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# The ABC of Governance Principles for Carbon Dioxide Removal Policy

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Climate change mitigation actions, including those aimed at developing and scaling carbon dioxide removal (CDR) activities spanning the industrial, energy, and agroforestry sector, emerge in a context of internationally shared norms that include governance objectives, legal provisions and informal expectations, and societal expectations. Established governance principles provide normative orientation for policy including when targeting the development and scaling of CDR. Knowledge of these principles can guide effective discussion and evaluation of policy options. To facilitate discussion of mitigation options among experts and CDR practitioners, this study excerpts governance principles from legislative texts, the climate governance literature, and the CDR literature with relevance to CDR policy considerations. To illustrate the relevance of the governance principles found for evaluating policy options, we apply them to three technology groups of CDR: Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Carbon Capture and Storage (DACCS), and forestry. This exercise indicates the importance of more intensive attention to the normative dimension of mitigation policies in ongoing deliberative and planning processes. Such efforts can help disentangle normative and factual dimensions and sources of (dis)agreement on the role of CDR in specific climate policy contexts.

**Keywords: policy instruments, climate change mitigation, norms, principles, public acceptance, negative emissions, carbon dioxide removal, governance**

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## INTRODUCTION

Carbon dioxide removal (CDR) methods[1] remove $CO_2$ from the atmosphere into durable storage (IPCC, 2022)[2]. CDR represents a rapidly growing, albeit contentious, topic in climate governance. Research on the techno-economic feasibility and mitigation potential of various CDR approaches is substantial, and a growing body of literature explores the ethics of CDR. However, emerging deliberations on policy design appear largely detached from established governance principles that have guided mitigation policy for decades.

[1]We use terminology from the IPCC's 6th Assessment Report. We would like to note that "methods" is often understood in the climate policy community as meaning methodologies for assessing the baseline emissions and monitoring activity emissions. Here "methods" means concrete approaches leading to CDR.

[2]We refer to CDR as Carbon Dioxide Removal, but acknowledge, that in principle also other GHG could be removed and durably stored away from the atmosphere (GHG removal) via "negative emissions technologies".

Policy action on CDR has been slow – in part due to a lack of orientation for policy makers (Geden and Schenuit, 2020). Against this backdrop, this article identifies possible governance principles applicable to CDR policy design. The article also points to possible interpretations toward decision-making guidance and legitimacy. Engaging with the normative dimension of CDR policy may help identify genuine differences in opinion regarding CDR implementation and finding common ground.

The article seeks to offer insights for two types of readers: 1. Seasoned climate policy actors to whom *CDR* represents an emerging policy field toward climate mitigation; and 2. CDR experts and practitioners to whom *policy* represents the next frontier toward CDR implementation. To bring both on board, we start with a brief history of CDR, followed by an outline of the concept and relevance of governance principles.

## A Brief History of CDR

Considering the notion of CDR solely based on the integrated assessment model (IAM) literature, one might easily think that CDR methods emerged on a blank normative slate (Low and Honegger, 2020), despite the rich history of removals recognized in social science literatures (Carton et al., 2020). Within IAM frameworks, CDR represents a variable in a modeled pathway designed to achieve a given target (for instance, a predetermined level of end-of-century warming). The one-dimensionality of this approach has been criticized in the past (Rogelj et al., 2019), but remains the frame of reference in climate policy. Although over a decade has passed since the first conception of combining bioenergy generation with carbon capture and storage (BECCS; Obersteiner et al., 2001), CDR has largely remained an abstract notion to climate policy makers in many countries. The degree to which well-below 2°C compatible IAM scenarios rely on dramatic scale up of CDR – alongside an unprecedented pace of decarbonization – arguably remains understated in public debates (Michaelowa et al., 2018).

With the emergence of serious public pressure to increase GHG mitigation, net-zero pledges have lately been communicated by many state- and non-state actors. CDR is now also unambiguously understood as legally representing a form of the mitigation of climate change for all intents and purposes of international (and thus also domestic) climate change governance (Honegger et al., 2021a). Consequently, CDR has – in principle – been firmly situated in the realm of climate change mitigation policy. Yet – in practice – CDR is hardly mentioned in the nationally determined contributions (NDCs; see e.g., Borth and Nicholson, 2021), which are the backbone of mitigation action under the Paris Agreement (PA). This will have to change, if the proposed net-zero pledges and eventually the 2°C – let alone the 1.5°C – goals are to be achieved.

## Governance Principles – Concept and Relevance

Climate policy experience suggests decisionmakers respond to political demands rather than to modeling results. Political demands are embedded in both a web of societal expectations and defined governance goals, each with associated norms that political action is supposed to meet. While the relevance of CDR policies is self-evident for CDR actors, the same is not necessarily true for other societal actors. Indeed, it appears as though for several years, policymakers lacking (normative) orientation have avoided CDR (Geden et al., 2019) and that presently they still struggle situating policy within societal expectations. It is thus important to reflect on the normative dimension of governance goals (such as those regarding climate action or sustainable development) as well as societal expectations in order to define principles that offer well-reasoned guidance for CDR policy implementation. Both stakeholders pushing for CDR use and actors concerned over their discursive relevance may benefit from examining the normative basis of their demands within norms including governance goals and societal expectations. This will help shaping policy instrument design on a sound normative basis.

## Review and Tentative Interpretation

In this article, we review key governance literature and legal texts to offer a conceptual framework regarding *norms* and *principles* relevant to CDR, including governance goals and societal expectations. The starting point for our literature selection was the PA and related UNFCCC documents, as they embody key norms for international climate governance. Our second step was to identify norms expressed in the emerging CDR policy literature *via* searches on Google Scholar based on keywords such as "CDR", "governance", "principles" and closely related concepts in different combinations. We selected articles based on recency and impact (number of citations) and complemented them with papers deemed particularly impactful in regards to their normative claims or demands. To reduce normative blind spots we complemented the selection through a project-workshop (with the CDR-PoEt consortium) in which we sought to map relevant norms and principles as well as their interlinkages and trade-offs.

After giving an overview on the key principles identified from our literature search, we outline how CDR policy can be situated within them. We focus on climate change mitigation governance and broader environmental governance on the international and national level, but also examine normative claims developed in the CDR-specific policy and governance literature. We then offer possible interpretations and applications of these presented norms and principles to policies targeting three groups of CDR methods, namely BECCS, direct air carbon capture and storage (DACCS), and forestry.

# ESTABLISHED AND EMERGING NORMS AND PRINCIPLES RELEVANT FOR CDR

Most policy decisions – including on climate change mitigation – take place at national or sub-national levels. However, we believe that they are normatively influenced by international governance norms, goals and principles. Our conceptual framework, review and examples focus on the international level, yet it points also to a need for localized (regional, national, and sub-national) mapping of norms and principles.

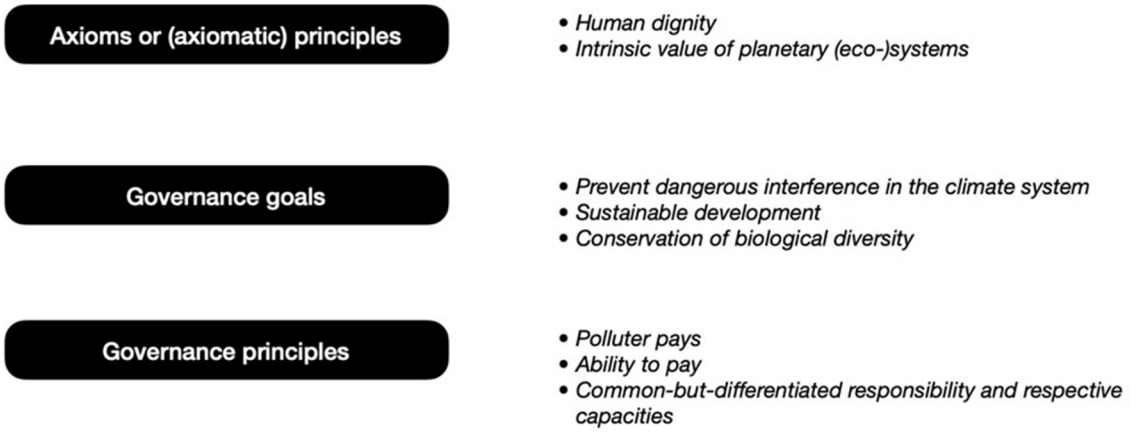


**FIGURE 1 |** The conceptual framework and context of "governance principles" with examples.

## Conceptual Framework: Governance Principles

In order to develop, select or evaluate policies for regulating CDR, it is necessary to know what policies should (not) do or be. This issue is the subject of the normative dimension. Normative discourses in governance and policy as well as in related scientific disciplines (political science, philosophy, economics, and others) are closely linked to the concepts of "norms" and "principles." However, these concepts hold somewhat different meanings within disciplinary and governance contexts. In what follows, we propose to use a possible cross-disciplinary, broad understanding of norms and to view principles as norms that stand at a particular point in the development of a theory or a structure of justification. Since the concepts of governance goals and societal expectations are frequently used in the discussion of governance principles, their location in the framework presented will be briefly outlined here.

Norms provide shared benchmarks to assess courses of action as right or wrong. Such benchmarks take various forms (cf. Mittelstraß, 2004). Understood in regulatory terms, norms comprise benchmarks in the form of rules for action, objectives, and rules constituting institutions. Within a descriptive understanding of norms, these include laws as well as customs. Finally, norms, as understood in moral theories, comprise benchmarks in the form of moral value judgments. We propose to use an overarching notion of norms for the development of policy instruments, encompassing all the aforementioned forms of benchmarks. With such a broad understanding of the concept, governance goals and societal expectations can also be interpreted as norms. Governance goals can be understood as norms within a regulatory understanding. Societal expectations usually represent norms in a regulative sense that are not (yet) institutionalized or established as a rule. These normative expectations that something should (not) be done are expressed, for example, in stakeholder or civil society surveys and are an important component of democratic policy development.

Across disciplines, *principles* are often used to mean *norms* that stand at the beginning of a (thought-) process. In the political context, for example, objectives such as equal pay or subsidiarity are referred to as principles that form the basis for political action (cf. European Union). In the context of international environmental law, principles are defined as "bedrock of this field" (Rajamani et al., 2021). These include, for example, the principles of precaution or of common but differentiated responsibilities (cf. Rajamani et al., 2021). In a philosophical context, principles originally denote axioms, i.e., insights that cannot and need not be proven, from which norms are usually derived. Axioms include, for example, the principle of causality or the principle of utility (cf. Rescher, 2012).

What the various norms and axioms referred to as principles have in common is that they stand at the beginning of the development of a theory or systems or a structure of justification, for example, at the beginning of the development of an ensemble of policy instruments.

We can distinguish principles of different order. A norm may constitute a principle in a certain discourse, while it does not do so in another. For example, *human rights* represent a principle if they form the axiomatic basis for climate action. However, they can also "merely" represent a norm when derived from the principle of human dignity as the subject of a moral theory. Since *human rights* are not the basis of theory development in the latter discourse, they do not constitute an (axiomatic) principle in this context. Axioms, therefore, represent the original principles, since they are generally not further substantiated or derived from any other principles (**Figure 1**).

We thus propose the term governance principle as follows: norms that are at the beginning of the development and justification of an ensemble of policy instruments and their evaluation. Based on this conceptual framework, we map norms that can serve as governance principles for the development of policies targeting CDR.

## International Governance Principles in Context of Climate Change Mitigation

Norms that can act as governance principles for mitigation under the international climate policy regime of the UN Framework Convention on Climate Change (UNFCCC) can be found in the legal texts directly – including as explicit provisions as well as by way of governance goals – and in the PA's governance architecture (Bodansky and Rajamani, 2015).

Provisions also point to governance principles embedded in governance contexts other than directly regarding climate change: (a) the consideration of various rights (including human rights and indigenous peoples' rights); (b) efforts toward the eradication of poverty; and (c) contributions to sustainable development. These are further examined in Section *Governance Principles Situated in Other Fields of Global Environmental Governance* and following.

We map potential climate-related governance principles embodied in the PA architecture in the following sub-sections and address the four main pillars in turn: (i) ambitious global long-term temperature goals translated into net zero targets, (ii) bottom-up national mitigation contributions, (iii) an ambition mechanism "ratcheting up" the contributions over time, bolstered by reporting of all countries on action and progress, and (iv) international cooperation and support. We discuss these elements below.

### Potential Governance Principles in the Context of Mitigation Ambition

There are numerous provisions in the PA on the aggregate pace and volume of mitigation efforts and regarding Parties' obligations of conduct. Art. 2.1a defines the long-term temperature goal of holding warming to "well below" 2°C, and to pursue efforts to limit warming to 1.5°C, inducing a collective obligation of result (Rajamani and Werksman, 2018). Article 4 induces an obligation of conduct including regarding CDR: Art. 4.1 specifies the global goal to reach "a balance between anthropogenic emissions by sources and removals by sinks of GHG in the second half of this century." CDR is thus observed to be an important part of mitigation (Honegger et al., 2021a). Each new iteration of NDCs (at least every 5 years; Art. 4.9) is to represent a progression over time in its ambition and reflects the parties' highest possible ambition (Art. 4.3). NDCs are to become increasingly comprehensive regarding economic sectors (Art. 4.4), and GHG covered across sources and sinks (UNFCCC, 1992; Art. 3).

Together, these provisions suggest possible governance principles to include (as listed in **Table 1**) (a) that CDR should be considered in NDCs, (b) that the efforts should not weaken other mitigation efforts, and (c) that they should be commensurate with the collective ambition of achieving net-zero GHG emissions (balance) and perhaps net-negative global emissions.

### Potential Governance Principles Regarding International Support and Cooperation on Mitigation and Adaptation

The UNFCCC and the PA include provisions regarding technology-transfer for accelerating the adoption of innovative mitigation and adaptation technologies globally (Art. 10, PA). Institutions such as the Technology Mechanism [including the Technology Executive Committee (TEC) and the Climate Technology Centre & Network (CTCN)] or the Green Climate Fund (GCF) have been set up to contribute *via* financial, capacity and other types of international support (Azam, 2021). The Paris Agreement provides for international cooperation to "allow for higher ambition" (Art. 6), which is widely regarded to fulfill a norm of mitigation efficiency (relating to *ambition;* Edmonds et al., 2021). Relevance of these provisions and institutions could increase for CDR due to large capacity- and cost- differentials as well as co-benefit potentials. Significant differences in respective responsibility (see below regarding fair-share norms) could further add to expectations of international climate finance for mobilization of CDR as international transfers can significantly improve the distributive implications of climate action for world regions with limited resources (Lenzi et al., 2021). In this context, the term "climate justice" has been widely employed by civil society stakeholders; "climate justice" considerations can have relevant repercussions on the ranking of alternative types of CDR. CDR technology could be relevant beyond mitigation: There are significant expectations for adaptation support, where certain CDR methods could potentially play a role also due to co-benefits (Buck et al., 2020).

These observations suggest governance principles to include also: (d) technology-transfer may need to help strengthen capacities for CDR implementation globally, (e) international cooperation may improve CDR efficiency (f) climate finance may mobilize CDR.

### Potential Governance Principles Regarding Environmental Integrity

Environmental integrity has emerged as a key – albeit somewhat complex – norm particularly relevant to international cooperation (PA Art. 6) but also mitigation more generally (PA Art. 4.13). A simplified definition by Schneider and La Hoz Theuer (2019)– applied to international carbon markets – stipulates that a policy or mitigation action leads to the same or lower aggregated global emissions. Generalizing their framework suggests that to achieve environmental integrity at least four conditions need to be fulfilled jointly: proper accounting; robust tracking (MRV) of mitigation results; ambition of the mitigation target; and spillover incentives for future action. These are intertwined and also relate to ambition, insofar that correct MRV is a precondition for tracking effective progress, and transparency is a condition for judging ex-ante the ambition level as well as ex-post the progress made. To achieve environmental integrity for CDR action, the durability (or "permanence") of carbon storage needs to be consistently addressed in accounting and MRV. This may require clarifying monitoring and reporting processes over defined periods of time, as well as liability associated with storage reversal or "leakage."

The above observations suggest that governance principles may also include an umbrella principle that CDR policies should be environmentally integer. Sub-principles operationalizing this umbrella principle (beyond previous ones regarding ambition) could include (g) consistent accounting for CDR results applying

conservative baselines and including leakage, (h) application of robust MRV methodologies including regarding leakage.

## Potential Governance Principles Regarding Fair-Share Efforts

Given that mitigating climate change is a globally shared challenge, norms regarding regions' countries', or companies' mitigation efforts involve considerations of distributive justice and equity. The same is true for any comparison of present and future efforts (intergenerational justice) inevitably included in the notion of mitigation pathways and policy planning. The norm of *common-but-differentiated responsibilities and respective capacities* (CBDR-RC) referred to explicitly as a principle under the UNFCCC and further qualified as "in the light of different national circumstances" under the PA (Art. 2.2) is central to fair-share considerations of mitigation efforts within individual national contributions and on aggregate for regional or global efforts. Fair-share considerations are increasingly being applied to CDR, where both the intragenerational (e.g., which economies should install and/or finance CDR activities) and the intergenerational (e.g., long-term permanence) dimensions exist (Lenzi et al., 2018; Fyson et al., 2020). Consideration of responsibility or proportionality based on historic emissions, capability and ability-to-pay, or 'per-capita' equality are central to this discussion. There is also a growing realization that biophysical limits would affect the respective capacities and thus may also influence fair-share judgments (but not of financial responsibility; Pozo et al., 2020). In many cases, especially for land-based CDR, potentials are high in low- and middle-income countries with relatively low historic emissions, such that inverse trends between responsibility and biophysical limits need to be navigated (Honegger and Reiner, 2018). The Polluter Pays Principle (PPP) represents one particular expression of intra- or intergenerational justice invoked for mitigation overall whereby revenues collected from emitters would flow to CDR implementation to clean-up previous pollution (Stainforth, 2021). The notion of forcing emitters to completely balance their emissions with permanent carbon removal has led to the idea of imposing a Carbon Removal Obligation on emitters (Bednar et al., 2021), which might meet both inter- and intragenerational justice.

The above observations suggest governance principles to include an umbrella principle for the (i) consideration of inter- and intragenerational equity which can be operationalized to include (j) common-but-differentiated responsibilities (k) differentiation by capacities and (national) circumstances.

## Potential Governance Principles on the National Appropriateness of Policy and Metrics

There are arguments based on the governance architecture of the PA (see Section *Potential Governance Principles in the Context of Mitigation Ambition*) as well as theoretical arguments that policies and their metrics of effectiveness need to be nationally determined and appropriate. Grubb (2014) makes the theoretical case for a broad policy mix that allows rapid development and diffusion of mitigation technologies. The theoretical economists' view that a single international emissions trading scheme would be singularly effective and efficient is increasingly being questioned (Haites, 2020). CDR policies thus ought to be part of a policy ensemble mobilizing a nationally determined range of mitigation technologies, including by funding of research and development, providing incentives for roll-out of maturing technologies, and overcoming non-monetary barriers. Targets for each policy instrument need to be specific enough to judge the respective instrument's ability to achieve them. Metrics of judgment against clearly formulated objectives also need to be nationally determined and span both the near- and the long-term: An intervention can for example be *effective* in increasing the number of CDR installations in the mid-term but remain *inefficient* at delivering meaningful mitigation results in the long-term (or vice-versa), if the costs of the technologies are not declining over time (Honegger et al., 2021c). Clear policy objectives, metrics and aligned policy mixes thus appear to be requirements following from norms regarding ambition, "environmental integrity" and particularly effectiveness. Efficiency – albeit highly relevant for achieving the highest-possible ambition – cannot be viewed in isolation, but within a long-term perspective to avoid solely focussing on temporary low-cost solutions that do not solve the problem, such as non-sustainable biomass-based CDR in settings with high risk of reversals.

The above observations point to further governance principles including on the (l) national determination of clear objectives, policies and metrics for CDR and (m) consideration of both short- and long-term effectiveness and efficiency.

## Potential Governance Principles Regarding Public Deliberation and Participation

Addressing a public good like climate change mitigation requires the public's support for policy instruments at national and local levels. The former may be particularly relevant in case significant costs be associated with the CDR measure. The latter is required to avoid rejection of necessary local infrastructure – often seen in the context of NIMBY (not in my backyard) movements. The scale-up of CDR comes with (perceived) risks and concerns associated both with the measures themselves, and with the broader societal implications and costs. Many of the expectations of outcome identified in this paper are potentially interwoven with public opinion of and support for CDR policies and projects. At the same time, there are long-established expectations and rules for public deliberation and participatory decision-making in environmental governance (Okoro and France, 2019), which may serve as governance principles. Early and consistent public deliberation is thus both a means and an end for climate change mitigation – particularly for measures that do not (appear to) have a self-interested and influential proponent, as may be the case for several types of CDR (Buck, 2019). Transparent and public deliberation processes can help address and alleviate concerns that could otherwise result in opposition at the local (NIMBY) (e.g., Pind Aradóttir and Hjálmarsson, 2018), or national level (Klinke and Renn, 2021). Integrative risk governance seems a prerequisite to legitimate policymaking; the procedural rule or objective regarding the development of policies thus includes deliberation among

experts and epistemic communities (epistemic deliberation), societal stakeholder groups (associational deliberation), and the general public (public deliberation) (Klinke and Renn, 2021). Perception of risks and fairness (both intragenerational and intergenerational) of policies are highly interlinked with trust in the implementing actors and communicators (experts, planners, and decisionmakers; Honegger and Reiner, 2018) and with intuitive public narratives, as found by studies of the public perception of CCS in Norway and Germany (Dütschke et al., 2016; Merk et al., 2022).

The above suggests an additional governance principle to ensure (n) procedural justice and (o) public participation and stakeholder involvement including through a transparent policy deliberation and design process.

## Governance Principles Situated in Other Fields of Global Environmental Governance

### Potential Governance Principle Regarding the Sustainable Development Goals

The perhaps broadest and most encompassing formulation of a common normative vision for the future can be found in the 17 sustainable development goals (SDGs) adopted by the United Nations – alongside the PA – in 2015. A particularity of the SDGs as a normative backdrop for technology and policy assessment is their integration of biophysical, socio-economic, political, and institutional dimensions and the corresponding recognition of their respective interrelations. One attempt at assessing CDR approaches against the backdrop of the SDGs found the broad range of the objectives to helpfully force the integration of hard-to-integrate factors into assessments (Honegger et al., 2021a). This wide lens could serve as a normative backdrop also for future regional and local evaluations of CDR proposals, where localized assessment of specific approaches is needed. Here, priorities across the diverse goals can be defined at an appropriate level. Governments tend to be unwilling to wield their sovereignty over nationally determined policies, yet decision-supporting tools can nonetheless be developed e.g., by international institutions working on mitigation, international cooperation, technology transfer or capacity building based on the SDGs that enable transparent evaluations without precluding policy choices.

Based on the above, governance principles for CDR policy include (p) a contribution to sustainable development.

### Potential Governance Principle on the Duty to Prevent Transboundary Harm and Preference for Rectifying Damage at Source

States are to ensure that activities within their national jurisdiction or control do not cause significant damage to the environment of other states or areas beyond their national jurisdiction or control (UN, 1992). As a forward-looking legal principle, this may become relevant to some CDR activities, especially if taking place in the open ocean or at sufficiently large scale to result in transboundary effects. The principle itself remains rather abstract and might only indirectly inform decisions regarding local CDR applications. A related norm is the notion that damage should be rectified at its source, as stated e.g., in the EU's guidelines for environmental policy (European Union, 2016). This concept expands the duty to avoid "exporting" environmental harm and/or damage from an international (as formulated in the duty to prevent transboundary harm) to a national or even local perspective. However, its relevance for CDR may depend on the operational definition of "damage."

This suggests governance principles for CDR may include q) the duty to prevent transboundary harm and r) a preference for rectifying damage at source.

### Potential Governance Principle Regarding Precaution

There has been surprisingly little analysis of the precautionary principle – the most formal characterization of precaution – with respect to CDR, despite this norm often being raised in the context of "geoengineering." Honegger (2020) finds precaution challenging for decision-problems on CDR, given risk-risk trade-offs and ambiguous interpretations (Wiener and Rogers, 2002; Sunstein, 2005). The PA also refers to the precautionary principle, evidently to call for mitigation action despite uncertainties over the severity of the climate change problem (Art. 3.3). This is in contrast to the "geoengineering" literature, where precaution signifies limiting deployment (Bodle, 2013).

Precaution can thus mean to proactively pursue a broad array of mitigation options including various forms of CDR, as well as caution in the reliance on individual options and in light of possible adverse effects. Governance principle could thus include the (s) proactive consideration of multi-risk trade-offs including policy or technology failure risks as well as countervailing risks of omitting policy steps.

## Expectations From the CDR Literature

Besides the previously discussed long-established norms on climate change mitigation as well as in other global environmental governance contexts, an emerging body of literature is identifying and proposing CDR-specific norms that can act – and sometimes are explicitly presented as – governance principles. We outline these in the following.

### Potential Governance Principle on the Long-Term CDR Needs for Net-Zero Targets

Much of the recent consideration of CDR has been fueled by a surge in net-zero targets among national and sub-national governments as well as in the private sector, including the EU, Scandinavia and Germany (Geden and Schenuit, 2020; Honegger et al., 2020). The European Commission has started a process for developing a Carbon Removal Certification Mechanism, and political dynamics around the role of CDR in the fair distribution of mitigation burdens are accelerating in discussions between EU member states and on the level of the UN climate regime (Geden et al., 2019; Pozo et al., 2020). In these developments CDR is ascribed a particular role – most frequently to offset residual, unavoidable emissions to reach net-zero. Congruently, a growing consensus narrative describes CDR as a necessity to fulfill ambitious climate targets (Otto et al., 2021).

This implies another governance principle (complementing (a) and (c)): (t) anticipate the longer-term CDR needs toward a stated net-zero or net-negative emissions target.

### Potential Governance Principle for Avoidance of Over-Promise and Under-Delivery

Some see CDR as an imaginary with little foundation in political and social realities (Low and Boettcher, 2020), but capturing public attention (Otto et al., 2021). Many fear a false sense of certainty regarding the feasibility and desirability of CDR (Low and Honegger, 2020). Avoidance of delaying, displacing or otherwise undermining decarbonization efforts is thus a prominent demand (also referred to as "mitigation deterrence," or "moral hazard" (McLaren, 2016; McLaren and Markusson, 2020; Morrow et al., 2020). Scaling CDR to levels anticipated in IAM scenarios will take decades and is highly uncertain in light of limited technological maturity. Lenzi et al. (2018) indicate there is no time to wait for CDR to become ready to be deployed on a large scale yet increasing reliance on decarbonization also involves deep uncertainty. Thus, the long-term role CDR is expected to play in every nation's long-term climate strategy – and corresponding short-term action – needs to be clear and the basis for policy-design (Morrow et al., 2020). Yet without dedicated policy accelerating CDR readiness, however, under-delivery is virtually certain (Honegger et al., 2021c). Mitigation policy overall and on CDR in particular must avoid over-promise and under-delivery.

Corresponding Governance Principles could include (u) communication of a strategy for preventing over-promise and under-delivery, (v) communication of intermittent targets and policy objectives, and (w) adapt policies if intermittent targets and objectives are missed.

### Potential Governance Principle for Specific (Separate) Targets

Calls for "separate" or specific targets for CDR and for emissions reductions are common in the CDR-policy literature (McLaren and Markusson, 2020; Morrow et al., 2020). A widely shared justification for focusing on CDR separately from emissions reductions is the need to incentivize action on both, without one (usually CDR) undermining the other. Yet a strict operationalization of such an expectation into siloed policies would generate trade-offs with other norms and ultimately act as a self-fulfilling prophecy, given that restricting fungibility of different mitigation options can cause inefficiency and render policies ineffective (Elkerbout and Bryhn, 2021). A "both-and" rather than an "either-or" toward defining targets and policy frameworks for CDR and other mitigation measures thus seems in order (Morrow et al., 2020). We postulate that "specific" targets rather than "separate" targets would better serve the underlying norm.

The above might suggest a potential Governance Principle to (x) formulate increasingly specific targets for various CDR and emission reduction methods within and across economic sectors.

### Potential Governance Principle for Specificity to CDR Cases

The term "CDR" covers a wide range of different methods ranging from so-called "nature-based solutions" such as afforestation to approaches such as DACCS. A further source of differences lies in their inherent socio-economic role: While DACCS is a pure mitigation measure with no other *raison d'être*, other approaches represent essentially a tweak of an ongoing productive activity – such as managing land and food production (forestry) or generating electric power and heat (BECCS). CDR types differ in other ways too – e.g., in regard to their resource needs and their potentials for co-benefits. In addition, regional and cultural differences also suggest that expectations and norms will vary across the globe. Contextualized, nuanced, and detailed analysis of conditions and circumstances on a case-specific basis thus appears to be an important condition for designing policy instruments that scale up different types of CDR (Morrow et al., 2020). Yet not every instrument needs to target every CDR method, so this norm may be met *via* an ensemble of instruments.

Governance Principles thus could include (y) consideration of each CDR methods specificities, and (z) pursuit of a sufficient policy ensemble that meets the needs of the targeted methods.

In the various applicable governance contexts and respective literatures outlined in Section *Established and Emerging Norms and Principles Relevant for CDR*, we have identified the governance principles summarized in **Table 1**. This represents by definition a debatable or incomplete list, given that other governance contexts can be evoked. They are – also by design – partly overlapping as they are designed to cover a specific range of governance contexts and point to particular interpretations thereof. They can nonetheless stand at the beginning of the policy design process for dedicated CDR policies and policy mixes. Governance principles should not be confused with a set of criteria (in the context of multi-criteria decision-making or specific assessments), where the priority is to ensure minimal overlap at the expense of normative breadth.

## APPLICATION TO POLICY DESIGN ISSUES FOR SPECIFIC CARBON DIOXIDE REMOVAL TECHNOLOGIES

In the previous sections, we have identified governance principles for CDR policy. In the next sections we explore whether and to what degree these governance principles could offer orientation in the policy design targeting three groups of CDR methods (BECCS, DACCS, and forestry). These three approaches cover a broad spectrum of CDR methods, but are of course only examples.

To acknowledge the broad range of policy options, we provide examples of potential outcomes, which might find heterogeneous solutions for trade-offs between the different pertinent norms. This outlines the large spectrum of possible compromises and approaches. Furthermore, we emphasize that the examples used here are far from exhaustive with regard to available and possible CDR methods and policy designs. They cover, however, a broad

**TABLE 1 |** The ABC of potential governance principles.

| Governance context | Governance principles |
|---|---|
| Mitigation ambition | a) CDR should be considered in NDCs,<br>b) CDR policies should not weaken other mitigation efforts<br>c) Resulting CDR efforts should be commensurate with the long-term collective mitigation ambition |
| International support and cooperation on mitigation and adaptation | d) Policy mixes should include technology-transfer to help strengthen capacities for CDR<br>e) Policy mixes should include international cooperation to improve CDR efficiency<br>f) Policy mixes should include international climate finance transfers to mobilize CDR. |
| Environmental integrity | g) Policies should ensure consistent accounting for CDR results applying conservative baselines and including leakage<br>h) Policies should apply robust MRV methodologies including on leakage |
| Equity and fair-share efforts | i) CDR policies should fulfill principles of inter- and intragenerational equity *(e.g.,* Polluter Pays or Ability to Pay).[a]<br>j) Efforts should internationally be differentiated per common-but-differentiated responsibilities<br>k) Efforts should internationally be differentiated by respective capacities and (national) circumstances. |
| National appropriateness of policy and metrics | l) Policies should include a national determination of clear objectives, policies, and metrics for CDR<br>m) Policies should consider both short- and long-term effectiveness and efficiency |
| Public deliberation and participation | n) Policies should be procedurally just<br>o) The policy design process should involve public participation and stakeholder involvement |
| Sustainable Development Goals | p) Policies should contribute to sustainable development |
| Duty to prevent transboundary harm and preference for rectifying damage at source | q) Policies should prevent transboundary harm<br>r) Policies should prioritize rectifying damage at source |
| Precaution | s) Policy designs should reflect multi-risk trade-offs including policy or technology failure risks as well as countervailing risks of omitting policy steps. |
| Long-term CDR needs for net-zero targets | t) Anticipation of longer-term CDR needs incl. toward net-zero or net-negative emissions targets |
| Avoidance of over-promise and under-delivery | u) Policy mixes should include strategies for preventing over-promise and under-delivery<br>v) Policies should include intermittent targets and policy objectives<br>w) Policies should be adapted upon missing intermittent targets and objectives. |
| Specific (separate) targets | x) Policies should involve increasingly specific targets for various CDR and emission reduction methods |
| Specificity of CDR cases | y) Policies should reflect CDR methods' specificities<br>z) Policy ensembles should meet the needs of the targeted methods |

[a]*Polluter Pays and Ability to Pay represent two widely recognized principles of distributional justice. However, they serve here only as examples of principles of fair distribution. Which principles the policies have to fulfill in detail can neither be discussed nor determined here.*

and heterogeneous spectrum of current CDR methods and therefore allow illustrating possible applications of governance principles presented in Section *Established and Emerging Norms and Principles Relevant for CDR*. Further cases, however, would require adjusted and detailed analysis – in specific (national, regional, or local) political contexts. In each sub-section, we list the letters of the principles that are relevant; space limitations prevent a discussion of each principle.

## Resulting Policy Considerations for Bio-Energy With Carbon Capture and Storage

In the following, we highlight examples of BECCS specific policy issues that may be further explored against the backdrop of the identified governance principles.

### Mitigation Ambition and Avoiding Over-Promises and Under-Delivery

BECCS is characterized by the tension between modeled potentials (Minx et al., 2018; Rickels et al., 2019; Low and Schäfer, 2020) and past controversy over biofuels as a mitigation measure (Beck and Mahony, 2018). Policy planning may thus need to proactively clarify the anticipated scale and role of BECCS to address inflated expectations and associated concerns. Careful interpretation of modeling results and realistic estimates should be made when policy targets for the short-, mid-, and long-term BECCS development are determined (governance principles: c, j, k, l, o, u, v, w, and x).

### Environmental Integrity

A key uncertainty for BECCS is the carbon-balance of biomass (which needs to be renewable, sustainably sourced, and not lead to depletion of biomass stocks elsewhere). To ensure this, MRV should consider the full value-chain (including biomass sourcing, carbon capture, transport and storage) and set a high bar of evidence especially regarding the biomass source. Storage permanence is also of relevance, but of lesser concern than for approaches resulting in lower inherent durability, and policy solutions exist at least in the EU (European Union, 2022). A newer method for storage through basaltic mineralization

promises virtually no reversal risk (governance principles g, h, and p).

### International Cooperation and Support

Policies can pursue international cooperation for BECCS as its value-chain can be split between countries. This is an opportunity for efficiency (principle e), but it introduces challenges for distributive fairness (principle j), and the transportation and storage infrastructure may be rejected due to perceived risks despite public participation (principle o; Gough et al., 2014; Pind Aradóttir and Hjálmarsson, 2018; Merk et al., 2022).

### Sustainable Development Goals

Land-use and biomass-use competition chiefly affects BECCS' sustainability. Policy instruments could pursue a (cascading) prioritization of biomass uses (prioritizing e.g., already existing plants and facilities, as well as waste feedstocks (agricultural residues, construction wastes). Biomass also holds important socio-economic dimensions: In low and middle income countries, biomass tends to serve low-income strata without access to commercial fuels. Policies thus must not divert biomass access from such populations to prevent severe social impacts and may need to address any such effects in their design (e.g., compensation or economic inclusion) which will require designing them with participation of such stakeholders (principles i, n, p, and s).

### Public Deliberation and Participation

Participatory policy design is relevant given the different types of industrial actors involved in the value chain (producers of biomass, energy producers, transport-providers, and storage-providers) and their likely heterogenous level of influence (principles n and o).

### Specificity of BECCS Policy Trade-Offs

BECCS represents a range of applications: purely biomass power-plants or combined biomass- and fossil fuels, solid- or liquid waste incineration, liquid biofuel- or biochar production with energy generation. Policies will need to target each case specifically for their inherent differences (incl. implications from biomass-flows, land-use, or socio-economic).

An obvious trade-off lies in the discrepancy between efficient mitigation and socio-economic consideration. On the one hand, a policy could also focus on either the capture side, aiming at large amounts of biomass to be combusted and the resulting $CO_2$ captured, or on the transport and storage side, in which case leakages in transportation and storage would also be addressed[3].

Policies with an overly strong focus on efficiently maximizing the amount of $CO_2$ captured would probably incentivize land-intensive production of biomass including fertilizers and pesticides, cheap capture technologies, transport, and storage sites. Besides the abovementioned consequences for SDGs focusing on biodiversity, land use conflicts and health issues stemming from the deployed chemicals might follow. More lenient transport and storage regulations and MRV could lead to efficiency in reaching the policy target while compromising environmental effectiveness.

On the other hand, focusing solely on minimizing BECCS' impact on socio-economic aspects could lead to relatively little capacity for BECCS in settings where agricultural land is a limiting factor. Such an approach could incentivize outsourcing BECCS, thereby increasing international cooperation and, if low- and middle-income countries are targeted, financial support for host countries of BECCS installations. While NIMBY conflicts would be avoided in the country implementing the respective policy, societies with a high awareness of equity related issues would likely face a lack of public acceptance, as the outsourcing of potentially conflict-prone technologies like BECCS might not be perceived as acceptable.

We acknowledge that both examples are extreme cases, which are not likely to materialize in a real-world setting. However, they show the necessity for politics to develop a holistic view on BECCS and careful considerations regarding the setting of weights to the many principles to be considered in designing BECCS governance.

## Resulting Policy Considerations for Direct Air Carbon Capture and Storage (DACCS)

Here we address DACCS specific policy considerations against the backdrop of the governance principles.

### Mitigation Ambition, Long-Term Needs, and Under-Delivery

The mitigation contribution of DACCS hinges on the abundant availability of usable, low carbon energy and the provision of a sufficiently high carbon-revenue due to high costs. If solely included within carbon pricing and carbon market systems, in direct competition with other mitigation options, DACCS would not be competitive, so dedicated policies will need to address its near-term requirements for scaling and driving down costs for a meaningful medium to long-term contribution (principles m, t, u, v, w, and z).

### Environmental Integrity

As a highly technological process, MRV of DACCS is straightforward and uncontroversial. Embodied emissions from its significant material requirements can be considered in its net emissions. The main concern for environmental integrity of DACCS policies may relate to its low-carbon energy needs which risk displacement effects. Policies thus should ensure deployment takes place on sites with a structural surplus of zero-carbon energy (principles b, g, h, q, and x).

### International Cooperation and Support

Capture and storage in separate jurisdictions can entail some efficiency gains if energy and storage availability are separate. But the more likely case is international cooperation through purchases of removal units produced in a country that has significant potential for both through international carbon

[3]The question is, thus, what the target variable of a policy is, and how CDR is governed to contribute to national or voluntary targets.

markets[4]. Basaltic mineralization in volcanic areas often also features geothermal energy potentials, as is the case in Iceland and potentially other volcanic island environments. Dedicated policies in other world regions should ensure international collaborations also foster technology transfer and capacity building to counter a potential imbalance in DACCS capacities (principles d, e, i, and k).

### Specificity of the DACCS CDR Case

DACCS also includes several value chain elements (direct carbon capture from ambient air, transport, and storage). The main requirements are electricity and heat[5] as well as suitable storage. As such, DACCS can be placed where energy availability and storage capacities are high. Land requirements are non-negligible but substantially smaller than of biomass-based CDR. The costs of DACCS processes are high compared to other CDR options but may decrease through technology learning. So DACCS policies will need to deal with the initially high costs, as well as with continuing energy requirements and carefully balance these with other mitigation efforts.

### Avoidance of Over-Promise and Under-Delivery and Precaution

Due to its relative immaturity and lack of a non-carbon revenue source, the biggest concern for DACCS policy may be under-delivery: With only a handful of serious technology developers and 19 small-scale pilot plants currently being active worldwide (International Energy Agency (IEA), 2021), DACCS is a novel and relatively untested approach, and could not be upscaled if its current mitigation costs remained unchanged. A precautionary approach driven by mitigation urgency would view the high costs as an "insurance premium" (Morrow et al., 2020), but this argumentation crucially hinges on the ability of DACCS developers to bring costs down. DACCS technology suffers from the inherent thermodynamic limitations that impose a firm minimum on material and energy needs and costs. This cost threshold may, however, be lower than the long-term mitigation cost for limiting warming per the PA. For DACCS to play a meaningful role, policy ensembles thus need to ensure balancing short and long-term needs, technology development with cost-reduction, and mobilizing high carbon-revenues to enable the technology to compete (principles c, e, i, l, m, s, t, u, v, w, x, y, and z).

### Resulting Policy Considerations for Re- and Afforestation and Agroforestry

In stark contrast to blackbox engineering methods, land-use based CDR methods are the result of numerous actors' behaviors and resulting trends for soil and biomass carbon contents. Multiple dimensions of success can in this case only be viewed in a holistic ensemble and the policy considerations are highly particular to the methods, which is why in this case we inverse the order:

[4]Note that not only capture, but also storage site operators should be covered in potential CDR inclusion to carbon markets, as these entities need to ensure permanence.

[5]At least in most currently pursued technologies.

### Specificity of Re- and Afforestation and Agroforestry Case

In the climate debate, land uses play an ambivalent role, as effectiveness, fairness, environmental integrity, and sustainability dimensions are strongly intertwined for re- and afforestation as well as agroforestry. The land-users, their economic situations and resulting choices themselves are the key factor of success and failure on all accounts, as described in the following.

### Mitigation Ambition and Avoidance of Over-Promise and Under-Delivery

On the one hand, conversion of natural forests into agricultural uses is an important driver of climate change. This holds true especially for conversion for the purpose of cattle ranching and agro-industrial production of commodities. In addition to the massive release of carbon, deforestation has significant negative impacts in terms of biodiversity, and it poses a massive threat to the livelihoods of many highly vulnerable indigenous and traditional communities. This is particularly true for many tropical countries with weak economies and governance structures, where the destruction of forests is continuing at an unabated pace and is the main contributor to national emissions. Accordingly, the protection of the remaining natural forests is seen as one of the most (cost)effective measures to mitigate climate change.

Given the structural barriers, agroforestry CDR may be among the technologies with overly optimistic pathways in the IAM literature (Rickels et al., 2019). Expanding to all kinds of forestry may increase the potential but comes with important repercussions.

### Sustainable Development Goals

In practice, re- and afforestation efforts are frequently operationalized through the establishment of large-scale monocultures of exotic timber and pulp species such as Eucalyptus, Pinus, and Acacia operated by large private sector entities. This allows capturing the benefits from efficiency-oriented policies such as carbon pricing, provided robust monitoring is undertaken. Given that forestry-based CDR belongs to the lowest cost CDR options, this can mobilize significant mitigation (relates to principle e), if incentives are not set perversely to induce deforestation for later reforestation and if the plantations are operated in a rotation system that ensures permanence of the forest in the long run. A drawback of monocultural forests are their negative social and biodiversity-related impacts (Pokorny et al., 2010).

The (re-)establishment of environmentally and socially adequate land use systems like agroforestry can achieve multiple goals including carbon removal, biodiversity, and provision of environmental services (Waldén et al., 2020), forestry and agricultural goods, and benefits to small-scale land users (Jose, 2009; Montagnini, 2017). These benefits can also be realized in formerly deforested areas, which are often highly degraded as a result of inappropriate land uses. In poor countries, agroforestry is typically a highly distributed activity involving mainly small-scale, often subsistence farmers.

All vegetation-based CDR approaches can have negative repercussions on several SDGs (2, 3, 6, and 15), if a purely quantitative sequestration remuneration is undertaken that does not consider co-benefits of the vegetation cover, such as biodiversity, health issues and water quality (relates to principle p). Positive ecosystem services related to vegetation are rather unique to agroforestry. The ecosystem services of agroforestry should thus be specifically considered and ideally be remunerated by public policies; they may also increase public acceptance of biomass-based CDR.

### International Cooperation and Support

Afforestation and reforestation, as well as agroforestry projects have a long history in international development cooperation (Pandey, 2002) but have encountered difficulties regarding upscaling. This is often due to lacking capacities of the local population, which often ekes out a living by unsustainable land use and has no access to markets or agricultural extension services. Moreover, in a policy context that systematically promotes input-intensive mechanized agriculture and livestock production aimed at clearly differentiated global value chains of a few commodities, agroforestry systems are often not competitive. If these challenges were overcome, agroforestry would be well suited for international cooperation under the PA, be it through international carbon markets under Article 6 based cooperation or through international climate finance.

### Environmental Integrity

All policy instruments for forestry need to particularly consider permanence due to high reversal risks of biomass-based CDR. So far, no policy instrument has been able to address this in a way that safeguards both environmental integrity and efficiency. Temporary credits as applied under the CDM have not been attractive to potential carbon credit buyers, while buffer stock requirements will only be effective if applied on a highly aggregated level and being administered by an institution whose existence is assured in the long run. The recent approach of Verra to apply a 100-year monitoring for its nature-based CDR projects and to operate a global buffer stock over such periods may be a harbinger of similar approaches on the national level. In contrast, buffer stock requirements in the low double-digit percentage like specified by the ART TREES[6] standard under the multi-billion USD "LEAF" initiative seem inadequate and in conflict with environmental integrity.

Due to the large number of actors and differences in removal potentials on small spatial scales, agroforestry generates large uncertainties and high transaction costs, especially if high environmental integrity is to be guaranteed by robust MRV.

### Equity and Fair-Share Efforts

Exclusion of marginalized groups from land use needs to be prevented. Policy instruments could for example set minimum requirements for local socio-economic considerations. Considering the competition between small-scale agroforestry and large-scale plantations, remunerating CDR solely in a carbon-results based approach can have negative distributional consequences, as activities might shift from current small-scale applications toward large-scale businesses, with potentially negative effects on local livelihoods.

[6]https://www.artredd.org

## SYNERGIES AND TRADE-OFFS: TOWARD PRINCIPLED POLICY INSTRUMENT EVALUATION AND DESIGN

Looking beyond the case studies, evaluating completely new policy proposals seems rather straightforward. However, the more likely scenario is the adaptation of existing instruments – such as the EU ETS or other established carbon markets or mitigation subsidy programmes – to be extended to also cover CDR (or particular types of CDR). This complicates the assessment but should not deter it.

Provisions and adjustments to include CDR directly into the scope of the EU ETS or indirectly by creating units that can be sold into the EU ETS are already under discussion both in academic (Rickels et al., 2021) and political (Liese, 2022) contexts. This approach is appealing in terms of efficient implementation, avoidance of transaction costs, and utilizing political synergies. But the details will be contested: the policy design will have to consider whether CDR methods will be able to compete directly with more mature means of emission reduction and may therefore install separate subsidies or removal mandates linked with credit trading schemes. For example, Pozo et al. (2020) argue that current carbon trading systems should be revisited or parallel markets for CDR created to separate CDR targets from established mitigation targets. This illustrates the existence of competing norms and principles and the need for careful deliberation to achieve a balance of competing interests while securing the public good of effective mitigation.

Trade-offs also exist at the aggregate level of policy mixes: Lenzi et al. (2021) for example have demonstrated how three stylized policy approaches toward net-zero (including a stronger or weaker reliance on CDR) have different distributional implications, and that there may not be an unequivocally better or worse policy mix across multiple equity dimensions with small changes potentially yielding dramatically different outcomes. It is thus even more important to allow public deliberation regarding the performance of different policy instruments in an environment of multiple principles, weighted heterogeneously by different stakeholders, and to approach policy (mix) design in an adaptive manner that allows iterative improvement based on broad-stakeholder-based practical learning.

## DISCUSSION

CDR is a partially novel (DACCS, BECCS), partially long-standing (forestry) category of climate change mitigation. It is developed within a pre-existing landscape of formal as well as informal, but nonetheless important norms used as principles that guide mitigation efforts. While their interpretation leaves room for specific political, regional, and socio-economic contexts, they may already offer some high-level orientation in

deliberation, planning, and policy implementation that aim at putting in place ensembles of CDR alongside emissions-reducing measures to mitigate climate change rapidly enough to "prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992, Art. 2).

Given that the feasibility and ultimate scalability of all mitigation technologies and measures – particularly more novel ones – to the levels commensurate with the long-term goals of the PA is fraught with social, economic, and political uncertainties, a portfolio approach appears sensible (Michaelowa et al., 2018). This is aligned with provisions of the international climate policy regime regarding ambition and the need for comprehensiveness in NDCs.

Ultimately, no policy design may be considered universally good or bad on its own. Such judgment must be done contextually – in the socio-economic and political as well as the geographical and environmental context in which a measure is being proposed. The same is true for CDR methods themselves as Honegger et al. (2021b) have emphasized. Technology arguably cannot be judged innately good or bad outside of its social and political context. This calls for contextualized and method-specific assessment of CDR-policy proposals in the national (and sub-national) contexts in which they are considered (and by the respective local or national actors and stakeholders).

Since the uncertainties mentioned above, as well as the broad range of situation-specific framework conditions for implementation of CDR measures characterize the planning and implementation of CDR action, a precautionary approach to limiting the risk of extreme emission overshoot could involve a two-pronged strategy: avoiding over-promise as well as under-delivery. This would mean to plan mitigation action on the assumption that individual CDR methods will fail to deliver, thus potentially "underselling" their potentials. Simultaneously, governments would have to work explicitly toward a broad portfolio of CDR options each becoming cornerstone methods – through appropriate research and development support and by generating effective long-term policy frameworks. Many forms of CDR do not generate revenues from the sale of goods or services, so they will require substantial amounts of funding, either from public or private sources. Public policy also needs provisions to "cut off" support for CDR methods that consistently underperform regarding economic effectiveness and overall SDG impacts compared to their peers. Experiences from the multi-decadal funding of underperforming technologies like nuclear fusion and fission should not be repeated. Given the scarcity of public resources, policy instruments can follow more detailed sets of principles regarding economic dimensions as laid out in Grubb (2014), and for mature technologies requiring scale prioritize efficiency.

The bottom-up nature of the PA suggests that each nation may need to figure out its own nationally determined and most appropriate pathways toward its mitigation targets and the policies utilized along the way. This implies that each party also needs to go through deliberative processes at the national level (based also on their respective actor-constellations and interests) in order to make legitimate decisions on how the public good of CDR is acted-upon. This includes identifying nationally appropriate prioritizations for the use of key resources. In the cases of agroforestry and BECCS this would mean to identify priority functions in ecosystems, living biomass, and harvested wood – to ensure policy incentives result in systemically sustainable mitigation action.

Since these differing national policies will lead to differing subsidy rates per unit of CDR, efficiency requires the availability of international carbon markets to harness cost differentials. In the past, such markets have shown their effectiveness by e.g., the CDM mobilizing over 7000 mitigation projects in over a 100 countries in <10 years (Michaelowa et al., 2019a). While we acknowledge the drawbacks and problems associated with the CDM, e.g., its relatively low carbon price and uneven spatial distribution of projects, the overall quantity and high utilization of credits generated under the CDM speak for its effective functioning. CDR has the inbuilt advantage that most CDR options can clearly show their "additionality" to business-as-usual, which has been difficult for emission reduction technologies that usually generate revenues from the sale of goods or services (Michaelowa et al., 2019b). This means the use of CDR under Article 6 of the PA needs to be rapidly operationalized. The development of CDR-specific methodologies, as pursued e.g., by the CCS+ initiative[7], could help to increase the number of CDR projects realized under Article 6. Possible, detrimental effects of such collaboration need to be avoided by robust governance on the international level, namely through the Article 6.4 Supervisory Body. The recent decision to require reporting of sustainable development implications of Article 6.4 collaboration serves as good basis but needs consistent operationalization in the next years.

Besides international carbon markets, international climate finance is essential for ambitious and fair mitigation action, yet could also result in over-promise and under-delivery, given past mixed outcomes of international transfers (Lenzi et al., 2021).

Identifying high-level norms and using them as governance principles to guide deliberations on CDR or proposed CDR policies is one way of approaching the policy challenges posed by CDR. Identifying operationalized criteria ready to be applied to specific policy decision problems is another. In identifying general norms, we have remained at a level of abstraction that allows painting a large picture with broad strokes. By illustrating some of the possible interpretations in CDR method specific cases we sought to point to possibilities for operationalization of principles into policy design guidelines. Such an approach allows approaching policy design and evaluation on a normatively transparent basis that can and should be contested.

However, assessment of CDR or climate policies is not always done in such a manner. In fact, a considerable body of literature already provides assessments of "large-scale" CDR (as a category of "Climate Engineering"; National Research Council, 2015; Schäfer et al., 2015). Yet much of that literature is not explicit as to its normative basis, and most of those evaluations are not situated within any particular governance context (e.g., the mitigation of climate change under the PA or national mitigation action in a particular country). Both – normative transparency

[7] see https://ccsplus.org/

and governance contextualization – are, however, key conditions for generating orientation knowledge. Another set of literatures offers criteria for the assessment of climate finance policies (see e.g., Gewirtzman et al., 2018; Michaelowa et al., 2020; respective chapters on (inter-)national climate policy in the IPCC Assessment Reports). While this is more explicitly rooted within a particular policy field, it largely remains unspecific to CDR to date.

Both types of literatures might be leveraged for moving toward normatively transparent evaluation of CDR policy options. Nonetheless, this necessarily politically deliberative move will take time, and the operationalization into criteria for CDR measures and CDR policies requires numerous contestable interpretative steps and inclusion of CDR-specific concerns. The work, however, does not stop with the development of operationalized assessment criteria, but political assessment will require a framework that clarifies how interdependencies of various assessment criteria are to be dealt with: Do several criteria – for example regarding efficiency and alignment with SDGs – jointly constitute necessary conditions (for sound policy)? Are there any hierarchies among criteria, in case of conflicts or trade-offs between them? For example, what should one do if a policy instrument is highly efficient but generates concentrated instead of widely shared co-benefits or revenues? Do criteria ultimately draw on commensurable or incommensurable value-systems, and, in case of the latter, how can policymakers and academics address genuine reasons for disagreement based on fundamental differences in worldviews? To which extent can such evaluations be done with a global claim to relevance and on which choices will countries or regions exercise their sovereign right to shape and pursue mitigation in a nationally determined manner? We offer our tentative identification of principles in form of various norms and expectations as another very early step on a long road toward holistic assessment frameworks for CDR policy, in which both normative and non-normative criteria transparently shape the evaluation of different options and pathways (see Baatz, 2017, 2018).

## CONCLUSIONS

Currently, net-zero emission targets are emerging in several jurisdictions, indicating the anticipated scaling-up of CDR. In this situation, we observe a move away from the abstract and "sanitized" view on CDR derived from the IAM top-down calculated "requirements" (Low and Honegger, 2020) toward a confrontation with real-world policy challenges. In this paper, we have argued that understanding CDR policy options in the light of structuring governance principles is required to make meaningful progress in this ongoing process.

Based on our observations of (potentially) pertinent governance principles stemming from the policy fields of climate change mitigation, other global environmental governance contexts, and CDR-specific governance literature, we view the political feasibility of CDR policy options to be intimately linked to their performance across such (interlinked) governance principles (Mace et al., 2018; Waller et al., 2020). These are increasingly understood to jointly shape a policy proposals' acceptability, social and institutional support, and ultimately political feasibility. Public support for CDR policy proposals depends on their (perceived) contribution to fair decarbonization transitions (Gough and Mander, 2019). A less holistic perspective on CDR policy proposals focusing on techno-economic factors alone would fail to capture such connections.

These observations indicate that a robust understanding of governance principles and the trade-offs between such principles is a precondition to the effective discussion and sound design of CDR policies. For such policies to contribute meaningfully and continually to climate mitigation action and, eventually, the achievement of national targets and global objectives their normative basis needs to be established within their respective local, national or regional context. Eventually, there will have to be a convergence of understanding which principles drive CDR policies and how a constructive debate addressing inevitable trade-offs can be held, both on the international and the national level.

## AUTHOR CONTRIBUTIONS

MH: initial conceptualization and writing–editing. MW: conceptual development and writing–editing. CB, SE, AH-C, AM, BP, and MP: writing–editing. All authors contributed to the article and approved the submitted version.

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