risks through the tripartite lens of energy justice [12].

4.1 Distributional Injustice: The Uneven Geography of Burdens and Benefits

The burdens of CDR deployment are unlikely to be shared equally, threatening to create new patterns of environmental injustice.

Land and Resource Grabs: Large-scale Nb-CDR and BECCS require vast tracts of land. Historical precedents of "green grabbing"-the appropriation of land and resources for environmental ends-suggest that these projects will likely be sited in regions with weak land tenure security, often in the Global South. This could displace smallholder farmers, pastoralists, and Indigenous communities, undermining their livelihoods and food sovereignty. For example, a single BECCS plant meeting a significant fraction of global CDR needs could require an area of plantation larger than countries like Hungary or Portugal, directly competing with food production [13].

Localized Environmental Impacts: CDR projects can generate localized pollution and resource stress. Enhanced weathering involves mining, with associated dust, noise, and water pollution. BECCS and DACCS plants require significant water for cooling and chemical processes, potentially straining local water supplies. The transportation of CO_2 for storage requires extensive pipeline networks, which have their own safety risks and land-use impacts, often routed through low-income and minority communities, replicating the patterns of environmental racism seen in the fossil fuel era.

Asymmetrical Benefits: The primary benefit of CDR-a stabilized global climate-is a diffuse public good. However, the financial benefits (e.g., carbon credit revenues, government subsidies) are likely to be captured by large landowners, biotechnology firms, and fossil fuel companies seeking to offset their continued emissions. This creates a perverse dynamic where the polluters who contributed most to the climate crisis can profit from its technological solution, while the burdens are externalized onto marginalized communities who contributed least to the problem.

4.2 Procedural Injustice: Exclusion from the Decision-Making Table

The development of CDR is currently dominated by a narrow set of actors, leading to a democratic deficit in its governance.

Technocratic Elitism: CDR research, funding, and policy design are heavily concentrated in the Global North, within elite scientific institutions, government agencies, and tech corporations. This creates a "top-down" governance model where the communities that will be most affected by deployment have little to no say in the fundamental research questions, technology choices, or regulatory standards [14].

The "Innovation" Narrative: The framing of CDR as an urgent technological innovation can be used to fast-track projects, bypassing robust environmental and social impact assessments, meaningful public consultations, and Free, Prior, and Informed Consent (FPIC) for Indigenous peoples. The complex, technical nature of CDR can also serve as a barrier to participation, disempowering communities that lack specialized knowledge.

Global Governance Gaps: There is currently no comprehensive international framework to govern CDR, particularly concerning transboundary impacts, liability for leakage, and the ethical allocation of removal quotas. Without such a framework, powerful states and corporations will set the rules, potentially at the expense of less powerful nations and communities.

4.3 Recognition Injustice: Erasing Worlds and Knowledges

Perhaps the most profound injustice lies in the failure to recognize alternative ways of knowing and valuing the world.

Commodification of Nature: CDR fundamentally reframes ecosystems and the atmosphere as a warehouse for waste and a sink to be engineered. This utilitarian, managerial worldview clashes with the cosmologies of many Indigenous and local communities, who may view nature as a living relative, a source of cultural identity, or a commons to be stewarded rather than a resource to be managed for carbon metrics. The very act of assigning a carbon price to a forest or a grassland can be seen as a form of ontological violence [15].

Marginalizing Alternative Pathways: The heavy reliance on CDR in climate models can sideline alternative, and potentially more just, climate solutions. These include radical demand-side reduction, degrowth economic models, systemic changes to food and transport systems, and support for community-led conservation and agroecology. By focusing on a technical fix that allows for business-as-usual to continue, the CDR paradigm fails to recognize the validity of these transformative, low-tech pathways.

The "Savior" Narrative: The portrayal of CDR as a necessary "savior" from the climate crisis can de-politicize the problem, shifting responsibility away from the political and economic systems that caused it and onto a suite of future technologies. This narrative fails to recognize the historical responsibility of industrialized nations and fossil capital for the crisis, thereby perpetuating a form of climate colonialism [16].

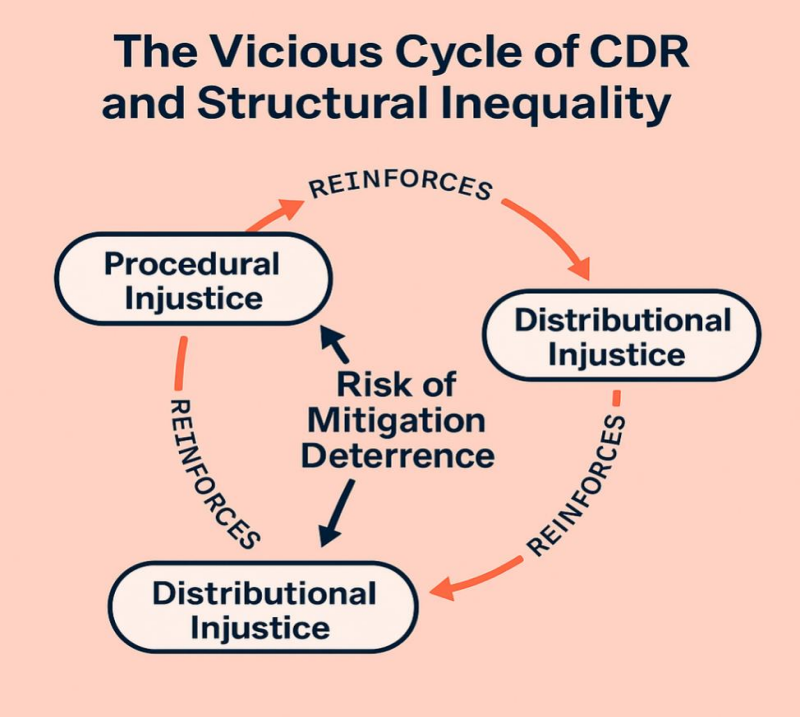

Figure 2. The Self-Reinforcing Cycle Between Carbon Dioxide Removal Deployment and Structural Inequality

Figure 2 is a circular flowchart.

It starts with a box: **"Dominant CDR Narrative & Power Imbalances."**

This leads to **"Procedural Injustice"** (Exclusionary decision-making), which enables **"Recognition Injustice"** (Marginalization of knowledges & values), which in turn facilitates **"Distributional Injustice"** (Uneven burdens/benefits).

The "Distributional Injustice" box feeds back into "Dominant CDR Narrative & Power Imbalances," reinforcing them.

A side-loop from "Dominant CDR Narrative" leads to **"Risk of Mitigation Deterrence"** (Delayed decarbonization), which exacerbates the "Distributional Injustice" of climate impacts themselves.

This figure visualizes how injustices are interconnected and self-reinforcing within the current CDR paradigm.)

5. The Specter of Mitigation Deterrence and Moral Hazard

A central risk associated with the CDR duality is "mitigation deterrence" (also called "moral hazard" or "carbon lock-in")-the phenomenon where the promise of future CDR undermines the political and economic impetus for rapid, deep decarbonization in the present [17]. By offering a apparent "way out," CDR can be used as a justification by fossil fuel interests and hesitant governments to delay the phase-out of coal, oil, and gas. This represents a profound intergenerational injustice, as it places a bet on unproven technologies at scale, risking catastrophic warming if those technologies fail to materialize as hoped. The continued investment in fossil fuel infrastructure, enabled by the promise of future CDR, directly reproduces the structural inequalities of the fossil economy, concentrating wealth and power while imposing the long-term costs of climate chaos on future generations and the most vulnerable.

6. Towards a Just CDR Governance Framework and Conclusion

The duality of CDR is not a predetermined fate. Whether it becomes a tool for climate stabilization or for exacerbating inequality depends on the governance structures we build around it. Navigating this duality requires a fundamental reorientation from a technology-centered to a justice-centered paradigm. We propose the following principles for a just CDR governance framework:

Subordination to Radical Decarbonization: CDR must be explicitly governed as a supplement to, not a substitute for, the urgent and comprehensive phase-out of fossil fuels. Policy should prioritize "abatement-first" and establish strict limits on the use of CDR for offsetting.

Prioritizing In-situ Benefits: CDR projects should be designed to deliver tangible local co-benefits, such as ecosystem restoration, soil health improvement, job creation, and community-controlled renewable energy, rather than solely maximizing carbon removal at lowest cost.

Robust Participatory and Democratic Governance: Mandatory, early, and meaningful public participation, based on FPIC for Indigenous peoples, must be a non-negotiable condition for any CDR project. Decision-making power should be devolved to the most local level appropriate.

Addressing Root Causes: CDR governance must be integrated with policies that address the root causes of vulnerability, such as land tenure reform, strengthening of common property rights, and redistribution of resources.

Precautionary and Adaptive Management: Given the uncertainties and potential for irreversible harm, a strong precautionary principle should guide deployment. Governance must be adaptive, with continuous monitoring and the ability to halt or modify projects based on social and ecological feedback.

Global Equity and Liability: An international regime is needed to ensure that the Global North takes responsibility for its historical emissions, both by leading in decarbonization and by financing CDR in the Global South only where it is demonstrably just and desired by host communities. Clear, long-term liability frameworks for carbon storage must be established.

In conclusion, the ascent of Carbon Dioxide Removal represents a critical juncture in the global response to climate change. This article has argued that CDR is characterized by a fundamental duality: it holds the potential to restore a geophysically safe climate while simultaneously possessing the capacity to deepen the structural inequalities that plague our societies. The analysis of distributional, procedural, and recognitional injustices reveals that without deliberate and transformative intervention, the large-scale deployment of CDR is likely to follow the well-trodden path of previous socio-technical fixes, benefiting the powerful at the expense of the marginalized. The promise of a techno-fix risks perpetuating the very system that caused the crisis. Therefore, the central task for researchers, policymakers, and civil society is not merely to engineer efficient carbon removal machines, but to forge a socio-political project that ensures these technologies serve climate justice, not the other way around. The future of the climate and the integrity of our social fabric depend on this choice.

References

[1] IPCC. (2018). *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.). Cambridge University Press. https://doi.org/10.1017/9781009157940

[2] IPCC. (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 University Press. https://doi.org/10.1017/9781009325844

[3] Luderer, G., Vrontisi, Z., Bertram, C., Edelenbosch, O. Y., Pietzcker, R. C., Rogelj, J., ... & Kriegler, E. (2018). Residual fossil CO2 emissions in 1.5–2 °C pathways. Nature Climate Change, 8(7), 626-633. https://doi.org/10.1038/s41558-018-0198-6

[4] McCauley, D., & Heffron, R. (2018). Just transition: Integrating climate, energy and environmental justice. Energy Policy, 119, 1-7. https://doi.org/10.1016/j.enpol.2018.04.014

[5] Schlosberg, D. (2004). Reconceiving environmental justice: Global movements and political theories. Environmental Politics, 13(3), 517-540. https://doi.org/10.1080/0964401042000229025

[6] McLaren, D., & Markusson, N. (2020). The co-evolution of technological promises, modelling, policies and climate change targets. Nature Climate Change, 10(5), 392-397. https://doi.org/10.1038/s41558-020-0740-1

[7] Carton, W., Asiyanbi, A., Beck, S., Buck, H. J., & Lund, J. F. (2020). Negative emissions and the long history of carbon removal. WIREs Climate Change, 11(6), e671. https://doi.org/10.1002/wcc.671

[8] Kevin Anderson, Glen Peters ,The trouble with negative emissions.Science354,182-183(2016). https://doi.org/10.1126/science.aah4567

[9] McLaren, D. (2020). Quantifying the potential scale of mitigation deterrence from greenhouse gas removal techniques. Climatic Change, 162(4), 2411-2428. https://doi.org/10.1007/s10584-020-02732-3

[10] Bastin, J.-F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., Zohner, C. M., & Crowther, T. W. (2019). The global tree restoration potential. Science, 365(6448), 76-79. https://doi.org/10.1126/science.aax0848

[11] Fleischman, F., Basant, S., Chhatre, A., Coleman, E. A., Fischer, H. W., Gupta, D., ... & Veldman, J. W. (2020). Pitfalls of tree planting show why we need people-centered natural climate solutions. BioScience, 70(11), 947-950. https://doi.org/10.1093/biosci/biaa094

[12] Macreadie, P. I., Costa, M. D., Atwood, T. B., Friess, D. A., Kelleway, J. J., Kennedy, H., ... & Duarte, C. M. (2021). Blue carbon as a natural climate solution. Nature Reviews Earth & Environment, 2(12), 826-839. https://doi.org/10.1038/s43017-021-00224-1

[13] Heck, V., Gerten, D., Lucht, W., & Popp, A. (2018). Biomass-based negative emissions difficult to reconcile with planetary boundaries. Nature Climate Change, 8(2), 151-155. https://doi.org/10.1038/s41558-017-0064-y

[14] Beerling, D. J., Kantzas, E. P., Lomas, M. R., Wade, P., Eufrasio, R. M., Renforth, P., ... & Banwart, S. A. (2020). Potential for large-scale CO2 removal via enhanced rock weathering with croplands. Nature, 583(7815), 242-248. https://doi.org/10.1038/s41586-020-2448-9

[15] Fairhead, J., Leach, M., & Scoones, I. (2012). Green grabbing: a new appropriation of nature? The Journal of Peasant Studies, 39(2), 237-261. https://doi.org/10.1080/03066150.2012.671770

[16] Talberg, A., Christoff, P., Thomas, S., & Karoly, D. (2018). Geoengineering governance-by-default: An earth system governance perspective. International Environmental Agreements: Politics, Law and Economics, 18(2), 229-253. https://doi.org/10.1007/s10784-017-9374-9

[17] Kallis, G. (2011). In defence of degrowth. Ecological Economics, 70(5), 873-880. https://doi.org/10.1016/j.ecolecon.2010.12.007