Environmental Science and Policy 153 (2024) 103659

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Carbon dioxide removal: A source of ambition or of delays? Examining expectations for CDR in Swiss climate policy

Juanita von Rothkirch [a,*], Olivier Ejderyan [b], Michael Stauffacher [a]

[a] Transdisciplinarity Lab, Department of Environmental Systems Science, ETH Zurich, Universitätstrasse 16, 8092 Zürich, Switzerland
[b] Research Institute of Organic Agriculture (FiBL), Switzerland

ARTICLE INFO

Keywords:
Carbon dioxide removal
Mitigation deterrence
Sociology of expectations
Residual emissions

ABSTRACT

Carbon dioxide removal (CDR) is recognized as an important tool for addressing residual emissions and achieving net-zero emission targets. While some have cautioned that a focus on CDR in policy processes may lead to delayed efforts to mitigate emissions, others have argued that such concerns are unwarranted. Nevertheless, the circumstances under which CDR could help or delay emissions mitigation in given contexts remain unclear. This paper explores the emerging discourse on CDR in Switzerland. We examined how the CDR community legitimizes CDR and limits its scope, and what the implications are for emissions mitigation. Switzerland is home to growing businesses in CDR and has pioneered the implementation of international offsetting projects under Article 6.2 of the Paris Agreement. We found that numerous promises help legitimize and attract interest in CDR. Actors use discursive strategies and rules to limit CDR and avoid disappointment in its contribution to climate mitigation. The idea that emission reduction should prevail over removal is promoted accordingly, which ironically helps legitimize the CDR idea yet dodges the question of how much removal is possible and for balancing which emissions. Superficial engagement with the issue is reinforced by the normalization of inflated promises and the sentiment that the mitigation deterrence rhetoric erodes trust in CDR. We argue that this can contribute to mitigation delays by evading the debate on what it is possible to remove and taking resources from alternative measures. We recommend a thorough discussion to examine the risks and the implementation of rules that minimize them.

1. Introduction

In 2018, a Green Party member of the Swiss Parliament asked the administration to report on the potential importance of carbon dioxide removal (CDR) in the country's future climate policy. Since then, the Swiss administration has examined the potential and adequacy of different removal methods in achieving net-zero goals. In this way, Switzerland has followed a similar path to the European Union and the United Kingdom in advancing policies on CDR to fulfill climate neutrality goals by mid-century or sooner. The term "CDR" describes a wide range of approaches that remove carbon dioxide from the air and durably lock it away. These includes methods such as afforestation, durable storage in timber for construction, carbon sequestration in soil, the enhanced weathering of minerals, and bioenergy or direct air capture with carbon capture and storage (BECCS and DACCS, respectively). Some of these methods were originally classified as the "enhancement of sinks" in the climate governance discourse (UNFCCC, 2016). CDR and solar radiation management were then grouped together under the concept of geoengineering (Caldeira et al., 2013). Currently, the Intergovernmental Panel on Climate Change views CDR as "sink enhancement."(IPCC, 2018).

Since its appearance in global emission reduction scenarios, CDR has generated tensions concerning its contribution to climate mitigation. The IPCC (2022a) stated that CDR is needed to help accelerate short-term mitigation, counterbalance residual emissions to reach net-zero goals, and achieve negative emissions. Thus, all the modeled pathways from the Sixth Assessment Report (AR6) that limit warming to 1.5 °C and 2 °C involve rapid emission reduction in all sectors and CDR methods to counterbalance residual emissions (IPCC, 2022c).[1] Academics and nongovernmental organizations (NGOs) have expressed

* Corresponding author.
E-mail addresses: juanita.rothkirch@usys.ethz.ch (J. von Rothkirch), olivier.ejderyan@fibl.org (O. Ejderyan), michael.stauffacher@usys.ethz.ch (M. Stauffacher).

[1] In modeled pathways that report CDR and limit warming to 1.5 °C with no or limited overshoot, total cumulative net negative emissions in 2020–2100 were 20–660 $GtCO_2$. In modeled pathways that limit warming to 2 °C, global cumulative CDR is 0–290 $GtCO_2$.

https://doi.org/10.1016/j.envsci.2023.103659
Received 5 April 2023; Received in revised form 29 November 2023; Accepted 18 December 2023
Available online 9 January 2024

concern over the extraordinarily large quantities of removals included in some of the assessed scenarios (Anderson and Peters, 2016; Biofuelwatch, 2022; Economy Land and Climate Insight (ELCI), 2021; European Academies Science Advisory Council (EASAC), 2022; Fuss et al., 2014; Perlman, 2022). They have affirmed that the assumed large-scale rollout of CDR methods in the scenarios is unlikely to be technically, economically, and socially viable, since such methods are difficult to implement at the scale needed, and many are expensive and can negatively affect biodiversity, water resources, and energy availability (Creutzig, 2016; Diaz et al., 2019; Heck et al., 2018; Realmonte et al., 2019; Smith et al., 2016). Therefore, placing unrealistic hopes on such methods can elicit irreversibly damaging consequences for future generations if they fail to deliver (Hansen et al., 2017).

These researchers and NGOs have also asserted that CDR may threaten ambitious decarbonization efforts. This is mentioned in the literature alongside terms such as moral hazard or mitigation deterrence, deferral, obstruction, or delay (Anderson and Peters, 2016; Carton, 2019; McLaren, 2016; Markusson et al., 2018; McLaren, 2016; Minx et al., 2018; Morrow, 2014). In this paper, we use the term "mitigation deterrence" (MD), defined as the prospect of reduced or delayed mitigation[2] resulting from the introduction or consideration of another climate intervention (Markusson et al., 2018). In contrast to concepts such as moral hazard, in MD, the substitution of reductions for CDR is not (1) necessarily the result of rational decision-making and (2) inherently undesirable, even though in practice, CDR is far from functionally equivalent to reductions (Carton et al., 2023; Markusson et al., 2018).

The MD risks surrounding CDR have gained attention in the literature from individualistic and structural perspectives. A body of research has focused on how CDR and its framings affect individuals' support for mitigation measures (Campbell-Arvai et al., 2017; Merk et al., 2018). Some of these studies have concluded that individuals do not prioritize CDR over reductions, which has led to the empirical basis of MD being questioned (Colvin et al., 2019) and to calls to avoid stigmatizing methods that are crucial to achieving climate goals (Jebari et al., 2021; Morrow, 2014; Reynolds, 2014). Carton et al. (2023) posited that structural conceptualizations constitute a more appropriate way to address the issue in the real world, since they account for the social, economic, and political processes that shape individuals' actions (Markusson et al., 2018; Oomen, 2021). In line with this, some studies have stated that MD can arise as a result of unrealistic expectations for the deployment of CDR (Beck and Oomen, 2021; Lamb et al., 2020; Low and Boettcher, 2020; Sendroiu, forthcoming) or of market logics, political promises, or interest in upholding current consumption patterns (Asayama, 2021; Carton, 2019; Hougaard, 2024). However, there is a lack of case studies that provide a better understanding how MD manifests in the real world or what is being done to contain it.

We examine the emerging expectations for CDR in Swiss emissions using a sociology of expectations lens. Expectations, in the form of promises and concerns, can be performative by creating legitimacy, attracting resources, building networks, and shaping actions today. In line with recent calls (Carton et al., 2023), our research aims to determine how CDR is legitimized or limited through the promises and concerns expressed by various actors and how they affect mitigation deterrence risks. Thus, we ask the following questions: How do promises and concerns, as posed by Swiss stakeholders, shape CDR in the public arena? What are the implications of these promises and concerns on mitigation deterrence risks?

Switzerland presents an interesting case for analysis. The country is the birthplace of growing CDR businesses and has pioneered the implementation of international offsetting projects under Article 6.2 of the Paris Agreement. The early integration of CDR into national climate policies provides an opportunity to examine the effect that CDR might exert on decarbonization strategies and expectations.

1.1. Expectations for emerging technologies

Expectations for the potential of CDR are rooted in the discourses that accompany the development and promotion of the technologies to achieve it. Since the late 1990s, research on the sociology of expectations has examined the expectations and visions that accompany the development of technologies (Van Lente, 1993). This field studies how actors involved in scientific and technological developments continuously refer to what is possible in the future, drawing from and adding to a repertoire of images, statements, and prophecies, as well as the dynamics created by them (Borup et al., 2006a; Brown et al., 2017; Van Lente, 2012).

The sociology of expectations is part of a growing number of approaches to "imagined futures" in the social sciences (Suckert, 2022) that explore how the representations of the future that circulate in society influence present actions. It relates to other approaches in science and technology studies, such as socio-technical imaginaries (Jasanoff and Kim, 2015) that study the relationships between collectively held visions of the future and (institutionalized) forms of governance of science and technology (Hess and Sovacool, 2020). It also focuses on how the expectations for specific emerging technologies can redistribute (or not) relationships among actors and hence reinforce or challenge existing imaginaries.

Borup et al. (2006, p.286) defined *expectations* as "real-time representations of future technological situations and capabilities. [as] wishful enactments of a desired future." They can be viewed as "generative," since they guide activities, provide structure and legitimation, attract interest, and foster investment (Borup et al., 2006a; Van Lente, 1993). Expectations play a role in coordinating actor communities at different levels, circulating among engineers, research centers, and policy circles (Borup et al., 2006a). They can be embedded in dedicated, formal assessments of the future, such as modeling scenarios and forecasting, as well as in elements of ongoing and informal technology assessments, such as grant proposals, presentations, and policy debates. Early expectations are often technologically deterministic, downplaying considerations such as cultural, societal, and organizational factors. The past is also usually downplayed when these expectations emphasize newness.

Expectations for the future development and implications of emerging technologies or framings are rarely presented as neutral statements but instead usually take the form of promises or concerns, implying a positive or negative valuation (te Kulve et al., 2013). *Promises* refer to optimistic expectations regarding the potential role and assumed benefits that may follow from a technology, and they usually require additional work to reach the desired outcomes (Van Lente, 1993). *Concerns* relate to expectations about possible problems and risks involved in the development and application of a technology (te Kulve et al., 2013). Promises help generate initial excitement and enthusiasm about an innovation or trend in hype cycles by creating a sense of possibility and potential benefits (Borup et al., 2006b). They often downplay the many organizational and cultural factors on which a technology's future may depend, leading to disappointment when the promised benefits do not materialize (Borup et al., 2006b). Concerns can anticipate and mitigate the potential cycle of disappointment by prompting critical thinking and action regarding the potential drawbacks and limitations of an innovation. Expectations in the form of promises or concerns shape the present (Joly, 2010; Robinson et al., 2021), since they implicitly or explicitly request resources to realize promised outcomes or measures to avoid disappointment.

The consequences of promises of the future volume of CDR have mainly been explored with regard to integrated assessment models (IAMs) (Anderson and Peters, 2016; Beck and Mahony, 2018; Beck and

[2] In the case of CDR, we refer in particular to the prospect of reducing or delaying the *avoidance* of emissions. Debates over climate adaptation generally refer to the broader concept of *mitigation*.

Oomen, 2021; Fuss et al., 2014; Vaughan and Gough, 2016), where there is general agreement that MD exists. IAMs include supposedly cost-effective technologies, such as BECCS, thereby substituting emission reductions. Thus, the inclusion of CDR in these models implies that reductions do not have to be as large, nor do they have to occur as fast.

This substitution dynamic is amplified by framings and assumptions that make CDR appear particularly attractive (Carton et al., 2023). This includes promises about the volumes of mitigation that can be achieved using CDR, linked to assumptions of technological feasibility and cost-effectiveness that have not been subject to rigorous scientific scrutiny (Beck and Oomen, 2021; Vaughan and Gough, 2016). It can also include promises of co-benefits between addressing climate change and other issues or "time-buying" rationalities for easing the short-term strain for societies and economies on the route to low-carbon transition (Low and Boettcher, 2020). The focus on removal is often embedded in narratives suggestive of novel opportunities and challenges for climate mitigation (Carton et al., 2020).

Despite the uncertainties of technologies and their negative effects on socio-ecological systems being known, such technologies are treated as critical components of mitigation pathways that, it has been argued, constitute a bold bet for the future (Asayama and Hulme, 2019; Fuss et al., 2014; Geden and Löschel, 2017). These assumptions narrow the political trajectory of pathways that are deemed technologically feasible by pre-empting the consideration of pathways based on social or political change (Beck and Oomen, 2021). This risks distracting policymakers and other actors from the mitigation challenge made clear by the Paris Agreement—namely, the need for immediate and radical change across all facets of society (Anderson and Jewell, 2019).

In this paper, we look at how the dynamics of MD studied in distant governance contexts take shape in a national context. We use a sociology of expectations lens to explore not only how actors legitimize CDR but also how they coordinate around the idea as well as express concerns to limit or regulate its role in climate policy.

1.2. CDR developments in Switzerland

The Federal Council (2021) estimated that CDR and CCS will be necessary to counterbalance residual and store hard-to-abate emissions,[3] such as those from waste incineration, agriculture, and certain industrial processes. The Swiss Federal Office for the Environment (FOEN) has estimated that around 7 million tons of CO_2 equivalent (CO_2e) will be removed annually from 2050 onwards—2 million tons domestically and 5 million tons abroad (The Federal Council, 2022). These 7 million tons make up about 16% of current domestic greenhouse gas emissions.[4] The remaining emissions from the international aviation sector might add to that (Federal Office for the Environment (FOEN), 2021). The FOEN noted that the CDR methods with the highest potential include BECCS of biogenic waste from waste incineration plants, biogas plants, and cement plants[5] and DACCS. These methods result in negative emissions by storing emissions underground or in recycled concrete. The Federal Council (2022) stated that "land-based" methods[6] are less likely to be considered, since they do not guarantee durable storage. Locations abroad are being considered for underground storage due to the uncertain capacity and suitability for CO_2 storage of geological structures in Switzerland. To date, these locations include the North Sea and Iceland (The Federal Council, 2020). The detailed exploration and use of underground storage in Switzerland for potential domestic storage is also being considered.

Efforts are also underway to increase the supply of CDR and CCS. In 2022, the Federal Council signed an agreement with operators of waste incineration plants to put at least one CO_2 capture plant into operation by 2030 (The Federal Department of the Environment, Transport, Energy and Communications (DETEC), 2022.).[7] Switzerland is the birthplace of growing businesses on DACCS and mineralization of biogenic CO_2 in concrete. The DACCS company Climeworks raised CHF 600 million in its last equity round, becoming a so-called unicorn—that is, a start- up with a market valuation in excess of CHF 1 billion (ETH Zurich, 2022). The FOEN has signed an agreement with the Climate Cent Foundation, which once collected voluntary contributions from fossil motor fuel importers,[8] to invest CHF 60 million in carbon removal by 2030 (Climate Cent Foundation, 2022).[9]

The Federal Council (2021) stated in its long-term climate strategy that removals should increasingly replace compensation projects. Switzerland has pioneered the implementation of international offsetting projects under Article 6.2 of the Paris Agreement, which forms the basis for trading in greenhouse gas emission reductions ("mitigation outcomes"). The country has established bilateral cooperation with 12 states to develop compensation projects that will allow fossil motor fuel importers to fulfill their obligations and, recently with Iceland and the Netherlands, to collaborate on the development of CDR and CCS (Federal Office for the Environment (FOEN), 2022). Talks on a potential collaboration with Norway have also begun (Ministry of Petroleum and Energy-Norway, 2022).

In June 2023, Swiss citizens voted in favor of the Climate and Innovation Act, which states that Switzerland must achieve net-zero emissions by 2050 (Klima- und Innovationsgesetz, 2022). Initially, proponents demanded a ban on fossil fuels, except where substitution was not technically possible (Gletscher Initiative, 2019). In contrast, the Act states that the consumption of fossil fuels must be reduced as much as technically possible and economically justifiable. Residual emissions by 2050 must be balanced by CDR in Switzerland and abroad. After this year, the amount of CO_2 removed and stored through the application of CDR methods must exceed the remaining GHG emissions, thereby achieving negative emissions.

2. Methods

We used a qualitative research approach employing stakeholder interviews, Swiss parliamentary motion documents, and participant observations for primary data collection.

We conducted 10 preliminary interviews to help guide the research design (see, e.g., Ellis et al., 2011) and conducted participatory observations at seven CDR events organized by academia, the Federal Administration, and CDR companies (See Appendix). Participant observation methods (DeWalt et al., 1998) were used to gain familiarity

[3] The terms "residual emissions" (in German, *Restemissionen*) and "hard-to-abate emissions" (*schwer vermeidbare Emissionen*) are often used interchangeably in the Swiss policy context. In this paper, we refer mainly to residual emissions as those tackled by CDR and to hard-to-abate emissions as those tackled by CCS.

[4] According to the FOEN, the domestic GHG emissions of Switzerland were estimated to be 45.25 CO_2e in 2021.

[5] Swiss cement plants cover some of their energy requirements using waste fuels.

[6] Land-based methods consist of soil carbon sequestration, biochar, afforestation and reforestation, and timber in construction.

[7] The plant is set to have a minimum nominal capacity of 100,000 tons of CO_2 per year and to capture as much CO_2 as the transport, storage, and use conditions allow. It is estimated that around half the emissions from incineration plants originate from biogenic waste.

[8] The Climate Cent Foundation received its funds from a levy of 1.5 centimes per liter on petrol and diesel imports between October 2005 and August 2012.

[9] Importers of fossil fuels are obliged to compensate domestically or abroad for some of the emissions caused by transport. They use, among other things, wood construction projects to comply with their emissons compensation obligation (Klik, n.d). When the next CO_2 law is formulated in 2024, the Parliament will reevaluate sinks or removals that are allowed as part of the compensation instrument.

with the community of CDR practitioners and researchers. To adjust the research question and interviewee pool accordingly, observations were reported in a research diary and used to understand how topics were discussed, which were promoted, and which should be omitted.

We conducted a document search of the Swiss Parliament's website for parliamentary documents concerning CDR methods (See Appendix).[10] The selection included texts containing terms related to CDR (e.g., CO_2 sequestration) and covering CDR methods, even if they were not labeled as such. The search generated 32 documents corresponding to interpellations, postulates, and motions. We coded for recurring themes surrounding CDR's role (e.g., emissions to be removed).

The lead author conducted 20 interviews in 2022 to understand perspectives on the use of CDR for removing Swiss emissions. The main selection criterion was having expertise on CDR and CDR methods as well as on relevant components or sectors whose emissions are supposed to be partially removed through CDR. The CDR methods considered followed the implementation options in the CDR taxonomy of the (IPCC, 2022a). We also included the storage of biogenic CO_2 in recycled concrete, an option being considered in Switzerland (Neustark, 2022; Zirkulit, 2022). We sought to maximize the diversity of perspectives. As such, the interview pool included parliamentarians; employees of the administration at federal, cantonal, and municipal levels; NGO representatives; researchers; and members of the CDR industry as well as sectors interested in balancing emissions with CDR (See Table 1). Consent was obtained from participants to join the research and interviews were conducted anonymously in German or English.

Each interview sought perspectives on (1) the need for and role of CDR in targeting Swiss emissions, (2) CDR methods to be employed, (3) regions where CDR methods should be implemented, and (4) the effect of removal on reduction efforts. In a semi-structured interview format, the interviewer used open-ended questions to allow interviewees to focus on the issues they viewed as important. The interviews were conducted either virtually or face to face and lasted for an average of 1 h.

The interviews were fully transcribed and, with the documents, were coded in English using MAXQDA. We looked for promises about and concerns over CDR as well as how interviewees used these to promote or (de)legitimize CDR, specific CDR methods, and their uses. We focused on what interviewees said, how they said it (e.g., connections made, areas of emphasis) and what this might mean. In the Results section, the interviewees are identified as belonging to research (R), government (G), civil society (S), consulting (C), industry (I), or parliament (P). In the quotations, we use parentheses when editing the language and brackets to provide brief explanations.

Table 1
Background and code for each study participant.

Interviewee	Sector	Area of Expertize/Association	Code
1	Research	Soil carbon sequestration	R1
2	Research	Biochar in construction	R2
3	Research	Technological assessment of CDR methods	R3
4	Research	Bioenergy	R4
5	Research	Sustainable construction	R5
6	Government	Energy	G1
7	Government	CCS and CDR	G2
8	Government	CO_2 compensation	G3
9	City government	Climate and energy policy	G4
10	Cantonal government	Climate and energy policy	G5
11	Civil society	Climate and energy policy	S1
12	Civil society	Climate and energy policy	S2
13	Civil society	Post-growth	S3
14	Industry	CDR company	I1
15	Industry	CDR company	I2
16	Industry	Waste to energy plants	I3
17	Industry	Carbon offsetting of fossil motor fuels	I4
18	Parliament	Swiss People's Party (SVP)	P1
19	Parliament	Green Liberal Party (GLP)	P2
20	Consultancy	Energy research and innovation	C1

[10] The search included the keywords "carbon dioxide removal" OR "negative emissions" OR "compensation" OR "sequestration" OR "sinks" AND "bioenergy with carbon capture" OR "biochar" OR "direct air capture" OR "afforestation" OR "reforestation" OR "enhanced weathering" OR "soil carbon sequestration" OR "ocean fertilization" OR "wood." Afforestation topics were considered only when conducted with anthropogenic interventions.

3. Results

3.1. CDR as indispensable for net zero

In all the interviews and documents, there was promissory discourse on the indispensability of CDR methods in reaching net-zero goals (See Table 2). CDR on an industrial scale was mostly legitimized through its depiction as being a necessity for meeting net-zero targets and, to a lesser extent, for counterbalancing historical emissions. Government interviewees highlighted how the political imperative of achieving net-zero emissions would be much more difficult—or politically impossible—without CDR. Some participants highlighted the need for certain sectors' products and services (e.g., waste management, agriculture, cement) and how CDR and CCS provide the only effective means to counterbalance and reduce, respectively, their emissions, asserting that there are no alternative methods to target them. One interviewee emphasized that CDR or conventional offsetting can be used to increase mitigation ambitions by removing the indirect emissions generated abroad that would not otherwise be targeted (G5). Thus, it can be assumed that CDR is easier to implement than reductions or that it is the only practical way to address certain emissions. The feasibility of CDR in Switzerland can be made more salient by focusing on what is hard to abate rather than having a reduced discussion on what may be difficult to remove or better to abate for reasons that go beyond climate.

A few interviewees countered this, stating that Switzerland should assume mitigation pathways with no or much less CDR by critically evaluating the amount of CDR required to achieve its climate goals (G1, I3, S1, S2, S3, P2). Some stated that there are no funds to counterbalance emissions from certain sectors and that CDR could therefore distract from the necessary reductions (P1). In some CDR group meetings, a few participants reported a desire to reduce the need for CDR.

3.2. CDR as a responsibility of and opportunity for Switzerland

The role of CDR as indispensable for climate policy was enhanced by statements on the responsibility of and opportunities for the country. Some parliamentary documents highlighted the "leading role" that Switzerland can play in exporting technologies and knowhow. At the macro level, this can legitimize engineered CDR as a sector in which the country has already assumed a pioneering role and can benefit from economically. Some asserted that Switzerland, as a wealthy country, has a responsibility to push for CDR developments to accelerate climate action and mitigate indirect and historical emissions (G1, G2, R3, I2, S2, C1)—for example, by replacing compensation achieved under Art 6.2 of the Paris Agreement through removal projects and by balancing some of the federal administration's emissions with CDR. These combined ideas of necessity, responsibility, and opportunity help to establish and strengthen national networks of actors. Switzerland is home to renowned CDR and CCS researchers, multiple carbon offset providers, and leading CDR industry and government actors who coordinate actions to combat climate change and leverage related research and business opportunities.

Table 2
The promises about and concerns over CDR presented in the material we reviewed. Promises legitimize CDR, while concerns limit or regulate its attractiveness and uses.

Category	Promises	Concerns
CDR as indispensable for net zero	• CDR is indispensable to achieve net-zero and negative emissions. • Certain sectors (planning on using CDR) are needed. • Sectors lack effective means to reduce emissions. CDR is easier to implement than reductions.	• Switzerland should assume pathways with less or no CDR, due to material limitations to scale up CDR. • There are insufficient funds for financing removals for certain sectors (e.g., agriculture).
CDR as a responsibility of and opportunity for the country	• CDR represents opportunities for the Swiss industry to export technologies and knowhow. • Switzerland has the responsibility, as a wealthy nation, to make additional efforts in climate mitigation. • Offsets should be replaced by removals in the long term. • The Federal Administration will balance some of its emissions with CDR, leading by example. • Networks of actors can benefit from the research and implementation of Swiss technologies.	• Switzerland should assume pathways with less or no CDR due to MD risks.
CDR as a supplement to reductions	• "Reductions should be first."	• Different expectations for "residual" emissions might lead to a demand for removals that cannot be met. • CDR companies should limit their sales to clients with reduction targets. • The use of fossil fuels should be banned, thereby reducing the amount of CDR needed. • Lack of discussion on CO_2 removal accounting across territories. • CDR companies/ industries lack incentives to push for reductions.
CDR as novel, pragmatic mitigation	• "All methods are needed." • Innovative methods are inspiring models of the way ahead. • Permanent methods are high-quality removals. • Expensive methods reduce substitution dynamics. • Methods can be implemented abroad, where resources to do so are available. • Methods such as soil carbon sequestration, biochar, and timber are readily available and should be used for specific applications.	• Skepticism over CDR companies' promises on the future scale of CDR. • Focus should not be on permanence but on durability, depending on where and in what form the CO_2 is. • Scarcity of resources (e.g., energy) and other challenges to scale up methods. • Skepticism over feasibility of CO_2 export for underground storage. CDR should be constrained within Swiss boundaries.

3.3. CDR as a supplement to reductions

Some interviewees accompanied calls for CDR with the caveat that removals should not hinder efforts to reduce greenhouse gas emissions (G1, G2, G3). The idea of "reductions first" was used in the introductory sentences of interviews, events, and texts. This created a general direction for the use of CDR—for example, "reductions first" was used as a temporal indication of when CDR should be available, situating CDR's role in the future of emissions that "cannot be reduced." "Reductions first" was also used to define the second priority of CDR after emission reduction policies, such as by restricting CDR sales to companies taking part in the Science-Based Targets Initiative. This was also mentioned in interviews to preempt criticism of the use of CDR or to express the necessity of saying this to the public to avoid a backlash over CDR. Thus, these statements legitimized CDR by claiming that it can be applied without causing MD.

While CDR is often promoted as a means of mitigating residual emissions, we observed that this definition is often empty or disputed in practice. Some interviewees acknowledged that there is not yet any definition of what constitutes "residuals," and some expressed concerns regarding the issue of defining and communicating what qualifies as such emissions (G1, G3, I1, I2). Emissions that would ideally be removed include all those remaining by 2050, those from sectors lacking technological alternatives, those from nonpoint sources, those that are too expensive to reduce, and non-fossil fuel emissions. Moreover, expectations of actual emissions to be counterbalanced went beyond the residual sectors imagined by the government, including balancing indirect emissions abroad, balancing emissions from buildings, and temporarily balancing emissions to reach net-zero goals before implementing reduction measures. We observed the participants to be silent about these disagreements and the lack of involvement of actors from the residuals sectors in CDR discussions. One interviewee noted, "I tried many times to say, 'Hey, can we just take a step back and just think about what we really need [emissions to be removed]?'. But it is something that (is not discussed]" (G1).

Thus, while the idea of "reductions first" helps legitimize CDR and give a rough direction for its role in climate policy, it does not coordinate the expectations of the many actors enrolled. Some interviewees highlighted the practical challenges of agreeing on the uses of CDR. A representative of the CDR industry mentioned the lack of consensus among CDR companies on the criteria for selecting customers (I2). A member of the government expressed unease over decisions of accountability (e.g., limited BECCS removals could be accounted for by the municipality where the carbon was captured or the biomass waste originated) (G5). Some mentioned the difficulty of incentivizing reductions within sectors developing BE(CCS), such as waste incinerators (P2, G1) and the cement industry (G1, C1, R5), where higher incineration of biowaste/production of cement would mean a higher amount of removals. Others expressed concern over the involvement of fossil fuel importers in the early support of CDR projects (see section CDR developments in Switzerland).

Stakeholders talked about and reacted to MD issues in very different ways. Some adopted an open attitude, stating that it is risky not to perform mitigation while relying on CDR, describing MD as a thorny issue about which they were vigilant (S1, S2, S3, I3, G4). Similarly, some described it as a systemic issue due to the lack of discussion and coordination between different stakeholders and policy departments (G1, C3). Some avoided the discussion, mentioning that "reductions should come first" and that markets reduce MD risks when the focus lies on permanent methods (G2, I2); some noted that it could be harmful for the reputation of CDR in the early stages of implementation (C3); and some stated that the correction of potential MD risks is not part of their role or within their power (G3, I3).

3.4. CDR as a novel, pragmatic mitigation approach

The interviewees and documents promoted using all methods collectively instead of the one method deemed most effective. In this way, a narrative is created that allows a variety of actors to enroll in the CDR community. Members of the CDR industry avoided devaluing other methods, saying that "all are needed" and that they "do not like criticizing competitors." The participants affirmed that CDR methods need support and flexibility in the early stages of development (G4, I1, I2, I3, I4, R1, R2, R5, S1, S2, C1). Several interviewees noted the field's fledgling status and the many uncertainties involved in some of the CDR methods as reasons not to pick winners too early. Others argued that all methods should be used because every gram of CO_2 removed counts to "minimize the level of desperation in 2050" (C1). They said the emphasis should be on supporting their scale-up and gaining experience through pilots and regulatory sandboxes (C1, R2) instead of focusing on "ideological debates on the merits of carbon (removal) technologies" (C1). Despite the openness they promoted, the interviewees' opinions differed regarding the individual methods that should be supported in the face of the opportunities and challenges identified.

Engineered methods were depicted as the most promising in terms of CDR events and networks. These methods were considered urgent for achieving net-zero emission targets and seen as easier to implement than changing consumer behavior in areas such as flying, waste avoidance, and diet. Their promises to tackle climate change were based on ideas of novelty and expansion potential. The innovative power of DACCS, in particular, was emphasized in the introduction of texts and events by, for example, calling the projects a "milestone in the fight against climate change" and highlighting that they can be implemented in any region with abundant renewable energy. This was emphasized by diverse actors who stated that developing removals abroad is valid because "for the climate, it does not make a difference." These strategies help attract attention to CDR and mobilize resources through events, research projects, and government reports.

Although DACCS was used to legitimize CDR, some participants expressed discomfort around the number of expectations that had "all of a sudden been put on a still very young industry" (I2). While some interviewees affirmed that DACCS might be attractive for certain applications, they cited issues with energy use, costs, and the use of space if scaled up, noting its current contribution to mitigation to be "cosmetic" (G1, G5, R4, R5, I1, I4, S1, S2, S3, C1, P2). In this way, they distanced themselves, at least in private, from the hype dynamics, questioning the role that DACCS will play in balancing Swiss emissions.

Some interviewees advocated for permanence as a key argument to legitimize the choice of engineered methods (G1, G2, G4, G5, I1, I2). In their opinion, permanent methods offer the best quality, have the greatest potential, can be monitored easily, and create a definitive solution to the problem. The potential for land-based removal methods is quite small in Switzerland; they lack permanence and, in the case of biochar, can be a source of contaminants (G2, G3, G4, G5, R2, R3). This was combined with the idea of "reductions first," as some actors argued that expensive methods reduce the likelihood of reduction substitutions. In contrast, others argued that in-depth knowledge of where CO_2 is, the form it takes, and for what it is used are much more important (R5), encouraging the consideration of methods such as soil carbon sequestration and carbon capture and utilization.

Most promissory statements favored using BECCS from waste incineration plants (G1, G2, G4, G5, I2, I3, R2, R3, S1, S2, C1). BECCS coordinates the interests of waste incinerators and governments in reducing emissions and achieving negative emissions to balance a mix of residuals. Thus, CDR methods and CCS are grouped together in projections and the topics of events. Some interviewees argued that capturing CO_2 from point sources offers the greatest potential, since biomass is already being burned and requires some additional infrastructure to capture emissions. Thus, BECCS coordinates the interests of diverse actors and is viewed as one of the least disruptive solutions to help achieve net-zero goals. CCS, which has been strongly criticized in the past, is now within the realm of possibility, with a new narrative and materiality. One interviewee argued that, unlike in the past, the narrative around CCS has distanced itself from the idea of "cleaning fossil fuels," which has allowed CCS to re-enter the arena (C1). Another interviewee noted that CCS could become an interesting offsetting measure as emission compensation for fossil fuel importers in the future. The compensation instrument will last until 2024, at which time it can be re-evaluated.

Despite the optimism toward permanent methods, a few interviewees cautioned against following promises concerning engineered methods and the interests of CDR companies (G1, I1, I2, S1, S2), affirming that "there's not a single company that will [deliver] what it promises" (I1); addressing the economic interests that CDR companies have in removals in contrast to reductions (S2), including the difficulty of incentivizing reductions within sectors developing BE(CCS) (G1, C1, R5, P2); mentioning the lack of standards that guarantee the quality of removals (I2, R5); conceding that there is a lack of resources to pay for expensive removals; and mentioning the enormous material challenges of scaling-up methods (G1, G2, I1, I2, I3, I4, S1, S2, S3, R1, R2, C1). We found that CDR stakeholders were less likely to express disagreement about material limits or technological promises in public than in private spheres.

Land-based methods were also described as attractive for specific applications. Several interviewees and parliamentary documents noted their role as either a temporary (stopgap) measure until engineered methods are ready for use or as a long-term measure (G1, I1, I2, S1, S2, R1, R5, C1), such as for balancing emissions from (past) land-use change and enabling net-zero buildings. In the case of the latter, one interviewee mentioned that land-based methods can be used immediately while cement industries will delay investment in BE(CCS) as long as possible (R5). The use of timber and other types of biomass were mentioned frequently in the interviews and parliamentary documents as a "reduction" (offsetting) method, a substitute for cement, and a removal option. However, some interviewees mentioned that intervention in this area is unnecessary because there is enough demand for timber. We observed that even though the idea of carbon storage in timber mobilizes a broad base of actors, they do not need to invest in coordination with the CDR community to attract resources.

4. Discussion

In this paper, we examined how stakeholder expectations shape the CDR landscape in Switzerland. We explored how efforts to legitimize CDR and anticipate challenges in its development may be contributing to comprehensive decarbonization or its delay. This work contributes to the emerging body of literature examining the ongoing debates and institutionalization processes of CDR in real-world contexts.

Our findings indicate that CDR in Switzerland is legitimized by notions of necessity, opportunity, feasibility, and responsibility. Actors thereby create a repertoire, or "sea of expectations" (Van Lente, 2012), that makes CDR "come alive" by elevating expectations of its pivotal role in the battle against climate change. Similar to the observations made in prior studies (Beck and Oomen, 2021; Low and Boettcher, 2020; Lund et al., 2023), the role of CDR was justified with arguments based on the needs of certain sectors; the assumption that removals are easier to implement or more likely to happen than social change and other alternative forms of abatement; and the opportunities that engineered methods represent, based on the expected scalability of components, and thus the expected volumes from removal and the associated reductions. These legitimization strategies have an effect beyond CDR. For instance, amalgamating CCS and CDR into the same policies and debates serves to integrate CCS, which has long been controversial, into a new narrative (Low and Boettcher, 2020; Schenuit et al., 2023).

These expectations are amplified in Switzerland by the prospect of CO_2 storage abroad, in territories perceived to have the necessary

resources, as well as the country's perceived responsibility as an affluent nation to undertake additional mitigation efforts, thereby "leading by example" (Boettcher, 2020; Boettcher et al., 2023). This matches the image of Switzerland as a strong diplomatic force internationally. In addition, it extends the logics of the current CO_2 compensation scheme by assuming that it is easier to conduct climate projects in countries that supposedly have the resources to do so. Despite these similarities, we observed profound silence on the discourse on possible historical continuities.

Despite the sea of expectations created around CDR, some actors acknowledged that "in terms of growth, none of the methods is there." They also showed skepticism and distanced themselves from some of the promises of CDR promoters by asserting that they might not be delivered. Studies in the sociology of expectations have shown that such attitudes are common and denote an internalization of hype/disappointment cycles (Borup et al., 2006b; Joly and Le Renard, 2021). This contributes to reifying the cycle by anticipating disappointment as a "normal" (almost natural) phase. This view absolves those who promise from their responsibility to make realistic promises, since disappointment is accepted as being part of the game. Joly (2010) and Joly and Le Renard (2021) described the dangers of such developments, arguing that while science and technological innovation have always advanced with promises, there has been a rift in the past 50 years, during which we have entered a "regime of technoscientific promises" that governs science (Joly and Le Renard, 2021). By stating necessity and multiplying unrealistic promises, technology promoters capture large financial resources that create path dependencies (by creating research centers, programs, etc.) that protect certain technologies from democratic scrutiny and debate.

Expectations serve as coordination devices for the actions of many different actors, helping align actors within the CDR community and enrolling new actors. We observed patterns in which scientific knowledge and corporate and political interests reinforce each other in the support of engineered methods to achieve net-zero goals. Our results suggest that discursive tools such as interpretive flexibility over terms and the "and" rhetoric (i.e., "we need reductions *and* removals") facilitate coordination by allowing actors to tailor broad expectations to their needs. Terms such as *residuals* and *hard-to-abate emissions* allow for interpretive flexibility as to what removals and CCS will be available for. Thus, the ambiguity of the terms helps obscure disagreements over what actors consider possible and desirable (Star, 2010). Similarly, ideas such as "we need all methods" reduce perceived competition and attract resources for the whole community, despite disagreements over the actual methods that should be supported. Suggesting that there is room for any solution that can contribute to removing CO_2 levels removes politics from the CDR discussion by wishing away the conflicts that are likely to appear when choosing certain technologies or policies over others (Carton et al., 2023). The characteristics of these expectations go beyond the discursive level because they are translated into laws, research programs, international collaboration agreements, and funding for specific methods.

Efforts to legitimize CDR and coordinate associated activities might create unrealistic expectations for the scale-up of CDR and its role in climate policy. Despite this, our results show that some interviewees anticipated multiple risks that might hinder the contribution of CDR to fast, effective mitigation. Some actors showed skepticism toward CDR companies' promises, acknowledging the multiple challenges in terms of regulations, resources, and practices that may impede the scale-up of CDR methods. We observed a collective effort to avoid the equivalence between the fossil and biotic forms of carbon that have been criticized in other regions (Carton et al., 2021; Geden and Schenuit, 2020; Seddon et al., 2019) by dealing carefully with the complexities of methods in terms of carbon cycles, durability, and substitution dynamics. This also includes steps by some CDR companies to diminish reputation risks by avoiding associations with the fossil fuel industry that have been questioned in the past regarding CCS in Switzerland (L'Orange Seigo et al., 2014; Wallquist et al., 2009). MD appears to have permeated the discourse, influencing how actors perceive risks and design rules to minimize them. This is in line with Bellamy et al. (2021), who noted that the dynamics of substitution in real-world contexts can be different from those in IAMs, since actors are aware of the importance of avoiding trade-offs between reducing emissions in the short term and encouraging future negative emissions.

On the other hand, discursively addressing MD risks might help legitimize CDR without leading to coordinated action to reduce them. Our results show that the idea of "reductions first" is commonly used to communicate the intended role of CDR in climate policy—that is, initiating discussions about CDR by referring to "reductions first" has become the norm. Our results suggest that this helps legitimize CDR by pre-empting criticism of its potential contribution to business as usual. Indeed, some actors suggested that debates on MD are detrimental, since they can erode support for CDR. However, coordination was lacking across the actors regarding what emissions should be reduced and which ones removed. This is consistent with Buck et al. (2023), who argued that no standard definition of "residual emissions" exists; the *need* for certain activities and the impossibility of decarbonizing them are social constructs that respond to groups' priorities and perceptions of what *can* be abated (Lund et al., 2023; Otto et al., 2021). Diverging expectations of the role of CDR can become problematic, since it is unlikely that all expectations for tackling emissions with CDR will materialize (see also Hougaard, forthcoming). This might prevent action in sectors that are not so hard to abate and risks distracting policymakers and others from their mitigation requirements in the present (Vaughan and Gough, 2016).

The positions prioritizing reductions over removals and how they are held explicitly highlight how concerns over MD have become part of the discourse within the CDR community. By dealing reflexively with the risk of MD and either minimizing it or emphasizing the urgency to take it seriously and address it, the CDR community gives the impression that it is under control. Furthermore, because it appears to be a risk that the community scrutinizes, it diverts attention away from questions of whether MD is happening now, how it is happening, and to what extent.

5. Conclusions and recommendations

To address climate change, it is necessary to examine the instances where CDR contributes to achieving or hinders comprehensive decarbonization. Being attentive to the expectations created by promises about and concerns over CDR plays a crucial role in this exploration. Our findings highlight that concerns over MD permeate the CDR discussion and can result in discourses and policies that minimize associated risks. In Switzerland, actors are carefully approaching issues such as methods' carbon cycles and cost-efficiency logics that contribute to the substitution of reductions by CDR in other regions and in IAMs. However, concerns can also have an opposite effect by legitimizing CDR and preventing its scrutiny. Discourses that prioritize reductions over removals, such as the idea of "reductions first," might paradoxically help legitimize CDR but fall short of fostering discussions and coordinating expectations for residual emissions. This, we argue, inadvertently fuels uncritical enthusiasm for CDR, rather than prompting its careful development. The perception of MD as unnecessary or harmful to CDR's reputation further sidetracks from assessing whether MD is occurring and how to mitigate it.

Our findings suggest that while promises are necessary to build support for CDR, they can contribute to MD by depoliticizing the discussion and leading to an overestimation of the potential of CDR methods. Overestimating these methods can lead to MD by attracting competing resources from and delaying the development of alternative measures—such as sufficiency—that might be less constrained by natural, social, and financial resources. The overestimation of CDR can occur through an exclusive focus on what is "hard to abate," which neglects the fact that some emissions might be "hard to remove" and

some resources better invested in reductions than removals. It may also be reinforced by ambiguous expectations over what CDR is available for, which helps to enroll new actors but avoids the question of what is possible and desirable to remove. The tolerance to hype can also contribute to MD risks when the responsibility of technology promoters to keep their promises in check is downplayed. It is therefore important to challenge the assumption that it will be easier to deploy large-scale CDR than it will be to avoid emissions in the first place, and to open up possibilities for alternative measures.

We recommend a thorough discussion to examine the contexts in which the construct of CDR can contribute to the delay of aggressive mitigation as well as the implementation of rules that minimize MD risks. Our data suggest that many of the consequences of the CDR construct for MDs arise from neglecting social dynamics rather than from anyone's active intention. Our results can be used as a stepping-stone to identify crucial areas for discussion, and the critical social sciences can provide further input on structural power dynamics to be targeted for change. Indeed, it has been said that the influence of power and culture on social norms is to people what water is to fish (Bulbeck, 1991; Risseeuw, 1988); that is, it is not intuitive for fish to recognize the water in which they swim. The critical social sciences can help us to see the water (Deutsch et al., 2023).

Funding

This research was funded by an ETH Zurich Research Grant (ETH-10 21-1)

CRediT authorship contribution statement

Juanita von Rothkirch: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Olivier Ejderyan:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Michael Stauffacher:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – original draft, 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.

Data availability

The data that has been used is confidential.

Acknowledgements

We want to thank out interviewees who took the time to engage in this study. Our thanks also goes to Cyril Brunner and Reto Knutti for their support throughout the research process, as well as to the editors and reviewers for their constructive feedback that helped us greatly improve this publication.

Appendix

Parliamentary documents consulted.

1 Baettig, D. (2011) Interpellation 11.3530 Geoengineering gegen Klimaerwärmung. Bewertung der Risiken und der lokalen Auswirkungen
2 Bourgeois, J. (2019) Postulat 19.3639 Kohlenstoffsequestrierung in Böden
3 Brenzikofer, F. (2020) Interpellation 20.4607 Potenzial von Holz zur Erreichung der Klimaziele von Paris
4 Burgherr, T. (2021) Interpellation 21.3883 Wood Waste in unseren Wäldern?
5 Candinas, M. (2021) Interpellation 21.3434 Interpellation CO2-Abscheidung. Die Schweiz zum Technologieführer machen
6 Cathomas, S. (2010) Interpellation 10.3802 CO2-Quellen und -Senken aus der Bodennutzung
7 Eymann, C. (2021) Interpellation 21.3210 Vermeidung von CO2-Emissionen beim Bauen mit Beton
8 Fässler, D. (2019) Interpellation 19.4176 Zukunft der einheimischen Holzversorgung, -verarbeitung und -verwendung
9 FDP-Liberale Fraktion. (2020) Motion 20.4063 Schluss mit der Blackbox. Klimaschutz, Energiesicherheit und Infrastrukturnutzung dank Erforschung des Untergrunds
10 Fischer, R. (2021) - Motion 21.4596 Ausrichtung der Kompensation der Treibhausgasemissionen der Bundesverwaltung auf das Netto-null-Ziel
11 Friedl, C. (2022) - Interpellation 22.4405 Pflanzenkohle in der Landwirtschaft. Wirksamer Einsatz für den Klimaschutz bei korrekter Anwendung
12 Flückiger-Bäni, S. (2009) Interpellation 09.4215 Wald bewirtschaften oder verwalten?
13 Gerhard, A. (2020) Interpellation 20.4724 Interpellation Mit Schweizer Holzbau einen wichtigen Beitrag zur langfristigen Speicherung von CO2 leisten
14 Girod, B. (2008) Interpellation 08.3064 CO2-Sequestrierung in der Schweiz
15 Graf, M. (2009) Postulat 09.3462 Landwirtschaft und Klimawandel. Auswirkungen und Massnahmen
16 Grüter, F. (2020) Interpellation 20.4352 CO2-Rückgewinnung als Teil der Lösung im Kampf gegen den Klimawandel?
17 Herzog, V. (2019) Fragestunde 19.5239 Kehrichtverbrennungsanlagen. Anpacken statt demonstrieren
18 Imark, C. (2021) Interpellation 21.3541 Kehrichtverbrennungsanlagen mit CO2-Rückgewinnungsanlagen ausstatten
19 Karl, V. (2019) Motion 19.4059 Erfolgreiche Investitionen im Untergrund mit der Digitalisierung
20 Klopfenstein Broggini, D. (2021) - Interpellation 21.4538 Bewirtschaftung von organischen Böden. In der Landwirtschaft ist eine strukturelle Veränderung nötig
21 Klopfenstein Broggini, D. (2021) - Interpellation 21.3556 Moore als wichtige Kohlenstoffsenken
22 Klopfenstein Broggini, D. (2021) Motion 21.3750 Agroforstwirtschaft. Im Dienste der Landwirtschaft, des Klimas und der Biodiversität
23 Kommission für Umwelt. (2022) Motion Nationalrat (UREK-NR) 21.4333 Forschung und Entwicklung von Negativemissionstechnologien fördern
24 Matter, T. (2021) Interpellation 21.3982 Strombedarf und Kosten des Gegenvorschlags des Bundesrates zur Gletscher-Initiative
25 Munz, M. (2022) Motion 20.4670 CO2-Sequestrierung in Partnerländern
26 Schaffner, B. (2021) Interpellation 21.4270 Schweizer Anteil am globalen Kohlenstoffbudget und Finanzierung von Korrektur- Massnahmen
27 Stark, J. (2021) Motion 21.3293 Erforschung und Innovation des Werkstoffs Holz für den Einsatz im Infrastrukturbau als Dekarbonisierungs-Beitrag
28 Suter, G. (2020) Motion Negativemissionstechnologien fördern
29 Thorens Goumaz, A. (2018) Postulat 18.4211 Von welcher Bedeutung könnten negative CO2-Emissionen für die künftigen klimapolitischen Massnahmen der Schweiz sein?
30 Vogler, K. (2019) Motion 19.4252 Verbesserung der Rahmenbedingungen für die Nutzung von Mist als Nährstofflieferant und Bodenverbesserer
31 Vonlanthen, B. (2019) Interpellation 19.3231 Klimapolitik. CO2 verschwinden lassen oder sinnvoll verwenden. Welchen Beitrag kann die Schweiz an die Konkretisierung der angekündigten disruptiven technologischen Entwicklungen leisten?
32 von Siebenthal, E. (2021) Motion 21.3355 Erforschung und Innovation des Werkstoffs Holz für den Einsatz im Infrastrukturbau als Dekarbonisierungs-Beitrag

Events attended.

	Event	Date
1	Webinar: “All about wood” - Swiss Carbon Removal Platform	18.11.2021
2	Workshop: Ethical challenges of CDR - Swiss Carbon Removal Platform	09.06.2022
3	Direct Air Capture Summit 2022 – Climeworks (virtual participation)	30.06.2022
4	Stakeholder workshop: Studie zu Negative missions-Technologien (Study on negative emission technologies) - TA-Swiss	01.07.2022
5	Swiss Green Economy Symposium 2022: Innovative Lösungen für Kreislaufwirtschaft und Dekarbonisierung (Innovative solutions for circular economy and decarbonization).	07.09.2022
6	Tagung CO2-Entnahme und -Speicherung 2022 (Session on CO2 Removal and Storage 2022) - Federal Office for the Environment	14.10.2022
7	DeCIRRA Workshop: CO2-Pipeline in der Schweiz: Status und Perspektive (CO2 pipeline in Switzerland: status and prospects)	02.11.2022

References

Anderson, K., Jewell, J., 2019. Debating the bedrock of climate-change mitigation scenarios. Nature 573 (7774), 348–349. https://doi.org/10.1038/d41586-019-02744-9.

Anderson, K., Peters, G., 2016. The trouble with negative emissions. Science 354 (6309), 182–183. https://doi.org/10.1126/science.aah4567.

Asayama, S., 2021. The Oxymoron of Carbon Dioxide Removal: Escaping Carbon Lock-In and yet Perpetuating the Fossil Status Quo. Front. Clim. *3*. https://doi.org/10.3389/fclim.2021.673515.

Asayama, S., Hulme, M., 2019. Engineering climate debt: temperature overshoot and peak-shaving as risky subprime mortgage lending. Clim. Policy 19 (8), 937–946. https://doi.org/10.1080/14693062.2019.1623165.

Beck, S., Mahony, M., 2018. The politics of anticipation: The IPCC and the negative emissions technologies experience. Glob. Sustain. 1, 1–8. https://doi.org/10.1017/sus.2018.7.

Beck, S., Oomen, J., 2021. Imagining the corridor of climate mitigation – What is at stake in IPCC’s politics of anticipation? Environ. Sci. Policy 123, 169–178. https://doi.org/10.1016/j.envsci.2021.05.011.

Bellamy, R., Fridahl, M., Lezaun, J., Palmer, J., Rodriguez, E., Lefvert, A., Hansson, A., Grönkvist, S., Haikola, S., 2021. Incentivising bioenergy with carbon capture and storage (BECCS) responsibly: Comparing stakeholder policy preferences in the United Kingdom and Sweden. Environ. Sci. Policy 116, 47–55. https://doi.org/10.1016/j.envsci.2020.09.022.

The Federal Department of the Environment, Transport, Energy and Communications (DETEC)., 2022.

Biofuelwatch, B.U.N.D. / Friends of the Earth Germany, CCFD - Terre Solidaire, CEO - Corporate Europe Observatory, CIEL - Center for International Environmental Law Corporate Accountability, European Coordination Via Campesina, Fern, Food & Water Action Europe, Friends of the Earth Europe, Friends of the Earth International, Global Forest Coalition, Heinrich Böll Siftung, & IATP - Institute for Agriculture & Trade Policy ReCommon. (2022, November 28). *Real Zero Europe -Statement* . ⟨https://www.realsolutions-not-netzero.org/real-zero-europe⟩.

Boettcher, M., 2020. Coming to GRIPs with NETs Discourse: Implications of Discursive Structures for Emerging Governance of Negative Emissions Technologies in the UK. Front. Clim. 2, 595685 https://doi.org/10.3389/fclim.2020.595685.

Boettcher, M., Schenuit, F., Geden, O., 2023. The formative phase of German carbon dioxide removal policy: Positioning between precaution, pragmatism and innovation. Energy Res. Soc. Sci. 98 https://doi.org/10.1016/J.ERSS.2023.103018.

Borup, M., Brown, N., Konrad, K., Van Lente, H., 2006a. The sociology of expectations in science and technology. Technol. Anal. Strateg. Manag. 18 (3–4), 285–298. https://doi.org/10.1080/09537320600777002.

Borup, M., Brown, N., Konrad, K., Van Lente, H., 2006b. The sociology of expectations in science and technology. Technol. Anal. Strateg. Manag. 18 (3–4), 285–298. https://doi.org/10.1080/09537320600777002.

Brown, N., Rappert, B., Webster, A., 2017. Contested futures: A sociology of prospective techno-science. Routledge,.

Buck, H.J., Carton, W., Lund, J.F., Markusson, N., 2023. Why residual emissions matter right now. Nat. Clim. Change 13, 1–8. https://doi.org/10.1038/s41558-022-01592-2.

Bulbeck, C., 1991. Reviewed Work: Gender Transformation, Power and Resistance Among Women in Sri Lanka: The Fish Don’t Talk About the Water. Pac. Aff. 66 (3), 442–444.

Caldeira, K., Bala, G., & Cao, L.2013. The Science of Geoengineering., Annual Review of Earth and Planetary Sciences *41*, 231–256. ⟨https://doi.org/10.1146/annurev-earth-042711–105548⟩.

Campbell-Arvai, V., Hart, P.S., Raimi, K.T., Wolske, K.S., 2017. The influence of learning about carbon dioxide removal (CDR) on support for mitigation policies. Clim. Change 143, 321–336. https://doi.org/10.1007/s10584-017-2005-1.

Carton, W., 2019. “Fixing” climate change by mortgaging the future: negative emissions, spatiotemporal fixes, and the political economy of delay. Antipode 51 (3), 750–769. https://doi.org/10.1111/anti.12532.

Carton, W., Asiyanbi, A., Beck, S., Buck, H.J., Lund, J.F., 2020. Negative emissions and the long history of carbon removal. Wiley Interdiscip. Rev. Clim. Change 11 (6). https://doi.org/10.1002/wcc.671.

Carton, W., Lund, J.F., Dooley, K., 2021. Undoing equivalence: rethinking carbon accounting for just carbon removal. Front. Clim. *3*. https://doi.org/10.3389/fclim.2021.664130.

Carton, W., Hougaard, I.M., Markusson, N., Lund, J.F., 2023. Is carbon removal delaying emission reductions? Wiley Interdiscip. Rev. Clim. Change 14 (*4*). https://doi.org/10.1002/wcc.826.

Climate Cent Foundation, 2022. Ausschreibung für CCUS/NET-Projekte [Call for proposals for CCUS/NET projects]. ⟨https://www.klimarappen.ch/index.html?lang=en⟩.

Colvin, R.M., Kemp, L., Talberg, A., De Castella, C., Downie, C., Friel, S., Grant, W.J., Howden, M., Jotzo, F., Markham, F., Platow, M.J., 2019. Learning from the climate change debate to avoid polarisation on negative emissions. Environ. Commun. 14 (1), 23–35. https://doi.org/10.1080/17524032.2019.1630463.

Creutzig, F., 2016. Economic and ecological views on climate change mitigation with bioenergy and negative emissions. GCB Bioenergy 8 (1), 4–10. https://doi.org/10.1111/gcbb.12235.

Deutsch, S., Keller, R., Krug, C.B., Michel, A.H., 2023. Transdisciplinary transformative change: an analysis of some best practices and barriers, and the potential of critical social science in getting us there. Biodivers. Conserv. *32*. https://doi.org/10.1007/S10531-023-02576-0.

DeWalt, K.M., DeWalt, B.R., Wayland, C.B., 1998. Participant observation. In: Bernard, H.R. (Ed.), Handbook of Methods in Cultural Anthropology. AltaMira Press, pp. 259–299.

Diaz, S., Settele, J., Brondizio, E., Ngo, H.Guèze, M., Agard, J., Amut, A., & Mayas, C.2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Economy Land and Climate Insight (ELCI), 2021. UK: Joint NGO Statement on Biomass for Net Zero. Institute of Physics Publishing. https://doi.org/10.1088/1748-9326/AAAC88.

Ellis, J., Janjic-Watrich, V., Macris, V., Marynowski, R., Ellis, J., Janjic-Watrich, V., Macris, V., 2011. Using exploratory interviews to Re-frame planned research on classroom issues. Northwest J. Teach. Educ. 9 (1), 1. https://doi.org/10.15760/nwjte.2011.9.1.1.

ETH Zurich 2022. Climeworks raises CHF 600 million. ⟨https://ethz.ch/en/news-and-events/eth-news/news/2022/04/new-eth-unicorn-climeworks-raises-chf-600-million.html⟩.

European Academies Science Advisory Council (EASAC)2022. Forest bioenergy update: bioenergy and its role in integrated assessment models. ⟨https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_BECCS_Commentary_2022_WEB_final.pdf⟩.

Federal Office for the Environment (FOEN)2021. Revision des CO2-Gesetzes: Erläuternder Bericht Zur Vernehmlassungsvorlage.

Federal Office for the Environment (FOEN), 2022. Bilateral climate agreements. ⟨https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/climate–international-affairs/staatsvertraege-umsetzung-klimauebereinkommen-von-paris-artikel6.html⟩.

Fuss, S., Canadell, J.G., Peters, G.P., Tavoni, M., Andrew, R.M., Ciais, P., Jackson, R.B., Jones, C.D., Kraxner, F., Nakicenovic, N., Le Quéré, C., Raupach, M.R., Sharifi, A., Smith, P., Yamagata, Y., 2014. Betting on negative emissions. Nat. Clim. Change 4 (10), 850–853. https://doi.org/10.1038/nclimate2392.

Geden, O., Löschel, A., 2017. Define limits for temperature overshoot targets. Nat. Geosci. 10 (12), 881–882. https://doi.org/10.1038/s41561-017-0026-z.

Geden, O., & Schenuit, F.2020. Unconventional Mitigation Carbon Dioxide Removal as a New Approach in EU Climate Policy. SWP Research Paper 8/2020. Berlin: German Institute for International and Security Affairs.

Gletscher Initiative2019. Der Initiativtext [The Initiative Text]. ⟨https://gletscher-initiative.ch/der-initiativtext⟩.

Hansen, J., Sato, M., Kharecha, P., Von Schuckmann, K., Beerling, D.J., Cao, J., Ruedy, R., 2017. Young people’s burden: requirement of negative CO_2 emissions. Earth Syst. Dyn. 8 (3), 577–616. https://doi.org/10.5194/esd-8-577-2017.

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

Hess, D.J., Sovacool, B.K., 2020. Sociotechnical matters: Reviewing and integrating science and technology studies with energy social science. Energy Res. Soc. Sci. 65 https://doi.org/10.1016/j.erss.2020.101462.

IPCC 2022c. Summary for Policymakers. In P.R. Shukla, J. Skea, A. Reisinger, R. Slade, R. Fradera, M. Pathak, A. Al, K. Malek, B. Renée Van Diemen, A. Hasija, G. Lisboa, S. Luz, J. Malley, D. Mccollum, & S. Some (Eds.), *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. ⟨www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf⟩.

IPCC2022a. Climate Change 2022: Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (J.M.P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, Ed.). Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: ⟨10.1017/9781009157926⟩.

IPCC, 2018. Annex I: Glossary. In J.B.R. Matthews (Ed.), Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change… (pp. 541–562). Cambridge University Press. ⟨https://doi.org/10.1017/9781009157940.008⟩.

Hougaard, I.M., 2024. Enacting biochar as a relevant climate intervention in Denmark. Environmental Science and Policy 152. https://doi.org/10.1016/j.envsci.2023.103651.

Jasanoff, S., Kim, S.H., 2015. Dreamscapes of modernity: Sociotechnical imaginaries and the fabrication of power. University of Chicago Press.

Jebari, J., Táíwò, O.O., Andrews, T.M., Aquila, V., Beckage, B., Belaia, M., Clifford, M., Fuhrman, J., Keller, D.P., Mach, K.J., Morrow, D.R., Raimi, K.T., Visioni, D., Nicholson, S., Trisos, C.H., 2021. From moral hazard to risk-response feedback. Clim. Risk Manag. *33*. https://doi.org/10.1016/j.crm.2021.100324.

Joly, P.B., 2010. On the economics of techno-scientific promises. In: Akrich, A., Barthe, Y., Muniesa, F., Mustar, P. (Eds.), Débordements.Mélanges offerts à Michel Callon. Presse des Mines, pp. 203–222.

Joly, P.B., Le Renard, C., 2021. The past futures of techno-scientific promises. Sci. Public Policy 48 (6), 900–910. https://doi.org/10.1093/scipol/scab054.

te Kulve, H., Konrad, K., Alvial Palavicino, C., Walhout, B., 2013. Context matters: promises and concerns regarding nanotechnologies for water and food applications. NanoEthics 7 (1), 17–27. https://doi.org/10.1007/s11569-013-0168-4.

L'Orange Seigo, S., Arvai, J., Dohle, S., Siegrist, M., 2014. Predictors of risk and benefit perception of carbon capture and storage (CCS) in regions with different stages of deployment. Int. J. Greenh. Gas. Control 25, 23–32. https://doi.org/10.1016/J.IJGGC.2014.03.007.

Lamb, W.F., Mattioli, G., Levi, S., Timmons Roberts, J., Capstick, S., Creutzig, F., Minx, J. C., Müller-Hansen, F., Culhane, T., Steinberger, J.K., 2020. Discourses of climate delay. Glob. Sustain. 3, 1–5. https://doi.org/10.1017/sus.2020.13.

Low, S., Boettcher, M., 2020. Delaying decarbonization: climate governmentalities and sociotechnical strategies from copenhagen to Paris. Earth Syst. Gov. *5*. https://doi.org/10.1016/j.esg.2020.100073.

Lund, J.F., Markusson, N., Carton, W., Buck, H.J., 2023. Net zero and the unexplored politics of residual emissions. Energy Res. Soc. Sci. 98, 103035 https://doi.org/10.1016/J.ERSS.2023.103035.

Markusson, N., McLaren, D., Tyfield, D., 2018. Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs. Glob. Sustain. *1*. https://doi.org/10.1017/SUS.2018.10.

McLaren, D., 2016. Mitigation deterrence and the "moral hazard" of solar radiation management. Earth's Future 4 (12), 596–602. https://doi.org/10.1002/2016EF000445.

Merk, C., Pönitzsch, G., & Rehdanz, K.,2018. Do climate engineering experts display moral-hazard behaviour? *19*(2), 231–243. *Climate Policy, 19* . ⟨https://doi.org/10.1080/14693062.2018.1494534⟩.

Ministry of Petroleum and Energy-Norway 2022. How can Switzerland and Norway cooperate on CCS? ⟨https://www.regjeringen.no/en/aktuelt/how-can-switzerland-and-norway-cooperate-on-ccs/id2948552/⟩.

Minx, J.C., Lamb, W.F., Callaghan, M.W., Fuss, S., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., De Oliveira Garcia, W., Hartmann, J., Khanna, T., Lenzi, D., Luderer, G., Nemet, G.F., Rogelj, J., Smith, P., Vicente Vicente, J.L., Wilcox, J., Del Mar Zamora Dominguez, M., 2018. Negative emissions - Part 1: Research landscape and synthesis. Environ. Res. Lett. 13 (6) https://doi.org/10.1088/1748-9326/aabf9b.

Morrow, D.R., 2014. Ethical aspects of the mitigation obstruction argument against climate engineering research. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. *372*. https://doi.org/10.1098/RSTA.2014.0062.

Neustark. (n.d.). *Neustark: co2ncrete* solutions today. Retrieved November 26, 2022, from ⟨https://www.neustark.com/⟩.

Oomen, J., 2021. Imagining climate engineering. Imagining Climate Engineering. Routledge. https://doi.org/10.4324/9781003043553.

Otto, D., Thoni, T., Wittstock, F., Beck, S., 2021. Exploring narratives on negative emissions technologies in the Post-Paris era. Front. Clim. 3, 103. https://doi.org/10.3389/FCLIM.2021.684135/BIBTEX.

Perlman, K.2022. BECCS: No time for false saviours. One Earth. ⟨https://www.oneearth.org/beccs-no-time-for-false-saviours/⟩.

Realmonte, G., Drouet, L., Gambhir, A., Glynn, J., Hawkes, A., Köberle, A.C., Tavoni, M., 2019. An inter-model assessment of the role of direct air capture in deep mitigation pathways. Nat. Commun. 10 (1), 1–12. https://doi.org/10.1038/s41467-019-10842-5.

Reynolds, J., 2014. A critical examination of the climate engineering moral hazard and risk compensation concern. Anthr. Rev. 2 (2), 174–191. https://doi.org/10.1177/2053019614554304.

Risseeuw, C.,1988. Gender Transformation, Power and Resistance Among Women in Sri Lanka: The Fish Don't Talk About the Water. In *Pacific Affairs* (Issue 3). Manohar Publications. ⟨https://doi.org/10.2307/2759647⟩.

Robinson, D.K.R., Audétat, M., Joly, P.-B., Van Lente, H., 2021. Enemies of the future? Questioning the regimes of promising in emerging science and technology. Sci. Public Policy 48 (6), 814–817. https://doi.org/10.1093/scipol/scab055.

Schenuit, F., Böttcher, M., & Geden, O.2023. "Carbon Management": Opportunities and risks for ambitious climate policy. SWP Comment, No. 29/2023, Stiftung Wissenschaft und Politik (SWP), Berlin, ⟨https://doi.org/10.18449/2023C29⟩.

Seddon, N., Sengupta, S., García-Espinosa, M., Hauler, I., Herr, D., & Rizvi, A.R.2019. Nature-based Solutions in Nationally Determined Contributions: Synthesis and recommendations for enhancing climate ambition and action by 2020.

Sendroiu, I. (forthcoming). "An exciting future is one click away": Mitigation deterrence and carbon dioxide removal suppliers. *Environmental Science and Policy*.

Smith, P., Davis, S.J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R.B., Cowie, A., Kriegler, E., Van Vuuren, D.P., Rogelj, J., Ciais, P., Milne, J., Canadell, J. G., McCollum, D., Peters, G., Andrew, R., Krey, V., Yongsung, C., 2016. Biophysical and economic limits to negative CO_2 emissions. Nat. Clim. Change 6 (1), 42–50. https://doi.org/10.1038/nclimate2870.

Star, S.L., 2010. This is not a boundary object: reflections on the origin of a concept. Sci. Technol. Hum. Values 35 (5), 601–617. https://doi.org/10.1177/0162243910377624.

Suckert, L., 2022. Back to the future. sociological perspectives on expectations, aspirations and imagined futures. Eur. J. Sociol. 63 (3), 393–428. https://doi.org/10.1017/S0003975622000339.

The Federal Council2020. Von welcher Bedeutung könnten negative CO2-Emissionen für die künftigen klimapolitischen Massnahmen der Schweiz sein? [Of what significance could negative CO2 emissions be for Switzerland's future climate policy measures?]. September, 1–29.

The Federal Council2021. Switzerland's Long-Term Climate Strategy.

The Federal Council2022. *CO2* -Abscheidung und Speicherung (CCS) und Negativemissionstechnologien (NET): Wie sie schrittweise zum langfristigen Klimaziel beitragen können [Carbon Capture and Storage (CCS) and Negative Emission Technologies (NET): How they can gradually contribute to the long-term climate goal].

United Nations Framework Convention on Climate Change (UNFCCC), 2016 The Paris Agreement. ⟨https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf⟩.

Van Lente, H.,1993. Promising Technology. The Dynamics of Expectations in Technological Developments. Twente University Press.

Van Lente, H., 2012. Navigating foresight in a sea of expectations: lessons from the sociology of expectations. Technol. Anal. Strateg. Manag. 24 (8), 769–782. https://doi.org/10.1080/09537325.2012.715478.

Vaughan, N.E., Gough, C., 2016. Expert assessment concludes negative emissions scenarios may not deliver. Environ. Res. Lett. 11 (9) https://doi.org/10.1088/1748-9326/11/9/095003.

Wallquist, L., Visschers, V.H.M., Siegrist, M., 2009. Lay concepts on CCS deployment in Switzerland based on qualitative interviews. Int. J. Greenh. Gas. Control 3 (5), 652–657. https://doi.org/10.1016/J.IJGGC.2009.03.005.

Zirkulit. (n.d.). Zirkulit: Der erste zirkuläre Beton. Retrieved November 26, 2022, ⟨https://zirkulit.ch/⟩.