

Expanding carbon removal to the Global South: Thematic concerns on systems, justice, and climate governance

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ABSTRACT

Conversations on how to assess, innovate, and develop policies for carbon removal are for now largely confined to the Global North – reflecting a concentration of academic interest (and concern), innovation capacity, early funding initiatives, and policy path-dependence in climate, energy, and land-use. However, future population growth, emissions trajectories, and even concentrations of economic (and technological power) are shifting to the Global South. Here, after explaining the positionality of the author, this paper summarizes the perspectives and concerns of 90 key academics, technologists, and policy entrepreneurs on expanding carbon removal assessment, innovation, and policy beyond early foci within (northern) Europe, the US, Japan, and Australia. It explores how concerns about systems (coupling and infrastructure deployment), justice (equity and inclusion), and governance (including pledges, funding, and offsets) markedly differ across Global North and Global South dynamics. It discusses how such issues intersect with each other, and concludes with insights for research and policy.

1. Introduction

Carbon removal – the evolving post-Paris strategy for balancing emission sources with a diverse range of carbon sinks – is spurring assessment, innovation, and policy at multiple levels. An early focus on assessing so-called “natural solutions” like forestry management and bioenergy carbon capture and storage (BECCS) is expanding: spatially, from terrestrial to marine areas (e.g. blue carbon to ocean based carbon removal); sectorally, from bioeconomy towards technological innovation and extractive industries (e.g. direct air capture and enhanced weathering); and conceptually, from the trade-offs of (re)creating carbon stocks to managing ecosystems for diverse purposes (e.g. avoided deforestation). Direct air capture and enhanced weathering are generating philanthropic and public-sector funding, field experimentation, and prototype development. Policy signalling is coming from Paris Agreement commitments, corporate Net Zero 2050 pledges, and the European Green Deal. The 2021 UNFCCC Glasgow COP26 meeting made a Leaders’ Declaration on carbon removal through the preservation of natural ecosystems. Weeks later, the European Commission reframed existing forms of marine- and land-use as “carbon farming” [1].

These are early stages, but the implications of upscaling carbon removal across natural and technological systems are planetary. Making

sense of these options should be undertaken through a global effort, across polities, issues, levels, and sectors. Still, conversations on how to assess, innovate, and develop policy for carbon removal are for now largely confined to the Global North – reflecting a concentration of academic interest (and concern), innovation capacity, early funding initiatives, and policy path-dependence in climate, energy, and land-use [2].

This paper summarizes the perspectives and concerns of 90 key academics, technologists, and policy entrepreneurs on expanding carbon removal assessment, innovation, and policy beyond early foci within (northern) Europe, the US, Japan, and Australia – and on identifying broad distinctions and inequities between the capacities and interests of the Global North and South. These networks acknowledge gaps in expertise and legitimacy that must be addressed through expanding the debate. At least two can be foregrounded. Concerns on carbon removal are often filtered through antecedent food, fuel, and resource conflicts, which are especially relevant in the Global South, and have the potential to be exacerbated through broader deployment [3,4]. Moreover, developing (and least-developed) polities tend to lack capacity to confront new strategies in climate governance, despite standing to gain or lose the most in how these develop [5].

The study groups expert perspectives into three thematic areas,

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covered in the three following sections. The first two areas represent sets of dimensions: *Systems* (Section 3), as challenges posed by coupling or integrating carbon removal approaches into energy, land-use, transportation, and other sociotechnical systems; and *Justice* (Section 4), as the capacity-building, technology development or transfer, funding, and social needs of different actors informed by principles of equity and inclusion. The final area transposes expert perspectives onto *climate governance* through the Paris Agreement (Section 5), including the design of the Nationally Determined Commitments and conventions surrounding Common but Differentiated Responsibilities. Section 6 discusses linkages between and across the three thematic areas.

To foreground an obvious shortcoming, the study relies mostly on Global North researchers and innovators active in carbon removal – reflecting the early knowledge economy of a novel climate strategy. The paper is written to prospect clear differences between North and South (based on the reflections of those persons), and set the stage for future research and engagement activities in the Global South.

2. Research design

2.1. Participant selection

Our participation and interview protocols are grounded in the “GeoEngineering and Negative Emissions pathways in Europe” (GENIE) project, and have been deployed on other topics in Baum et al. [6], Enevoldsen et al. [7], Low et al. [8,9], Sovacool et al. [9–11] and Sovacool et al. [12–14]. We conducted semi-structured interviews with 90 experts (Annex 1), each with publications or patents in carbon removal between 2011 and 2020, and all of whom are active in assessment, technology development, or policy engagement. They were also selected for a mix of general and specific expertise within a spread of ten carbon removal approaches with strong visibility in current assessments (Annex 2). All but one currently work in the Global North, though many focus on issues more specific to emerging or developing regions. This is an unfortunate consequence of focusing on foundational researchers in carbon removal as a post-Paris Agreement strategy. Many long-standing forms of agriculture, forestry, and land or marine ecosystems management are being reconceptualized in the Global North as carbon removal, which generates many concerns and potentials. We set the stage for engaging Global South (research) communities who might contrast these reorientations with their uses and framings, and develop new lines of questioning.

2.2. Questions, technology focus, and reporting

Our interviews were underpinned with seven question sets designed to cover a broad range of thematic concern, across innovation, assessment, and policy gaps, sectoral couplings, risks, and governance

Table 1
Semi-structured expert interview question sets.

1. Innovation	Which particular options have high or low innovation potential in technical, communication, societal appraisal, and policy dimensions?
2. Coupling	What energy systems or other sociotechnical systems could or should be coupled to carbon removal?
3. Business models	What business models and markets could carbon removal create or disrupt?
4. Risks	Which serious risks (e.g., social, political, military, ethical, environmental) may arise?
5. Sustainability	What are the synergies and trade-offs of deployment for the Sustainable Development Goals and other societal objectives?
6. Justice	What vulnerable groups could be affected, positively or negatively?
7. Actors	Who are the relevant (or most important) actors (or stakeholders / networks), e.g. for commercialization, development, and/or acceptability?

Source: Author.

dimensions and mechanisms (Table 1).

To maintain consistency, we asked all participants to define their technological focus according to their own interests and expertise – speaking to singular approaches, groupings, or carbon removal as a broad emerging strategy. In our data (Sections 3–5), our grounding examples focus on three broad approaches or groupings thereof:

- Direct air capture, an engineered approach leveraging carbon capture and storage;
- Enhanced weathering, accelerating processes by which the breakdown of rocks and minerals absorb carbon dioxide from the atmosphere;
- Agricultural and forestry management, incorporating land-use approaches such as soil carbon sequestration, afforestation, reforestation, and ecosystems management.

Annex 2 contains all approaches and should be consulted for fuller descriptions.

To convey our results, we adopt a streamlined ethnographic approach. The following sections communicate three thematic concerns, pointing out key prospective differences between areas of general concern that functionally focus on the Global North, and the South in particular. We supplement the text with tables that connect the thematic concerns with illustrative and representative quotations, to give the reader a flavour of the richness of the experts’ collective contributions. Our interview protocol offered partial anonymity in the style of the Chatham House rule to solicit honesty on emerging, even controversial topics – we therefore list all interviewees (Annex 1), but preserve their anonymity in relation to specific statements.

2.3. Bias, positionality and limitations

Whenever one engages in research on topics related to justice, power, place, or space, it is meaningful and salient to acknowledge one’s possible biases and positionality. As Brasher [15] helpfully writes, positionality refers to “how one’s position within the social and political context of the field – in terms of identity markers like socioeconomic status, race, nationality, gender, sexuality, and ability status, amongst others – shapes the way that participants interact with you, whether they do so at all, what they share with you, and ultimately the results of the research.” To be transparent, my positionality as an author is a qualitative social science scholar committed to climate and energy justice, but one who happens to identify as male, white, heterosexual, and who resides in the Global North supported by three elite institutions in Denmark, the United Kingdom, and United States.

To be even more transparent, the author—and indeed much of the larger team involved in the GENIE project—comes from locations that would be considered in the Global North. Because of this limitation, and a general wariness to speak on behalf of those in the Global South, the research team did execute five steps to encourage inclusion and minimize possible bias. This included firstly a double ethics approval from the European Research Council, the funder behind the study, and a second approval from Aarhus University, which both determined that the research design for the study posed no direct harm to participants in the Global South (or elsewhere). Secondly, the research team intently invited as many respondents from the Global South that they could identify. In other words, the sampling strategy for the interviews focused on overrepresenting and maximizing the inclusion of Global South experts. Nevertheless, although more than 30 were invited through this oversampling, only 12 participated. Thirdly, however, is that the current paper features as many quotes from these 12 Global South participants as possible, to maximize their voice in the research output, given the topic. Fourthly, to remain true to the data collected, the paper does not silence or sanitize any of the results from these experts, it reports them fully without reshaping or reinterpreting them, so that the paper features their ideas in their own words, from their own voices. It is

interesting that experts from the Global South did disagree most with some experts from the Global North over notions of justice and equity (Section 4), followed by governance (Section 5), with the least disagreement, dissensus or contention on technological systems (Section 3). Finally, the research team recommended explicitly numerous Global South experts as preferred peer reviewers for the editor to consider inviting to assess this work.

Moreover, although multiple steps have been undertaken to ensure as much balance in our interview data as possible, the argument that Global North researchers should never undertake research in the Global South, or engage with or speak on behalf of the Global South, does raise some analytical, ethical, and practical problems. As noted above, my ethnicity is white and my birthplace is in the Global North, but I didn't choose these attributes of my identity. To discount or deprive my views or thoughts for reasons outside of my own choices or control is to perpetuate a different type of discrimination against me, and elevating particular perspectives based *only* on their location (i.e., the Global South) can be just as dangerous as degrading perspectives based only on such a location [16]. As justice theorist John Rawls [17] argued, behind a veil of ignorance all people should be treated equally and fairly, regardless of where they are born, or the circumstances of their birth. To discount my views only because of my birthplace is also a form of dehumanization.

In addition, researchers in the Global South may not always have the sufficient training, resources, capacity, or interest to conduct research on Global South topics. They may not be able to speak out in some cultures of repression, with authoritarian regimes such as China, Russia, or Saudi Arabia (to name only a few) coming to mind as they place restrictions on academic freedom and freedom of speech. Moreover, Giwa [18]: 2 cautions that “many overseas students and researchers from the Global South are ill-equipped to deal with some of the tensions that can occur when researching home or somewhere in-between.” Scholars in critical geography, area studies, development studies and feminism have come to acknowledge that some research questions cannot be answered without the Global North intervening in and collecting data in the Global South [19].

Furthermore, what constitutes the Global South or how one may or may not identify as coming from the Global North or Global South is fluid, and constantly changing based on circumstance and experience. Giwa [18] notes that where one considers “home” may not be where they were born; it can extend to include ethnic communities and diasporas cutting across the Global North and South. In the author's own experience, it may also include communities of practice or knowledge that are even more important than communities of place in shaping identity. Fisher [20] adds that many researchers may have mixed ethnicity or heritage, or may have been subject to racism or colonialism, and thus identify as being both of the Global North and Global South. To reduce one's identity to only the Global South (or North) is to perpetuate a spatial determinism that reduces one's authority only to location. In the extreme, it collapses identity, power and politics to space, at the expense of other important attributes such as gender, education, or class, which also occur across or intersect with the Global North and Global South divide. Hausermann and Adomako [21] compellingly write that cultural and racialized postcolonial conditions, as well as people's graciousness, are entangled with disability, race, class, gender, education and citizenship privileges—it expands well beyond location.

Finally, even if the boundaries and identities between Global North and South were fixed and knowable, arguing that only one group of scholars is authorized to speak on a given topic could have a prophylactic effect on research. It would limit researchers to only doing place-based work where they are, or require that Global North teams always partner with Global South teams, something that could be prohibitively expensive, time consuming, or even inappropriate in some instances. What of the geographer who lives in Ohio, but is passionate about studying human-nature coexistence in places like sub-Saharan Africa? How effective a teacher and scholar would they be if they never travelled

to nor did true research at any of those study sites? Should we all study only things that exist where we live, and pass on experiencing distant subjects directly? The world already suffers from a lack of attention to the people, creates, and habitats that too often go unseen.

Thus, spatial and other forms of bias always exist. Knowledge is always partial, and knowledge production always affirms power relations of some sort [22]. If done unreflexively, Global South research done by Global South researchers can also perpetuate exclusion, inequality, and injustice. As Brasher [15] concludes, “researchers always bring with them into the field a multiplicity of identities that cleave along various and conflicting lines of power and privilege,” whether they are from the Global South or Global North. Brasher goes on to argue that respect for the subaltern needs balanced with working with them, with action, noting that “It is our responsibility to practice a politics of resourcefulness that centers marginalized participants' needs and political goals in our work.” The author would say this moral obligation holds true regardless of one's location.

To attempt to meet this responsibility, the author was inspired to adhere to a framework offered by Bádéjo et al. [23] for engaging with subaltern voices in Global South research. The principle of *neutrality* involves recognizing that one does not possess an inherently superior knowledge system, nor do they seek to create reverse hierarchies of knowledge in favour of the Global South. This is done in the study by balancing viewpoints across the Global North and South. The principle of *collective intentionality* means advancing a research agenda focused on democracy and justice, and actively representing Global South scholarship. This is done in the study by showcasing justice and equity themes in the paper, and by citing Global South scholars. The principle of *cultural relativism* means appreciating alternative knowledge systems and an awareness of the context specific and intersectional nature of knowledge. This is done in the study by presenting a diversity of often intersubjective viewpoints on the topic of carbon removal. The principle of *co-constitution* means actively involving and representing Global South scholars in the data collection or knowledge making. This is done in the study through recruitment of Global South participants. Giwa [18] adds that it is a laudable goal to contribute to the growing knowledge base that chronicles the experiences of researchers from the Global South, something this study aspires to do. Finally, Bádéjo et al.'s [23] principle of *co-orientation* means committing oneself to promoting egalitarian change that helps resist dominant modes of thinking. This is done in the study (at least partially) through the policy recommendations made in the section on governance and in the Discussion and Conclusion.

3. Systems: thematic concerns regarding sectoral and infrastructural coupling

Table 2 shows that our experts pointed out the general significance of couplings – either integration or trade-offs – with different sectors or infrastructures, distinct across the carbon-removal approaches. At the same time, experts extended these concerns to dimensions thought to be especially significant for demographics in the Global South, emphasizing that systems and coupling depend on scale – with implications for more localized energy and agricultural systems in developing countries.

Agricultural and forestry management approaches have the clearest precedents and are thought to contain synergies or trade-offs between the use of crops or vegetation as food, fuel (biomass energy), and storage (carbon stocks). These mirror past debates over the global bioeconomy, or over the distinctions between deliberate land-use change (e.g., large-scale afforestation and reforestation) and preserving or regenerating carbon stocks through kinds of conservation (e.g., avoided deforestation). Trade-offs and synergies on land and marine space-use have more direct and significant implications in subsistence-based smallholder communities in the Global South, though these also describe many rural and indigenous communities across the Global North. Many experts highlighted the value of mixed-use ecosystems services (e.g.,

Table 2

Expert interview quotes about thematic concerns regarding technological systems.

	General concerns	Global South dimensions
<i>Systems depend on scale</i>	<p>Small-holders and local-scale economies: So, it's very centralised, these are large-scale solutions, so it calls for centralisation, which actually dilutes the opportunity for small scale, for cooperative scale, local scale, municipal scale business models, which basically triggered or drove the energy transition in the first. So, energy, for example, tends to be a bit driven by small scale energy cooperatives, we saw that also fanning out in the UK. A lot of energy democracy kind of solutions in the US, also even in Southeast Asia. (R90)</p>	
<i>Agriculture and forestry management</i>	<p>Food, fuel, fibre, and carbon stocks trade-offs: I think that most of the solutions or proposed solutions that involve biology, so essentially the photosynthetic capacity of the planet, are going to run into trouble in terms of the fact that we have other societal uses for that photosynthetic capacity: food, fuel, fibre, aesthetic value of land, biodiversity ... I think it's unrealistic to hope that we can balance the carbon budget on the backs of nature. I think that is liable to cause huge stresses and strains, not just on nature, but the people who interact on the land. (R51)</p>	<p>Ensuring co-benefits over trade-offs: ... how do we make sure to integrate the co-benefits from a societal perspective into the business models [so that] instead of making crops [a farmer] will not just start growing whatever will get him the most credits... a [carbon removal] project needs to be a side project for a lot of stakeholders, but it should not be the main project for a lot of stakeholders ... (R68)</p>
<i>Direct air carbon capture and storage</i>	<p>Should cheap gas power air capture? If you think about this from an engineering point of view, all you care about is tons [of captured CO₂]. That's why ... we spent a lot of time looking at even the unabated gas options [for powering direct air capture]... because US gas is about \$2.50 USD per million BTUs. You can run a lot of machines, plus you get to run them 24/7. (R87)</p> <p>Renewables not at needed scale: There is a very strong argument to say that direct air capture is not even a thing [to consider] without renewable energy provision on a scale that we don't currently have. (R18)</p> <p>Carbon as waste or new products: Direct air capture... could be tied to products like CO₂ itself, at the smaller modular scale, tied directly to things like beverages or industry. [It's] not trillions but still hundreds of millions of dollars, not as small as you would think – [the] crux of that market is... Transporting it is costly and a pain [but] the economics are not wildly out of control ... as opposed to taking it out of the air and store it, where it has no value to it... The other tie is the hydrogen economy [where] it will be a niche market thing in industrial processes. (R3).</p> <p>Carbon for Enhanced Oil Recovery: We could be ... directing resources towards something that in the end we don't want. One big example of CO₂ utilization is actually enhanced oil recovery. I mean – it works, it's commercial, but it's maybe not the thing that we have envisaged for the end point (R31).</p>	<p>Expanding CCS infrastructure beyond Europe: I would not say it would take 30 years. I think for CCS infrastructure in Germany we have more the problem of public acceptance. I do not see Germany as an important player anyway. It depends a bit on what the rest of Europe is doing. The Netherlands is not big enough to have a CCS infrastructure network. France does not have so much industry. Hard to tell. But on a global level, we should not only look at Europe. In Europe, I see CCS only for industry. If you look at China and look how much they have still invested in coal, I could imagine that they will have CCS for coal plants. That would mean that they have a large CCS infrastructure, with pipelines, making it very easy for them to integrate direct air capture or bioenergy CCS. (R72)</p>
<i>Enhanced weathering</i>	<p>Speculative scale of mining and energy: This would require – to reach the scale which the IPCC has discussed – a doubling of global mining activities. Have you hater thought about the land-use of that? Already, now, about 80% of biodiversity loss is caused by mining or processing of mining goods. What is the land demand? What is the energy demand for all that? (R77)</p> <p>Speculative scale of mining and shipping for ocean-based enhanced weathering: ...alkalinisation is one of those because people have said that, if we were to try and raise the alkalinity of a global ocean, we'd need the entire world shipping fleet to ship the stuff around. We'd need a mining industry that's probably as big as the rest of the mining industry, almost, as exists today. Of course, the energy and so on to grind and all that sort of stuff would be enormous, so I think alkalinisation is never going to be a global solution. (R86)</p>	<p>Replacing industrial fertilizer: At the same time, you use enhanced weathering to optimise the soil, and also because in the rocks like basalt you have important nutrients like phosphorous or potassium – this is needed. If you remove plant material from the field, you need to replace the nutrient. Normally we use industrial fertiliser... What we propose is to replace some of these industrial fertilisers by slow-release fertilisers. Specifically, where the combination of the methods makes sense, like in the humid tropics, like in South America or in Africa. There, often, the farmers do not have the money for the expensive industrial fertilisers so there is the question: "what are alternatives?" Slow-release fertilisers made out of minerals is what is coming into play. (R38)</p> <p>Co-benefits with soil health could feed monocultures and land-grabs rather than help small-holders: The reason why you might do enhanced rock weathering is you do it on agricultural land. If you can do it safely and if you can get crops growing better as well as create carbon sequestration. Then you think about the great Midwest in the US or in Brazil where they're growing all sorts of things, or in the palm oil plantations, let's say, in Southeast Asia and sugar cane in Australia is the other one we've looked at, then there's a big synergy that's not there with bioenergy and carbon capture and storage. The argument is always bioenergy crops will compete with food production. (R62)</p>

Source: Author, based on expert interviews ($N = 90$) with details concerning methodology mentioned in [Section 2](#) Research Design, and the full sample of respondents mentioned in Annex 1.

agroforestry) to try to mitigate trade-offs in land-use, and dependence on one kind of land-use.

Direct air capture represents a more immature approach, and precedents are less clear. Experts saw direct air capture's 'front end' of tremendous energy inputs as being immediately relevant. It might be powered by an as-yet insufficiently scaled renewable energy economy, ideally posing synergies between carbon capture and a host of other societal needs. Powering direct air capture, however, would pose near-to-medium term competition in demanding energy provision from the growing but still-limited renewables sector – which already has unclear prospects in much of the Global South, and when scaling up should go towards more basic needs. If gas-powered, direct air capture would more

directly leverage the fossil fuel sector, which has significant national industries in the Global South (examples in various interviews were Qatar, Algeria, Iran, China, and Saudi Arabia, which have varying degrees of autocratic institutions). Some speculate that where gas sources (and storage reservoirs) are plentiful, direct air capture could be more cheaply situated and powered, creating an industry and offering a source of credits – although many of these countries in the global South are emerging economies with highly competitive technology and resource sectors rather than least-developed countries (LDCs).

The 'back-end' component of carbon storage represents a proven but yet un-scaled infrastructure that would make use of oil and gas reservoirs or natural formations. Experts tended to map storage capacities

within first-movers in the Global North – for example, emerging Norwegian interests for re-purposing their oil reservoirs. In prospecting equivalent storage locations or infrastructures across the Global South, experts again highlighted fossil fuel reservoirs in the Global South's emerging economies, dovetailing with their capacity to also power the technology. Alternatively, carbon might form a diverse and expanding range of second-life products in a circular economy (e.g. building materials, plastics, synthetic fuels). Still, since carbon is still mostly envisaged as waste, the scale and diversity of a carbon product economy is speculative, and again limited mostly to first-movers in the Global North. This space is unmapped rather than irrelevant to the Global South.

Enhanced weathering requires rock and minerals as material inputs and is necessarily coupled to the mining sector – which could provide the required mine tailings or industrial waste materials, as well as the equipment and know-how needed to further mine basalt, limestone, and equivalent minerals. Many experts hypothesized the need for a dramatic expansion in the mining and extractive industries to accommodate the scaling-up of enhanced weathering. If enhanced weathering takes place in ocean environments – the linked approach of 'ocean alkalinity enhancement' – elements of the shipping and dredging sectors would be implicated, by providing the logistics and transportation for disseminating sediment or material. Enhanced weathering is also assessed to have potential agriculture and food economy co-benefits: acting as a substitute for costly fertilizers and helping to increase soil health and crop yields, particularly in the nutrient-poor soils of tropical regions. Some experts pointed to potential synergies between agriculture and land-use carbon removal approaches, though others underscored concerns over potential contaminant material. Projection or speculation has generally taken place, again, largely in Global North contexts, with the same almost exclusively true of ongoing field trials (see [24]). In the context of the Global South, experts debated potential trade-offs with existing claims on land and marine environments for food, fuel, and fibre resources as well as tourism, as well as how the growth of extractive mining economies in countries with comparatively looser environmental and labour standards.

4. Justice: thematic concerns on equity and inclusion

Prospective discussions over synergies and trade-offs regarding sectoral and infrastructural couplings are extended into concerns over justice and equity (Table 3). Although a complex term with a long history grounded in earlier approaches of environmental and climate justice [25,26], by justice and equity we refer to attempts to minimize patterns of unfairness (lack of fairness of process, outcomes or recognition), to prevent inequality (disparities in equal opportunity or access), and/or to reduce vulnerability (exposure to the possibility of being harmed) [10]. Davoudi and Brooks [27] add that injustice can also refer to unfair distribution of risks or benefits, lack of recognition in policymaking, poor participation in planning processes, disproportioned responsibility for actions, or the limiting of capabilities or freedoms. Such tenets of justice have only recently been applied to carbon removal (e.g. [10,28]). Experts highlighted many of these dimensions that overlapped between Global North vs. South, emerging vs. least developed states, and rural vs. urban demographics.

With regard to agriculture and forestry management, experts generally noted resilient urban/industrializing vs. agrarian/rural divides, as well as how policies (e.g. emerging European policies for 'carbon farming', [1]) would intersect with existing interests and laws in the agriculture, ranching, and forestry sectors; or for tourism, national parks and other conservation initiatives. These concerns were extended to and deepened for tropical nations with large land-use sectors. Here, the precedent of the global bioeconomy prompted discussion of land (and by extension, coast) grabs, pressure to choose between food, cash crops, or carbon stocks, precarious dependence on single-commodity economies and fluctuating price, and/or the development of

hype-driven economies around crediting projects. Experts argued that subsistence farming, fisheries, or forested areas would be re-configured as a source of cheap credits for industry. Indeed, many pointed out the inflationary effects of innovation and industry in the Global North for carbon credits, both through a general demand for offsets to buy time for their own transitions, as well as a supply of offsets from speculative carbon removal approaches. Many suggested strengthening land ownership and tenure rights across smallholder communities for mixed-use of lands and coasts, alongside efforts to return stewardship of previously seized lands to indigenous communities in the Global North.

For direct air capture, there is concern that leveraging the oil and gas industry for powering facilities and using reservoirs for storage (e.g., enhanced oil recovery) would act as a fig-leaf for the industry and prolong the global carbon economy, rather than buy time for it to transition. Evoking parallels for inequitable land-use change for agricultural and forestry management, potentially pollutive or hazardous infrastructure for both energy inputs and carbon storage might follow precedents based in extractive industries, sited in areas where local populations suffer direct environmental harms, or are dependant upon the income generated and possess little power to protest. Again, these are heightened concerns in Global South contexts, which may have looser political regulation and socio-environmental standards, or developmental needs powered by fossil fuels – and which may be driven further by Global North demands for offsets. Experts questioned if direct air capture based on prolonging the stranded assets of the fossil fuel industry would entrench inequitable social structures or even autocratic rentier economies, or provide initial, niche opportunities for rethinking these issues. If powered by renewables, experts noted that direct air capture poses a near-term trade-off with existing green energy capacity, and that LDCs largely lack this infrastructure. Questions of technology transfer, financing, and capacity building arise: if Northern nations (and China) will help scale up renewables, and with what strings attached.

Concerning enhanced weathering, much of the discussion echoed similar points to that of agriculture and forestry management, particularly where enhanced weathering was proposed to work in tandem with these sectors. Further intersections with the mining sector were stressed – positively around the potential for just transitions in legacy fossil-fuel communities, and negatively on where new mines might be sited and who would bear the risks, i.e., for human health and the environment. The fraught prospect of large companies engaging in jurisdiction shopping had experts concerned that countries and communities in the Global South would bear more than their share of the risks due to asymmetric protections or regulations. Mining companies which would look to employ enhanced weathering to greenwash their images might thus target those regions with weaker protections for land tenure. Set against the background of climate change more generally, there is also the issue of why beaches and coasts of tropical developing countries should serve as the sites field trials that could have negative impacts on terrestrial or marine environments, given how limited historical contributions have been within developing countries for emissions.

Experts highlighted several broader thematic concerns (Table 4). The first is mitigation deterrence or moral hazard – that considering or developing carbon removal poses systemic disincentives to pursuing decarbonization and motivates actions that delay it. Here, we highlight variants related to carbon offsets: demand for offsets from Global North aviation or heavy industries, or more a more purportedly 'progressive' information technology sector, that greenwashes a lack of desire to transition; fossil fuel and extractive industries as energy and infrastructure suppliers for direct air capture and enhanced weathering, creating additional revenue streams and prolonging operations; and lobbying and influence over policy development that favour industry interests. In a systemic sense, distracting further from reducing emissions causes disproportionate harm to least-developed countries. More specifically, demand for cheap land-use and forestry offsets could entrench bioeconomy inequities and conflicts more prevalent in the Global South, further shifting to them the responsibility for 'growing

Table 3
Expert interview quotes about thematic concerns regarding equity and justice.

	General concerns	Global South
<i>Agriculture and forestry management</i>	<p>Workers and communities: I do think the spatiality of a lot of carbon removal is different because many of the techniques are rural, would take place in rural areas, which often have different demographics... you can think about rural workers [and] who's going to benefit from the carbon sequestration payments. Is it going to be migrant workers on the farm, or is it going to be the landowner? (R10)</p> <p>Agricultural interests: Farming lobbies are strong players. So I would expect that the agricultural options will gain traction of the agricultural lobbies see them as a way to generate new revenues and new relevance for farmers, and once it sees it clearly in the context of the nature-based solutions in general. (R60)</p> <p>Food security: Food security is a huge issue... Whether it's going to be [like] OPEC, I don't know, but... if you were to do it at scale, it will absolutely change where the power dynamics are in this. It'll create all sorts of interesting international and national-level questions about crops, food crops vs. energy crops, imports vs. exports. (R13)</p> <p>Forestry interests: Where you've got countries like Sweden with paper and pulp industry, obviously, bioenergy CCS becomes a big issue. Of course, there is a big debate about whether it makes sense, how far forestry in the northern hemisphere makes sense, in comparison with growing trees in tropical zones. There are issues of the effects of developing forests on albedo in the northern hemisphere and whether there's a net gain to us in that process. (R44)</p> <p>National parks as eco-systems management: In the US, obviously, your national parks will be a huge player... In the UK, national parks are much smaller in scale, but essentially, who owns that land, and who's making the decisions? (R88)</p> <p>National parks as mixed-land-use and indigenous stewardship: In Australia, actually we're sort of in the middle of a big speeding up of recognizing those land-rights and giving those lands back [to the indigenous]... Essentially, what you're talking about is co-management of national parks, because national parks are the only places left not cleared. (R23)</p>	<p>Usage trade-offs and land grabs: ... current strategies of bioenergy rollout are mostly highly intensive. So if there are mass plantations and they are historically known to actually lead to land capture and land enclosures from societies that have traditional property rights on land... there are definitely cases where you can have some level of bioenergy in accordance with the needs of local communities... There are also cases [that] increase biodiversity... And both of these are dimensions are usually not happening at a mass rollout, but only in specific case studies (R17)</p> <p>Usage trade-offs and land grabs: A lot of the planting of trees is contemplated to be in abandoned areas, like in sub-Saharan Africa, which are not abandoned. There are a lot of people relying on those areas. There is a real fear that elites in Ethiopia, Kenya, etc. are going to kick those people off that land to get quick carbon credits. There is a lot of fear that the areas that are being targeted are things like prairie grasslands and savannahs, which are high in biodiversity. And nobody is figuring out what those trade-offs are – plus, they hold a lot of carbon. (R9).</p> <p>Usage trade-offs and coast-grabs: So if you start having coastal zone enrichment, growing macroalgae, then you're losing access to the coastline, and resources on the coastline, for other purposes. And when you think... three fifths of the world's population live within X miles of the coast, that could be potentially quite important (R70).</p> <p>Hunger and subsistence land-use: The world hunger report [FAO, 2021] just came out... from 8.5% of the world under hunger conditions to almost 10%... so 800 million people. The risk of that - for the sake of bioenergy - to try to reduce climate change, which one of the exacerbating factors in hunger but not the only factors, is to me a serious risk. (R50)</p> <p>Precarious pricing: I mean, if you made your bet on a carbon price of \$10, and then it goes to \$1, and you have no say about that... I know that farmers are used to that, that coffee prices or cocoa prices or corn prices go up and down, and it makes life really hard. (R49)</p> <p>Preserve carbon stocks, then restore via mixed-land-use: A first priority must, of course, be protecting natural forest where it still exists. The second would be reforestation where that is possible and appropriate ... and where a competition for land is, then it would not be full reforestation, but a shift from plain-field agriculture to agroforestry. (R77)</p> <p>Improve land ownership and rights: You really need to go back to land management and land ownership in order to, I think, in order to protect lands. In some cases that could be formal protected areas, conservation status, in other cases and in many, many cases it's likely to be securing or recognising customary land rights. Often increasingly it's a mix of the two, where protected areas are increasingly actually managed by indigenous or customary people. (R23)</p> <p>Direct air CCS poses trade-off with renewables (for global South): In the coming 50 years or so, we're in a position where every unit of new, renewable energy either has to be offsetting a unit of fossil energy or providing for an unmet energy need in a developing, poor part of the world. So, there isn't some sort of mythical, surplus, renewable energy, so then you hear the CDR advocates often talk about stranded-energy assets. (R55)</p> <p>Leakage and supply-chain emissions: I think one of the risks could be entrenched interest, like fossil fuel interests... going into countries that don't have as robust institutions, and say they are doing DAC in those areas, and in fact maybe the natural gas supply chain is really leaky. And so they're using DAC to justify continuing to extract oil, but then they're not really making sure that the supply chain is good... and so you end up offsetting or completely eliminating a lot of the climate benefit of doing DAC. (R32)</p> <p>'Resource curse' and authoritarianism: The dirtiest fossil fuels... they have produced what sociologists refer to as the 'resource curse', because they offer this enormous monopoly profit... Fossil energies... reinforce dictatorships from Venezuela to Saudi Arabia to Russia. I mean, it's only Norway that we have as a positive example. (R34)</p> <p>New opportunities: There is also thinking in Saudi Arabia [about] using direct air capture to create green fuels. (R28)</p> <p>Exporting carbon storage: When it comes to the large-scale deployment, direct air capture and CCS face huge problems of where to store the CO₂... I feel it's better to actually deploy direct air capture in Saudi Arabia and the [Global North country] government or a company pays for that, to help and store that. That's more economical and politically viable. (R4)</p> <p>Inequitable distribution of capabilities and risks: We need to ensure that, actually, the balance of deployment, both in terms of</p>
<i>Direct air carbon capture and storage</i>	<p>Oil and gas industry synergies: There's a lot of negativity about oil companies... But there's also opportunities for re-skilling them or utilising their skills in the synthetic fuel industries, in the offshore geological storage options, and in the capture technologies. (R43)</p> <p>Workers and communities: In terms of benefits, who's going to be working in your direct air capture plant? Is it going to be the same dudes that are working in your fossil fuel plant? Are there going to be opportunities for women? Without really strategic applications of policy and education... it seems really likely that those patterns will reproduce themselves for carbon removal. (R10)</p> <p>'Sacrifice zones': We've seen areas, which are 'sacrifice zones' at the moment, and they are generally the areas of high of high fossil fuel extraction. It's the Niger Delta, it's the Alaskan tar sands... where there's severe transgressions of ecological rights, of human rights. (R35)</p>	

(continued on next page)

Table 3 (continued)

	General concerns	Global South
<i>Enhanced weathering</i>	<p>Mining industry synergies: You have these coal-mining communities that, at least in the US, are already ‘collapsing’... But you’ve got all this mining infrastructure... That coal is collocated with limestone, right? So, you’ve got all of the social and physical infrastructure you need for large scale ocean-liming (ocean-based enhanced weathering) industry, for instance. (R58)</p> <p>Worker and community health: Nature protection is affected, people are affected, workers are affected, because think about the amount of rock which is being cut into pieces, and the pieces must be relatively small to have a high surface, which is exposed to the air to be able to bind the sufficient amounts of carbon. When you have ever been to an area where they have a mining industry for granite or anything like that, you have experienced the enormous amounts of water that they need to keep the dust down, and still the enormous amounts of dust which are SPM10 particles, which affect air quality and human health. So that is a big problem. (R77)</p>	<p>the impacts that has, but also then who pays for it is equitably distributed. I think there are potentially some risks, less on the payment, because I think if rich nations don’t pay for carbon removal, it probably won’t happen. But if we’re paying for carbon removal in other countries, then that balance of impacts could lead to some inequalities there. (R35).</p> <p>Greenwashing and jurisdiction shopping: [Some countries] have large extractive industries, they may have mining, this makes one think about whether they have potential for enhanced weathering. As you know, there are companies in the mining industry who are trying to think about greening their image by adding an element of enhanced weathering to their product line or making sure that the tailings from mining are used in a constructive way. The word ‘diamond’ usually associates with the words ‘blood’ and ‘war’. De Beers is one such company that is trying to look at the potential of using mine tailings either in situ in terms of what they can do on site to make their great mounds of tailings sequester carbon or, of course, spread out over agriculture land in the more conventional way in which people think about carbon removal being applied. (R44)</p> <p>Lack of regulation and standards: ... I worry that there are folks out there who might have a pile of waste materials that they then sell to farmers for CO2 removal, without a proper system for environmental risk management or monitoring and verification. I think that’s fine in a lot of places in the world. The UK, for instance, has pretty strong regulation about what you can put onto agricultural fields. I imagine the same goes for a lot of places in Europe and North America, but the regulation, and at least the enforcement of that regulation, might not necessarily be that strict in other parts of the world... It’s the protocols for waste, for material management, and spreading onto agricultural fields, and how that might not necessarily be uniform. Or there’s probably a lot of asymmetry across the globe. (R65)</p> <p>Unequal burden-sharing: But, of course, there are more risky options, like ocean alkalinity, where you may not know what the actual impact would be. Those are a bit more risky, I suppose. And even some beach-based enhanced weathering... I think they are proposed for more tropical locations, and that may be risky, from the point of view that those are developing countries: should these [trials] be in developing countries, or probably more developed countries? The highest emitters should take the risks. (R28)</p>

Source: Author, based on expert interviews ($N = 90$) with details concerning methodology mentioned in Section 2 Research Design, and the full sample of respondents mentioned in Annex 1.

carbon removal’ and associated externalities.

Experts also generally questioned how carbon removal could preserve or create room in the carbon budget for essential or ‘hard-to-abate’ sectors – and by extension, how to define ‘residual’ emissions (left over after exhausting feasible mitigation measures), or differentiate between ‘luxury’ from ‘subsistence’ emissions, or preventing industrial sectors from using land-use based offsets. The lattermost has a further North-South dimension, with industry demanding offsets historically based in the North, and land-use crediting projects based in the (tropical) South. In Global South contexts, debate over carbon budgets and essential emissions was extended into questioning over where carbon removal could make room in mitigation pathways assessment, or the Nationally Determined Contributions, for further emissions and economic development in the Global South.

Experts probed dimensions of the ‘Not in (or under) my backyard’ phenomenon (NIMBY- or NUMBY-ism). Questions of hazardous siting of carbon storage or resource extraction facilities constitutes exporting pollution, and of opposition to pollution, to areas with less power to oppose – or even where unpopulated, could cause environmental damage. NIMBY-ism again dovetails with numerous concerns for agrarian or ecosystems-based smallholder demographics – a demand for carbon offsets shifts responsibility from industrial and post-industrial decarbonization into land-sector reconfiguration for generating credits.

At the same time, experts pointed out broad avenues for combatting inequities (Table 5). Instead of treating carbon removal approaches as monolithic systems with inevitable trade-offs, experts made pleas for breaking them down into diverse supply-chain stages, components, and locales, and developing plans to ensure co-benefits and minimize harms through regulatory guardrails. Others pointed out that the lack of

infrastructure for renewables (e.g., for powering direct air CCS) or for new kinds of carbon utilization, or MRV infrastructure, poses opportunities for technological leap-frogging [29].

5. Climate governance: thematic concerns on NDCs, CBDR, funding, and offsets

Experts noted that the Paris Agreement implicates carbon removal as part of ‘a balance of sinks and sources’ on route to ambitious climate targets. At the same time, the articles of the Agreement and existing mechanisms of the UNFCCC have not been adequately purposed toward a carbon removal strategy, and much depends on how these incorporate carbon removal into target-setting, financing, and other instruments (Table 6).

The principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC, determining the historic or incoming responsibility for reducing emissions via the NDCs) could also be altered. The Paris Agreement cemented a sea change from mandatory emissions restricted to Annex I (industrialized Global North) countries to universal but voluntary and nationally determined reductions. Carbon removal could open a host of concerns or opportunities regarding such ‘contributions’ – on one hand, renewed rationales for finance, tech transfer, and capacity building, or opportunities for land-use removals and eco-systems restoration towards NDCs, or creating more room for development in the carbon budget; on the other hand, further tactics for delaying and displacing responsibility, or distraction from claims over Loss and Damage.

In a related concern, carbon removal could generally create a perverse incentive to overemphasize its role within Nationally Determined

Table 4

Thematic concerns regarding justice: Mitigation deterrence, carbon budgets, NIMBY-ism.

	General concerns	Global South
<i>Mitigation deterrence, especially industry exploiting low quality offsets</i>	<p>Land sector as a source of cheap, low-quality credits for industry: For example, companies that want to exploit the tar sands in Canada are saying, “We’re going to be Net Zero by planting trees somewhere,” and using that as a justification. So that is a kind of moral hazard in action.... Is planting trees actually a robust way of offsetting emissions permanently? (R51)</p> <p>Abusing MRV for ‘avoided deforestation’: I think it’s interesting looking at the thinking that has gone on in the progressive corporates around Net Zero – basically the ‘dot-coms’, Microsoft, Stripe, around how do we go for really kosher [high quality] carbon removals versus whatever is cheapest? I mean, this appalling terminology that crops up [around] ‘avoided deforestation’. You think, “So, you’re buying somebody not chopping down a tree?” (R74)</p> <p>Captured carbon prolongs oil and gas production: ...many of the DACCS companies, they kindly sell their capture carbon onwards. In the US, I think it’s Occidental which buys from DACCS plants to do enhanced oil recovery. For us, that’s a very strange way of using potential carbon removal technologies, to expand oil and gas production. (R84).</p>	<p>Demand for offsets prolong bioeconomy inequities: I think [mitigation deterrence] has been dismissed to a large extent in the literature but I don’t think it can be dismissed, particularly in circumstances where we have international carbon trading under Article 6 of Paris in attempting to reach a net zero interim position around the middle of the century. I am slightly concerned that offsets may become problematic because there will be an enormous market power behind the buyers of offsets, as it were. I think it may risk increasing inequalities between the more developed and the developing world who may feel that... Their natural assets are the only thing that they have left to sell in this developing climate-managed world. (R44)</p> <p>Prolongs bioeconomy inequities: ... I’ve already mentioned that the forest users – particularly, indigenous interests in forests – as one set of people affected by, essentially, the industrial capitalist world annexing more of the bio-productivity of the planet to sustain its existence in the face of climate change. (R55)</p> <p>Prolongs inequities of oil and gas export economies In interviews [at an intergovernmental conference] we heard from people in fossil-fuels-producing states. They talked about it as – carbon removal and carbon capture and storage would allow them to go on producing fossil fuels. That’s why they’re supporting it. (R55)</p> <p>Widening carbon budget for Global South: I see people now trying to reframe direct air capture as a way to deal with legacy emissions and to climate restoration on a global scale, and frame it as a justice issue, or frame negative emissions as a way for industrialised countries to pay back their climate debt. (R29).</p> <p>Separating (Global South) land-use offsets from (Global North) industry demands: We talk about not substituting: for example, trying to maybe disaggregate CDR according to different sectors, so that it becomes clear that you can only do CDR that is land-based and impermanent to compensate for emissions that come from that sector. And that if you want to find ways to compensate for residual emissions that come from fossil fuels, then you will need to look at a much more permanent form of CDR, basically, and you can’t go to tree planting. So that’s one particular safeguard: trying to put up a really strict barrier between fossil and biogenic carbon removal and avoidance. (R15).</p> <p>Exporting pollution to Global South: So it’s not just about who loses control of the land or who is adversely affected by food prices... When approaches to carbon removal that are locally polluting... if those are implemented, they have to get sited somewhere. Given historical trends, the expectation is that they would end up getting sited in places that are already subject to high levels of pollution, thus compounding environmental injustice. (R58).</p>
<i>Carbon budgets between sectors and countries</i>	<p>Calculating residual emissions: I think, in national political arenas, the big debate will be about residual emissions versus carbon dioxide removal under net-zero pathways, and what counts as legitimate residual emissions. (R29)</p> <p>Calculating residual emissions: And most ambitiously, I would like agreements on residual emissions that limit them and allocate them amongst sectors, because I think that will be necessary in the next decade, in the 2030s, at least... (R10)</p> <p>Defining luxury vs. essential emissions: It’s about the regulatory space that says, aviation, it’s a hyper-competitive industry. On the other hand, it’s a luxury industry as well. (R74)</p>	
<i>Hazardous siting and NIMBY-ism</i>	<p>Hazardous siting: ... we know that in industrialised countries, [people] who live near sites with a lot of pollution – social stratification plays a role in that as well. (R29).</p> <p>Different reasons for NIMBY-ism: ... if you were putting in these massive installations to capture carbon... I could see pushback from communities. Both in the NIMBY way, but also in the genuinely, “We’ve been shafted on all these other things. Don’t put that here too.” (R67)</p> <p>NIMBY-ism and exporting pollution: So you have to find places where communities don’t mind that you are going to put this stuff [carbon] underground... So I am guessing that, depending where those places are, communities would say, “Well, we don’t really like that underground.” Certainly in the EU, I think the feeling is that they don’t want to store carbon dioxide under land. So almost certainly... they will pipe carbon dioxide to the North Sea and store it in undersea formations. (R24)</p>	

Source: Author, based on expert interviews ($N = 90$) with details concerning methodology mentioned in [Section 2](#) Research Design, and the full sample of respondents mentioned in Annex 1.

Contributions (NDCs) – national negotiators, reflecting a country’s more recalcitrant industries and sectors, could shape emissions targets, emissions baskets, and commitments to maximize carbon removal and substitute it with emission reductions. Direct air capture and enhanced weathering, as more immature approaches, are not yet visibly a part of this calculus – but land-use management, especially for agrarian and forested nations, would potentially be in the near term.

Regarding agriculture and forestry management, experts pointed out that calculations of emissions from AFOLU (agriculture, forestry and other land use, incorporating a formerly distinct sector of land use, land use change and forestry, LULUCF) would have to incorporate carbon removal [30]. REDD+, a crediting mechanism for Global North countries to finance tropical Global South countries to avoid deforestation, was cited by numerous experts both for difficulties in incentivizing

forest protection on the necessary scale, as well as in establishing the additionality of projects that have gone ahead (potentially exaggerating emissions reduced and credits earned). The now-defunct Clean Development Mechanism of the Kyoto Protocol was also cited for its historic issues in proving additionality. AFOLU-based CDR also have potential trade-offs with nature conservation and efforts to reverse biodiversity loss.

Experts then turned to more general concerns over the conduct of scientific assessment, the role of carbon offsets as a pillar of ‘marketized’ climate governance, and the shape of global climate and environmental governance. Some pointed out the prevalence of techno-economic assessment via IPCC reports as the dominant means of mapping mitigation strategies – through emissions pathways calculated by integrated assessment models – at a global-planning, cross-sectoral, non-country-

specific level. On the other hand, the reliance on models arguably reflects and worsens a lack of representation and funding of – especially least developed – Global South nations in climate assessment processes. Moreover, such pathways underplay the biophysical impacts as well as political and equity dimensions of scaling up biogenic carbon removal, with a historic focus on the sequestration potentials of tropical countries. Locally-driven knowledge of more immediate relevance to ‘front-line’ states and communities are not lens through which carbon removal is currently assessed.

Experts pointed out general concerns about the creation of novel pools of carbon capture for generating offsets, and for regulating accreditation and trading through Article 6. These highlighted concerns over vastly different storage lengths (permanence), life-cycle emissions, and supply chains for engineered (with more immediate energy input and technological couplings) or biogenic (with more immediate land and marine space couplings) in developing proper ‘monitoring, reporting, and verification (MRV)’ processes for carbon accreditation. There was a general fear over the inflation of voluntary carbon markets with credits of poor quality, and again, a specific fear that perverse episodes from the Clean Development Mechanism and REDD+ [31] would be replayed – with projects providing a much-needed source of climate finance to developing states, but also acting as sites of cosmetic climate action underpinned by corrupt or inadequate MRV processes, as well as uneven power dynamics and distribution of both risks and benefits.

Funding and technology transfer for climate action towards the Global South were touched upon as a trend within climate governance that has never reached its potential. Experts noted that the Global North could count on regional or national institutions (e.g., the EU Innovation Fund), or philanthropic and innovation-driven funding (e.g., X-Prize, Stripe). Others noted that most Global South countries lack capacity or cannot qualify for such initial financing, and if relying on UNFCCC instruments being repurposed towards carbon removal, that existing funds (e.g., the Special Climate Change Fund, Least Developed Country Fund,

Green Climate Fund, and Adaptation Fund) are poorly supported. New rationales for funding – or creating new instruments – would pile promises atop promises.

Some experts questioned if carbon removal leans into a mode of marketized climate governance, where the focus is on how to integrate (or separate) carbon removal and mitigation, via a renewed EU Emissions Trading Scheme, voluntary markets, border carbon adjustments, and national policies undergirding funding, pricing, innovation, and markets. Others argued against this framing of climate governance as carbon management, and pointed out that a focus on overall emissions reductions privileges developed countries, rather than issues and dimensions of greater relevance to many demographics and states in the Global South: energy needs and access, poverty alleviation and socio-economic development, health impacts and infrastructure, the agro- and bioeconomy, and more immediate adaptation needs. As such, there is a further need to connect carbon removal assessment and governance to areas of global governance beyond the climate regime – for example, to biodiversity, food systems, and marine pollution.

6. Discussion and conclusion

Discussions of systems, justice, and governance issues concerning carbon removal, moreover, do not exist in a vacuum. As Fig. 1 indicates, these themes intersect with each other. It shows how issues of justice, which are primarily about equity and inclusion, can still shape governance, or responsibilities and norms, through a bridge of procedural equity and participation. Similarly, issues of governance can shape technological systems through various mechanisms including financing and pressure from actor coalitions (notably civil society), which can all shape how carbon removal technologies are coupled and integrated. Analogously, issues of technological systems can be influenced by notions of citizen engagement in the design of technologies or concerns about the fairness of deployment plans, shaping justice.

Patterns of justice or injustice can cement and shape citizen engagement dynamics and the fairness of chosen systems being implemented for carbon removal. These can help determine whether such systems are comparatively democratic - or inclusive and participatory - by design, or exclusionary and exploitative. One example is (worker) communities in the vicinity of storage locations or extractive processes for resource inputs to carbon removal (e.g. mining for enhanced weathering, natural gas for powering air capture); another describes subsistence farmers or fishermen faced with unclear tenureship and trade-offs in the use of local spaces (food vs. fuel vs. ecosystems services vs. carbon stocks).

Similarly, systems shape, and are shaped by, the decisions of different actor coalitions – scientists, civic organizations, policy-makers, innovation and industry, funding and financing – trying to improve or erode climate governance. This, in turn, shapes the degree of path dependence (especially socio-political and techno-economic path dependence) for the development of carbon removal. An example is the pre-dominance of Global North actors in almost every relevant sector: researchers and academic institutions in IPCC assessments [5], firms and technologists driving the engagement of private sector innovation [32], and early policy actions in the EU and US [33] – all of which shape plans for the carbon removal approaches prioritized, where they are located (or exported via NIMBY logics), future funding and technology transfer (or lack thereof), how ‘hard-to-abate’ sectors, offsets, and MRV are regulated nationally and internationally [28], and how Common but Differentiated Responsibilities are (re)defined [34].

Lastly, interlinkages exist between justice and governance as well, with norms of procedural equity, due process, and informed consent shaping not only outcomes but the processes involved in determining carbon removal plans. For example, communities on the ground can give crucial feedback on trade-offs on land or coast use, or means to maximize mixed-use for multiple purposes (agro-forestry, mangroves and fisheries, or national parks); on how communities engage with being

Table 5
Avenues of action.

Synergies, not trade-offs:

At the risk of sounding like Naomi Klein, I think there is an opportunity to simultaneously slash emissions and deliver some of the social transformation and political transformation we need... But I think there's probably more potential in trying to link rapid, accelerated emissions cuts with political and social transformation in line with the SDGs... That's where CDR gets – interesting, I think, that you can do some of those things, even the technological ones... can be deployed in ways that help us move in that direction. (R55)

Supply chains, not holistic technologies:

... I would say carbon dioxide removal is not one single technology, it's a menagerie of different technology chains ... BECCS is an arch example.... it's actually a concatenation of growing stuff for biomass, creating a product from that, deriving some kind of energy product and sequestering the CO₂. So, I would say, a lot of the concerns that are raised about removal technologies are often not purely about carbon dioxide removal. They are concerns around elements of the chains... (R79)

Choices and guardrails, not inherent technology characteristics:

It's worth noting that is largely, to some extent, a social choice that a lot of those, the local pollution, could be mitigated, but it would be more expensive. So, to the extent a country says, “We're going to use technologies X, Y, and Z, and we're not going to require local pollution controls A, B, and C,” that's that society saying, “We are not willing to pay for environmental justice.” So, it's not inherent in the technology. It's in the social choices that get made. (R58)

Technological leap-frogging:

... what we have been seeing is that we have this leap-frogging. You see that, for example in terms of telecommunication, [least developed states] never had this extensive landline infrastructure, they just started using mobile phones. The same with the energy production systems... We want the developed countries to act but they are kind of in a locked-in situation already because they have invested, in the past, in massive infrastructure, so they would need to change infrastructure or need to reuse infrastructure in a way. Whereas, in a lot of the developing world you're not seeing the same kind of locked-in situation, so there's a lot of innovation potential that can be more easily implemented. (R76)

Source: Author, based on expert interviews ($N = 90$) with details concerning methodology mentioned in Section 2 Research Design, and the full sample of respondents mentioned in Annex 1.

Table 6

Expert interview quotes about thematic concerns regarding climate governance.

	General concerns	Global South
<i>Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC) and Nationally Determined Contributions (NDCs)</i>	<p>Pledges vs. action: ... I have worked on the precursors to the NDCs, as well as sectoral policy ideas to decarbonise specific sectors in particular countries, which then constituted building blocks for the NDCs in many of those countries. And just basically saw how haphazardly this is, in many contexts, being done to fulfil public demand [and] pressure, to come up with a superficial response and pledges. But at the same time those same pledges serving as an entry point and a lever to accelerate action effectively. (R47).</p> <p>Incorporating carbon removal in pledges: ... as long as deployment and removing carbon through the major carbon removal techniques does not count against the Nationally Determined Contributions, there is no incentive to do it... Today [many emerging approaches do] not count, and for good reasons... We do not know how to monitor that. We do not know if it is permanent. So it is less obvious that the carbon removed through direct air capture, from afforestation, from BECCS, will remove permanently sequestered. (R27)</p>	<p>Can carbon removal be part of Global South NDCs and CBDR? [In the past] from the South, they were almost entirely opposed to any kind of geoengineering intervention, letting the industrial North off the hook, disproportionate risks for them, and so on. In the last year, you hear a couple of governments, including the Indian government, make the opposite argument, which is that CBDR under Paris and the Framework Convention actually should legally mandate that developing countries start developing carbon removal approaches. So will other countries in the South also take that position? Are they going to supply lots of biomass and take all the negative impacts and externalities? Are they going to benefit financially from some of it? (R9)</p>
<i>Agriculture and forestry management</i>	<p>Cheap land-use credits from Kyoto to Paris: The whole LULUCF started with the Kyoto Protocol... the EU and AOSIS were absolutely opposed to LULUCF being included in the KP until the eleventh hour. It was never supposed to be part of the climate focus mitigation, the Kyoto Protocol was all about reducing fossil fuels, and then LULUCF came in and since then there's been a disproportionate amount of climate mitigation energy focused on land use. As I said, land use is the most uncertain to monitor. The CDR, the Net Zero thing, so then this all kind of got worse, this all changed and got worse with the Paris Agreement. Suddenly, the way you met the objective of the Paris Agreement was via sinks, or CDR. (R23)</p> <p>'Co-benefits' might be a fig leaf for cheap land-use credits: Another political risk is that while we now... [It's] more of a deception risk. Now that countries in Europe realise, "Okay, Net Zero means some residual emissions," and they all go for the so-called nature-based solutions, ecosystem-based solutions or what we simply, in a regulatory sense, count under LULUCF. They all like to expand that because you can sell that to the public, and then it's all about co-benefits. (R29)</p>	<p>Needed funding for Global South vs. Additionality: Some would argue that it's almost justified that the people the money is going to come from [Global North actors] are the people who have caused the problems in the past... but the complexities they introduce in terms of developing an efficient, large scale trading system... We've seen it with the Clean Development Mechanism and the mitigation offsetting mechanisms... the problem of proving additionality (R43).</p> <p>Socio-environmental consequences of projects: But I fear that when we look beyond Europe at, for instance, either the Clean Development Mechanism, and afforestation, reforestation under REDD+ has worked, there have been massive social consequences. They've been easy to ignore by the countries and companies that have been buying the credits, because they're not responsible for the issuing of the credits and how they are created. But they can use those credits and claim to be environmentally friendly, while actually these projects on the ground have massive social justice and climate justice impacts as well. (R84)</p>
<i>IPCC assessment</i>	<p>Need from carbon removals implied from models rather than reality: When you start looking at ... how opaque the integrated assessment models are... it became obvious that since the early 2000s, they've been hiding loads and loads of these technological imaginaries which are called greenhouse gas removal. (R85)</p> <p>Models create deceptively simple road maps for carbon removal: In the nicely defined rules of the model, I have the best estimate of population and development and yields. And I can nicely define where there is room for bioenergy CCS in addition to food production. But if I create an incentive in the real world, and yields could not develop exactly the same way as in the model, I've created this clear tension. (R81)</p> <p>Techno-economic modelling in Global North: [We need] diverse disciplinary expertise and perspectives ... gender and developing country or a Global South perspective into the mix of defining, characterizing and implementing a research agenda. You know... it's been initiated primarily European and EU experts from their own perspectives, with embedded understandings on what the ethical and technical dimensions of these issues are... (R25)</p>	<p>Models highlight potential in tropical countries: ... if you looked at the pathways and the models, many of the large carbon removal potential often is in tropical countries, which, arguable, should not be the ones paying for carbon dioxide removal for emissions they have not caused (R69)</p> <p>Assessments neglect Global South perspectives: I think for us the most influential actors will be – and I have some bias here – the researchers, the knowledge producers, largely because we lack the really locally driven, or national driven, or regionally driven kind of knowledge on the impacts, the risks, of these technologies to our countries, and even to our regions, because again, [research] is very trans-national. (R90)</p> <p>Indigenous knowledge: ... there is a huge, epistemic gap between the climate community generally, but particularly the climate engineering community, and indigenous forms of knowledge and knowledges. There was a debate in Nairobi [where] it was interesting that even Bolivia got the EU supporting other knowledges [for evaluating climate interventions]. And many others, actually, but that, seen through a lens of as an epistemic injustice, is an interesting one. (R55)</p>
<i>MRV and accreditation, carbon offsets, and markets</i>	<p>MRV complexities for hypothetical or immature approaches: ... there's an innovation need on monitoring, reporting, and verification ... particularly to trees, there's some uncertainty about that. But also, carbon in soils and the particular methods which involve putting carbon in soils via biochar, or via crushed minerals and soils. Enhanced weathering methods where you've got issues of the carbon flowing through the earth system, through water, into oceans, via soils or staying in soils. So, there's a challenge to tracking the carbon flow there, and verifying that it actually has removed carbon. (R79)</p> <p>Carbon market trading incentives warp MRV: I'm deeply sceptical about the value of carbon markets... They</p>	<p>Cheap credits from avoided deforestation: Voluntary carbon markets, or carbon markets in general, often deal avoided emission certificates, which are super cheap. How do you plug removals into that system? ... It's all about ensuring standards and accountability and presenting a race to the bottom, which is not an easy task. (BEUTTNER)</p> <p>Offset in-country before moving to international carbon markets (relying on cheap credits) I think it may risk increasing inequalities between the more developed and the developing world who feel that their natural assets are they only thing that they have left to sell in this developing climate-managed world. I think that one has to be very, very, careful about the design of any kind of market</p>

(continued on next page)

Table 6 (continued)

	General concerns	Global South
	<p>seem to have particularly severe problems of, I would say, accounting, verification, environmental integrity, additionality, which mean that they are necessarily going to drive finance towards the lemons... fraudulent carbon offsets. We see cases under the Clean Development Mechanism of businesses being set up only for the purpose of them being closed down to claim credits... There was a CDM evaluation... saying, '80% of projects are not additional.' The second big problem with them is that they lock-in a particular set of interests. The interests of carbon-market traders are... not in reducing emissions, or even in maximising carbon removals. They're simply in increasing the volume of trades so that they can make their commissions on multiple trades.... You're introducing actors [who will] as happily make money hedging that the whole thing fails as they will making money from delivering it. (R55)</p> <p>Separation of approaches and targets: All these side-effects that come up from what we call the 'misplaced fungibility' of assuming that a tonne of carbon in a forest in the Congo is the same as a tonne of carbon in a field in Britain or a tonne of carbon drawn out of the atmosphere in Canada. It is this broader sociotechnical analysis of the coupled systems that tells you that that's not the case, that these things can't just be seen as directly equivalent. (R55)</p> <p>Different kinds of innovation: Stepping back, though, to the innovation frame, the problem I see here is that innovation is a contested space itself. On the one hand, you've got the Silicon Valley-types, the idea that innovation is a matter of mobilising venture capital behind start-up organisations to generate nice ideas, turn nice ideas into practice. At the other end you've got – or maybe it's not the other end, maybe orthogonal in some ways – certainly you've got the Mariana Mazzucato-type, mission-driven innovation, state setting the goal-funding programmes. (R55)</p> <p>Philanthropic seeding: I've had a lot of consultations with people from Stripe, X-PRIZE, so all these very rich people putting a lot of money out there for the climate and having competitions and trying to seed fund, especially CDR. X-PRIZE had a challenge specifically on CDR, and Stripe as well. I think Bezos also gave money to ClimateWorks, and some of it trickled down to EDF and other net-zero efforts. That's also a factor, I think, that young companies can jump on. (R31)</p> <p>State or regional funds: You know about the Innovation Fund in the EU which runs off the money generated from Emissions Trading Scheme? And the Innovation Fund effectively can fund various large-scale projects which can aid decarbonisation of heavy industry, for example. (R68)</p> <p>Sustainable Development Goals: We need to get serious about the Sustainable Development Goals, and not serious about a small sub-aspect of the climate problem. We need to look at options that attack multiple SDGs and climate at the same time. (R34)</p> <p>Marine pollution: I think the London Protocol's main interest at the moment is looking at techniques that might be particularly being developed, particularly those involving field trials, because they are all ones potentially, obviously, where harm to the environment might be caused if it's not handled properly....I think most of the marine techniques could, potentially, be governed through the London Protocol amendments, if that's what the parties want to do...The big unknown, really, is whether there would be a global geoengineering regime of any type, and where it might be located. People have speculated about things like UNFCCC. Some people have suggested the CBD and a few other places, as well. (R86)</p> <p>Biodiversity and ecosystems services: I see the highest risk in bioenergy [as] land use. And land use is the main driver of anthropogenic mass extinction that we are currently witnessing, which is arguably at the same level and scale as climate change... in terms of species loss and in terms of ecosystem services that we are losing. Because assuming for the moment that the issues of ecosystem service loss and mass extinction are as serious as climate change, any option that aggressively demands further land is a problem and a high-risk strategy. And the high risks specifically relate to biodiversity loss and to ecosystem service loss. (R17)</p> <p>Food security: Everything that requires biomass requires fertile land. You always have to think about this competition with the food system, for example, with the livelihoods of people. I'm also not saying that any kind of traditional agro-pastoralist society must be kept in its current state indefinitely. If they want to change, that may be a good thing. So I'm not saying, "Traditional societies, always good and must be preserved at all costs," but certainly what we cannot do is say, "Well, we need this, and therefore, we expel you." So it must be done in a manner that really involves them and not with many of these land-grab things where people are expelled from the land with the military, and under the banner of, "We are modernising them."...That's a very colonialistic way of looking at people, so I think that's something we do not want and which is not consistent with the Sustainable Development Goals. (R40)</p>	<p>mechanism to make sure that those kinds of inequities and risks don't develop and that one has so-called high quality offsets, that one maximises in-country offsets before one starts moving to the international market. (R44)</p> <p>Needed funding vs. externalities: [Carbon offsets might] massively increase financial flows to the Global South. [But there is] a kind of convenient and creative accounting, I would say, that serves a very particular purpose and intent to bias the conversation in the direction of things like carbon removal. That tends to lead to certain undesirable outcomes, like the outsourcing to the Global South, where things are cheaper... (R15)</p> <p>Global South interest on carbon removal offsets are unknown: So, I think that is something to be teasing out, especially Southern positions on this, and more generally, what is happening, if anything, inside of Paris on this. Is it going to get written substantively into the rulebook? ... It is far from clear that it is more than [investigation] by academics at this point. (R9)</p> <p>Expanding mechanisms to the Global South: I would like to see a much wider jurisdiction-by-jurisdiction assessment of the potential of GGRs whereby the political lead in that process is taken by the countries themselves. I'm thinking largely of developing countries in this context. The scientific capacities of the Northwest of the world, if I can put it in those terms, are employed in the service of the agendas of those countries to assess what can be done. Of course, we are seeing real problems about the financing of any of this kind of progress and this agenda at the moment with countries not keeping up with their stated commitments to provide climate finance at the rate that we expect it. I'm not sure what the answer to that is... (R44)</p>
<i>Funding, tech transfer, capacity building</i>		
<i>Direction of climate policy from carbon management towards more systemic governance?</i>		

Source: Author, based on expert interviews ($N = 90$) with details concerning methodology mentioned in Section 2 Research Design, and the full sample of respondents mentioned in Annex 1.

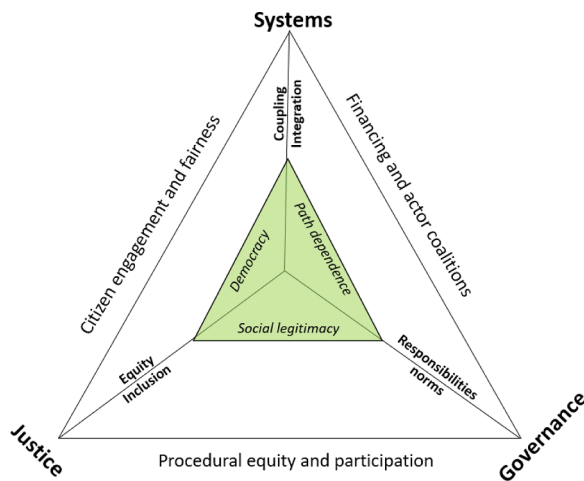


Fig. 1. Visualizing linkages between thematic concerns of systems, justice, and governance
Source: Authors.

drivers or recipients of carbon removal infrastructure as NIMBY-ism or pollution- or waste-exporting [35]; or on mapping risks and co-benefits for local society and development [36], or for technological leap-frogging [29]. Efforts to increase social legitimacy and co-design in turn shape how carbon removal assessment, development, and governance are conducted.

In conclusion, we reiterate a point raised by many participating experts: that assessments of benefits and risks, R&D roadmaps, and regulatory measures have thus far taken place with a ‘global planner’ or EU- and US-focused perspective that functionally prioritizes sectors, governments, and publics in the industrialized countries of the Global North. Where a focus on potential Global South concerns and inequities may exist, these are drawn from previous experiences – the Clean Development Mechanism, REDD+, and voluntary carbon markets in driving projects of unclear additionality and/or low-quality credits [3], the introduction of growing carbon stocks [4] to food vs. fuel dynamics [37], and the potential of extractive industries of mining and fossil fuels to export a pollutive and exploitative mode of carbon removal to marginalized areas [38,39]. Marketized climate governance, big agriculture, and big oil-and-gas still present the dominant lens through which concerns are seen.

Many concerns are certainly transferable, or extendable, between Global North and South – rural and indigenous populations may share concerns, as may countries with gas-extraction infrastructure and fossil fuel reservoirs. Still – and as can be expected – many experts noted that assessment of carbon removal must update concerns drawn from these antecedents with a more granular engagement with the Global South. Indeed, the ‘Global South’ was questioned as too broad a distinction [40]. Certain common interests could be pinpointed on the historic responsibilities of the industrialized North and developmental needs. Otherwise, experts noted nuances between least-developed and emerging economies, technology- and funding-capable states (e.g., China, or Saudi Arabia), and the presence of different energy matrices and material inputs (biomass or fossil fuels or minerals) and reservoirs (biogenic carbon stocks or oil reservoirs) that would imply couplings to different kinds of carbon removal approaches and supply chains. These regional and national-level assessments and engagements have yet to be addressed meaningfully [41]. Moreover, assessments of any kind mostly focus on techno-economic factors, with an eye to innovation and policy contexts that might incentivize business models for capturing carbon. The assessment of political and cultural environments is only now beginning in the EU and US – but again, this cannot be witnessed in Global South contexts.

This issues stem from endemic inequities, and we echo calls for

further research and action in three overlapping areas. In *assessment*, academic research and innovation funding has to be put in greater service of developing countries, through the topical focus of research (programmes) and stakeholder engagement, and more ideally through collaboration and co-design with local and regional experts, publics, organizations, and industry [42]. Moreover, IPCC pathways modelling can be supplemented with qualitative, context-orientated assessments of carbon removal undertaken through vulnerability, resilience, and related lenses that underpin work on adaptation – a concern of greater and more immediate relevance in least developed countries (e.g., [43]).

In *innovation*, a focus has to be put on more than creating a market case and business models for different carbon removal approaches [44], which in states without regulatory capacity or marginalized demographics, will drive demand for offsets and exploitative land-use, extractive, and pollution-importing practices – and which are more-over tailored to local circumstances, including the particular capabilities which exist in those areas [36]. Overall, a greater attempt to understand and focus has to be placed on a regulatory environment, and this goes beyond policy guardrails on-the-ground more broadly to governance.

In *governance*, greater attention must be paid to how carbon removal approaches might alter and influence how future NDCs in the Global South are constructed, in tandem with how the CBDR-RC principle is understood. Developing countries may see carbon removal as an opportunity to receive funding or expand their own share of the global carbon budget; or at the same time see opportunities for industrialized states and multinational companies to shift both harms and responsibility [34]. MRV processes may need to account for more than the carbon sequestered or leaked over life cycles, to incorporate diverse co-benefits for distributed and localized societies and economies [8,45,46]. Finally, the climate regime must make clearer connections in assessment and governance to aspects of justice [47,48] not only in carbon removal as carbon management, but as food systems, energy provision and security, biodiversity, development, and other issues of more immediate relevance to the Global South [49,50].

Data availability statement

The datasets generated during and/or analysed during the current study are not publicly available due to Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation).

CRediT authorship contribution statement

Benjamin K. Sovacool: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data that has been used is confidential.

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Annex 1: List of 90 semi-structured expert interview respondents

Name	Actor Type	Gender	Country	Institution
Asayama, Shinichiro	Universities + Research Institutes	Male	Japan	National Institute for Environmental Studies
Bazilian, Morgan	Universities + Research Institutes	Male	USA	Colorado School of Mines
Bellamy, Rob	Universities + Research Institutes	Male	United Kingdom	University of Manchester
Beuttler, Christoph	Private Sector + Industrial Associations	Male	Switzerland	Climeworks
Biermann, Frank	Universities + Research Institutes	Male	Netherlands	Utrecht University
Boettcher, Miranda	Universities + Research Institutes	Female	Germany	German Institute for International and Security Affairs
Brickett, Lynn	Government + Intergovernmental Organizations	Female	United States	US Department of Energy
Briggs, Chad	Universities + Research Institutes	Male	USA	University of Alaska, Anchorage
Brown, Marilyn	Universities + Research Institutes	Female	USA	Georgia Institute of Technology
Bruce, John	Private Sector + Industrial Associations	Male	Canada	Carbon Engineering
Buck, Holly Jean	Universities + Research Institutes	Female	USA	University at Buffalo
Burns, Wil	Universities + Research Institutes	Male	USA	American University
Caldeira, Ken	Universities + Research Institutes	Male	USA	Breakthrough Energy, Carnegie Institution for Sciences, and Stanford University, and Stanford University
Carton, Wim	Universities + Research Institutes	Male	Sweden	Lund University
Chavez, Anthony E.	Universities + Research Institutes	Male	USA	Northern Kentucky University
Clarke, Leon	Universities + Research Institutes	Male	USA	University of Maryland
Clarke, William S. (Sev)	Private Sector + Industrial Associations	Male	Australia	Winwick Business Solutions
Cobo Gutiérrez, Selene	Universities + Research Institutes	Female	Switzerland	ETH Zurich
Cox, Emily	Universities + Research Institutes	Female	United Kingdom	Cardiff University
Creutzig, Felix	Universities + Research Institutes	Male	Germany	Mercator Research Institute on Global Commons and Climate Change (MCC)
Delina, Laurence	Universities + Research Institutes	Male	Hong Kong	Hong Kong University of Science and Technology
Di Marco, Leon	Private Sector + Industrial Associations	Male	United Kingdom	FSK Technology Research - Consultant
Dooley, Kate	Universities + Research Institutes	Female	Australia	University of Melbourne
Draper, Kathleen	Civil Society	Female	USA	International Biochar Initiative
Elliott, David	Universities + Research Institutes	Male	UK	The Open University
Erbay, Yorukcan	Private Sector + Industrial Associations	Male	United Kingdom	Element Energy
Florin, Marie-Valentine	Universities + Research Institutes	Female	Switzerland	EPFL International Risk Governance center (IRGC)
Forster, Piers	Universities + Research Institutes	Male	United Kingdom	University of Leeds
Frumhoff, Peter	Civil Society	Male	USA	Union of Concerned Scientists
Fuhrman, Jay	Government + Intergovernmental Organizations	Male	United States	Pacific Northwest National Laboratory (PNNL)
Fuss, Sabine	Universities + Research Institutes	Female	Germany	Mercator Research Institute on Global Commons and Climate Change (MCC)
Gambhir, Ajay	Universities + Research Institutes	Male	United Kingdom	Imperial College London
Geden, Oliver	Government + Intergovernmental Organizations	Male	Germany	German Institute for International and Security Affairs (SWP)
Ghosh, Arunabha	Civil Society	Male	India	Council on Energy, Environment and Water (CEEW)
Grant, Neil	Universities + Research Institutes	Male	United Kingdom	Imperial College London
Gruebler, Arnulf	Universities + Research Institutes	Male	Austria	International Institute for Applied Systems Analysis (IIASA)
Guillen Gosalbez, Gonzalo	Universities + Research Institutes	Male	Switzerland	ETH Zurich
Haberl, Helmut	Universities + Research Institutes	Male	Germany	BOKU Vienna
Hamilton, Clive	Universities + Research Institutes	Male	Australia	Charles Sturt University
Hartmann, Jens	Universities + Research Institutes	Male	Germany	University of Hamburg
Hawkes, Adam D.	Universities + Research Institutes	Male	United Kingdom	Imperial College London
Healey, Peter	Universities + Research Institutes	Male	United Kingdom	Oxford University
Heap, Richard	Civil Society	Male	United Kingdom	Carbon Removal Centre, Foresight Transitions
Hepburn, Cameron	Universities + Research Institutes	Male	United Kingdom	Oxford University
Herzog, Howard	Universities + Research Institutes	Male	United States	MIT
Heyward, Clare	Universities + Research Institutes	Female	Norway	UiT - the Arctic University of Tromsø

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Name	Actor Type	Gender	Country	Institution
Honegger, Matthias	Universities + Research Institutes	Male	Switzerland	Perspectives Climate Change
Kammen, Daniel	Universities + Research Institutes	Male	USA	UC Berkeley
Keller, David	Universities + Research Institutes	Male	Germany	GEOMAR - Helmholtz Centre for Ocean Research Kiel
Keller, Klaus	Universities + Research Institutes	Male	USA	Penn State University
Kruger, Tim	Private Sector + Industrial Associations	Male	UK	Origen Power
Lawrence, Mark	Universities + Research Institutes	Male	Germany	Institute for Advanced Sustainability Studies (IASS)
Lehmann, Johannes	Universities + Research Institutes	Male	USA	Cornell University
Lenton, Andrew	Government + Intergovernmental Organizations	Male	Australia	CSIRO
McLaren, Duncan	Universities + Research Institutes	Male	United Kingdom	Lancaster University
Mengis, Nadine	Universities + Research Institutes	Female	Germany	GEOMAR - Helmholtz Centre for Ocean Research Kiel
Merk, Christine	Universities + Research Institutes	Female	Germany	Kiel Institute for the World Economy
Michaelowa, Axel	Universities + Research Institutes / Private Sector + Industrial Associations	Male	Switzerland	University of Zurich / Perspectives Climate Group
Montserrat, Francisc	Universities + Research Institutes	Male	Brazil	Project Vesta / University of Sao Paulo
Morrow, David	Universities + Research Institutes	Male	USA	American University
Muri, Helene	Universities + Research Institutes	Female	Norway	Norwegian University of Science and Technology (NTNU)
Obersteiner, Michael	Universities + Research Institutes	Male	United Kingdom	Oxford University
Parson, Edward (Ted)	Universities + Research Institutes	Male	United States	UCLA
Pasztor, Janos	Civil Society	Male	Switzerland	Carnegie Climate Governance Initiative
Pidgeon, Nick	Universities + Research Institutes	Male	United Kingdom	Cardiff University
Pongratz, Julia	Universities + Research Institutes	Female	Germany	University of Munich
Preston Aragonès, Mark	Civil Society	Male	Norway	Bellona Foundation
Raimi, Kaitlin T.	Universities + Research Institutes	Female	United States	University Michigan
Reiner, David	Universities + Research Institutes	Male	United Kingdom	Cambridge University
Renforth, Phil	Universities + Research Institutes	Male	United Kingdom	Heriot-Watt University
Rickels, Wilfried	Universities + Research Institutes	Male	Germany	Kiel Institute
Rothman, Dale	Universities + Research Institutes	Male	USA	University of Denver
Rouse, Paul	Universities + Research Institutes	Male	United Kingdom	University of Southampton
Schleussner, Carl	Civil Society	Male	USA	Climate Analytics
Schmidt, Jörn	Universities + Research Institutes	Male	Denmark	International Council for the Exploration of the Sea
Schneider, Linda	Civil Society	Female	Germany	Heinrich Böll Foundation
Scott, Vivian	Universities + Research Institutes	Male	United Kingdom	Edinburgh University
Simonelli, Lucia	Civil Society	Female	United States	Carbon 180
Smith, Pete	Universities + Research Institutes	Male	United Kingdom	University of Aberdeen
Smith, Steve	Universities + Research Institutes	Male	United Kingdom	Oxford University
Smith, Wake	Universities + Research Institutes	Male	USA	Harvard University
Spangenberg, Joachim	Universities + Research Institutes	Male	Germany	Sustainable Europe Research Institute SERI Germany e.V
Stoefs, Wijnand	Civil Society	Male	Belgium	Carbon Market Watch
Sugiyama, Masahiro	Universities + Research Institutes	Male	Japan	University of Tokyo
Sunny, Nixon	Universities + Research Institutes	Male	United Kingdom	Imperial College London
van Vuuren, Detlef	Government + Intergovernmental Organizations	Male	Netherlands	PBL Netherlands Environmental Assessment Agency
Vaughan, Naomi (Nem)	Universities + Research Institutes	Female	United Kingdom	University of East Anglia
Victor, David	Universities + Research Institutes	Male	USA	UC San Diego
Vivian, Chris	Government + Intergovernmental Organizations	Male	UK	GESAMP
Wolske, Kimberly S.	Universities + Research Institutes	Female	United States	University of Chicago
Workman, Mark	Universities + Research Institutes	Male	UK	Energy Futures Lab, Imperial College London

Annex 2: Ten carbon removal approaches with high visibility in the assessment literature

Option	Description
Carbon capture and utilization and storage	Employing technologies, processes or solvents that extract, capture, transport, utilize, and/or store carbon dioxide
Afforestation and reforestation	Planting trees or vegetation to absorb carbon dioxide
Bioenergy with carbon capture and storage	Harnessing specific energy crops (e.g., perennial grasses, or short-rotation coppicing) or increased forest biomass to replace fossil fuels, and capturing and storing consequent carbon dioxide
Biochar	Managing the thermal degradation of organic material in the absence of oxygen to increase soil carbon stocks and improve soil fertility
Soil carbon sequestration or enrichment	Growing cover crops, leaving crop residues to decay in the field, applying manure or compost, using low- or no-till systems, and employing other land management techniques to improve soil

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Option	Description
Ocean iron fertilization	Utilizing planktonic algae and other microscopic plants to take up CO ₂ and convert it to organic matter, some of which sinks and is sequestered in ocean
Enhanced weathering and ocean liming or alkalization	Deploying physical or chemical mechanisms to accelerate the geochemical processes that naturally absorb CO ₂ at slow rates.
Direct air capture	Capturing carbon dioxide from the air via engineering or mechanical systems, and then using solvents or other techniques to store it safely
Blue carbon and seagrass	Harnessing the ability for coastal mangrove forests, tidal marshes, and seagrass meadows to accelerate their uptake of carbon dioxide
Ecosystem restoration	Managing the restoration of ecosystems (including wetlands, peatlands, and grasslands) to reverse environmental damage and increase their ability to absorb greenhouse gases

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