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Research article

Delaying decarbonization: Climate governmentalities and sociotechnical strategies from Copenhagen to Paris

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ABSTRACT

An era (2005–2015) centered around the Copenhagen Accord saw the rise of several immature sociotechnical strategies currently at play: carbon capture and storage, REDD+, next-generation biofuels, shale gas, short-lived climate pollutants, carbon dioxide removal, and solar radiation management. Through a framework grounded in governmentality studies, we point out common trends in how this seemingly disparate range of strategies is emerging, evolving, and taking effect. We find that recent sociotechnical strategies reflect and reinforce governance rationalities emerging during the Copenhagen era: regime polycentrism, relative gains sought in negotiations, 'co-benefits' sought with other governance regimes, 'time-buying' or 'bridging' rationalities, and appeals to vulnerable demographics. However, these sociotechnical systems remain conditioned by the resilient market governmentality of the Kyoto Protocol era. Indeed, the carbon economy exercises a systemic structuring condition: While emerging climate strategies ostensibly present new tracks for signalling ambition and action, they functionally permit the delaying of comprehensive decarbonization.

1. Introduction

In 2005, a long-brewing sea change in global climate governance became visible. The Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) formally began negotiations for an agreement needed to succeed 1997's Kyoto Protocol. Now, a combination of historic grievances and contemporary challenges would swiftly stall progress on a new agreement. A large literature recounts how these efforts culminated disastrously at the 2009 COP in Copenhagen, and were resurrected with guarded optimism through the 2015 Paris Agreement (e.g. Falkner, 2016).

Many works have traced the history of climate governance in terms of institutions, negotiation agendas, and factional interests (e.g. Gupta, 2010), or hidden dynamics underlying more visible activities and alignments (e.g. Aykut, 2016). This paper is situated within the latter, and poses an account of recent climate governance as a history of emerging sociotechnical strategies designed to address climate change (e.g. Markusson et al., 2017). We focus on a 'Copenhagen' era (2005–2015) centered around the 2009 Copenhagen Accord, but that we stretch to include its negotiation, as well as evolution into the Paris Agreement.

The Copenhagen era saw the rise or consolidation of a range of sociotechnical climate strategies currently at play: carbon capture and storage (CCS), the forest emissions crediting mechanism of REDD+, next-generation biofuels, shale gas, short-lived climate forcing pollutants (SLCPs), solar radiation management (SRM) as a kind of 'climate engineering', and carbon dioxide removal (CDR) as novel carbon sinks. In this paper, we present an interpretative review of secondary literature, through a framework grounded in governmentality studies, to explore common trends in how this seemingly disparate range of strategies is emerging, evolving, and taking effect.

We make three arguments. Firstly, recent sociotechnical strategies reflect and reinforce governance rationalities emerging during the post-Kyoto Copenhagen era. Secondly, distinct characteristics link various sociotechnical systems to each other, and to the resilient market governmentality of the Kyoto era. Thirdly, the carbon economy exercises a systemic structuring condition. While emerging climate strategies ostensibly present new tracks for signalling ambition and action for reducing some palette of greenhouse gas emissions, they functionally permit the delaying of comprehensive decarbonization.

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The following section outlines our conceptual framework, synthesizing insights from governmentality studies in global environmental governance, science and technology studies (STS), and critical political economy. Section 3 details our analytical approach. Sections 4 and 5 assess the fit between the Copenhagen era's governmentalities and sociotechnical climate strategies in a two-part analysis – section 4 maps the strategies sequentially, while section 5 steps back to map overarching relationships between these strategies in their rationales and practices. Section 6 concludes that as we move into the implementation of the Paris Agreement, understanding how climate strategies are shaped by persistent structuring conditions may help to develop guardrails to avoid repeating past mistakes.

2. Conceptual framework: Sociotechnical strategies, governmentalities, and 'fixing'

Following STS, we refer to various Copenhagen-era strategies as 'sociotechnical' infrastructures that combine technological hardware with the software of societal contexts, beliefs, and choices. 'Sociotechnical strategies' is a terminological compromise on two counts. We recognize that what we call sociotechnical (e.g. carbon markets) includes socio-ecological (e.g. forestry management) practices, and that 'strategies' is an imperfect attempt to capture a mix of scaled (e.g. shale gas), immature (unscaled beyond the project level, e.g. CCS), and imagined systems or interventions (e.g. SRM).[1] But our focus is not on precise types, stages, or scales. Rather, what bridges these strategies across their scales of implementation is their unfinished nature, and despite this – or possibly, because of it – their reified roles in climate discourse and policy.

This brings us into contact with the STS literature on 'expectations' (Brown et al., 2000) and a more recent one on 'sociotechnical imaginaries' (Jasanoff and Kim, 2015), which highlight the forcefully promissory nature of envisionings and projections of a technology's future. The latter, following Jasanoff's (2004) idiom of 'co-production', argues that polities design technological systems to mirror what they desire societally. Building on initial explorations of how these concepts can be applied to limited suites of climate strategies (e.g. Hansson, 2011; Markusson et al., 2017), we expand the scope of inquiry to the recent history of climate governance, and to tie them to that era's structuring rationalities (a comparable effort is McLaren and Markusson, 2020).

Here, we refer to 'governmentality', a Foucauldian concept describing the logics and practices by which societies make themselves subject to control. Governmentality studies expand the climate governance literature's purview from states and institutions to strategies and practices dispersed at multiple levels (Okerere et al., 2009), and explore these activities as reflections of systemic understandings that coordinate governing of the climate, the market, polities, and even the individual (Stripple and Bulkeley, 2014, eds.).

We therefore see governmentalities as ensembles of climate governance rationalities, institutions, and strategies – in this paper, our main focus is on emerging rationalities, and how these condition sociotechnical strategies. Governmentalities and Jasanoff's 'imaginaries' overlap; both reflect some overarching rationality that manifests, respectively, as systems of (environmental) governance or techno-science. Our paper reflects a connection of these literatures. Indeed, governmentality and STS studies are part of the same wave of exchange between global governance studies and critical disciplines, and both governmentality (Stripple and Bulkeley, 2014, eds.) and STS (Miller, 2004; Hulme and Mahony, 2010) approaches encourage the analyst to be aware of the rationales and processes by which 'climate change' – as a problem and adjoining solutions – is constructed.

We speak to governmentalities that came to animate climate governance in the extended period surrounding the 2009 Copenhagen Accord (2005–2015). We rely on seminal work by Bäckstrand and Lövbrand (2006, 2016), who describe how Kyoto-era forest projects reflected discourses that remained resonant as political rationalities long into the Copenhagen era. Two of these retain importance in our paper's account: *'green governmentality'* describes the globally-focused and managerial rationality that underpinned the formation of the Intergovernmental Panel on Climate Change (IPCC), the UNFCCC, and the Kyoto Protocol; coupled with *'ecological modernization'*, the socialization of environmental governance within neoliberal market logics (ibid).

Over a decade, Kyoto's governmentalities morphed to account for the evolving demands of global politics. The shift in the regime's emphasis from operationalization of the Kyoto Protocol (1997–2007) to the Copenhagen era's search for a post-Kyoto framework was marked by numerous adjoining challenges: the rise of emerging economies; the US withdrawal from Kyoto in 2001; the erosion of multilateralism in post 9/11 geopolitics; the financial crisis of 2007–2009 (Ciplet et al., 2015). In the leadup to the Copenhagen COP - where a post-Kyoto framework was to have been agreed upon - it was clear that collective confidence in the UNFCCC had broken down. Key issues included global targets, a redrawing of where responsibilities for emissions reductions would now lie, and issues of finance and adaptation in most vulnerable states; with a fragmenting global politics and austerity-driven lack of resources hanging over the regime (Gupta, 2010; Held and Roger, 2018). Layering Bäckstrand and Lövbrand's papers with concurrent analyses, we note that both governmentalities began to converge upon a set of overlapping characteristics that is still being cemented today.

'Green governmentality'- the Kyoto-era's regulatory, top-down, compliance-based logic - was rooted in a post-1970s tradition of centralized environmental regime design. With the Kyoto Protocol's failings increasingly exposed, and short on resources and attention, pre-Copenhagen COP negotiations pivoted from 'making Annex I larger' towards voluntary, non-binding, 'nationally determined' efforts (Held and Rogers, 2018). This arrangement attracted support from states on either side of the Annex I divide. The ensuing 2009 Copenhagen Accord is recognized today as the in-between stage that was tweaked and formalized as the 2015 Paris Agreement's pledge-and-review system (ibid; Falkner, 2016). This evolution reflects the fragmentation of climate governance towards what has been problematized as 'a regime complex' (Keohane and Victor, 2011), 'polycentricism' (Dorsch and Flachsland, 2017), or a 'global fractal' (Bernstein and Hoffmann, 2019). Discussion mirrored discourse of the era, still familiar today: 'coalitions of the willing', as well as all manner of public-private and multi-level networks. But its potentials, then as now, were in flux. For some, Kyoto's logics had always needed to cater to more plural perspectives, sites, and activities than could be managed by an IPCC-UNFCCC duopoly (Prins and Rayner, 2007). For others, the cloud overshadowed the silver lining, with Copenhagen representing an 'enhanced status quo [in which] states did what they were willing' (Held and Roger, 2018) in a system of 'shared unaccountability' (Ciplet and Roberts, 2017).

Broadening the sites and objectives of post-Kyoto governance in a time of austerity also multiplied the rationalities by which the Copenhagen-era regime was kept alive. Dovetailing with the trend

[1] Using 'strategies' might connotate agency, or deliberate intent by particular agents, rather than the 'systemic structural conditioning' referenced in the introduction. This is not our intent: We could also have used neutral terms like 'practices' or 'activities', but chose a more overarching term commensurate to the scale of global climate policy. We also do not intend to come down definitively on either side of the agent-structure debate. This paper *emphasizes structures* and how choices and actions to address climate are thereby conditioned, but climate governance is a fluid interplay between the two.

towards polycentrism, there was an escalation of ‘co-benefits’ sought between addressing climate change and other governance issues, regimes, and sectors – from energy and food security, to land-use forestry, to air pollution and health (Bäckstrand and Lövbrand, 2016; Bain et al., 2015; with Mayrhofer and Gupta, 2016 indicating this was a wider governance trend). Relative gains were sought to sustain the negotiations agenda at the UNFCCC (Dimitrov, 2010; Khan and Roberts, 2013). Rationalities on the value of ‘bridging’ and ‘time-buying’ options began to solidify, ranging from transitional fuels that might temporarily substitute for high-carbon fuels on route to renewables, to wider strategies that might reduce climate impacts and allow room for polities and economies to adapt and transition in the near term (Buck et al., 2020). Appeals to an array of nongovernmental stakeholders and to the world's ‘most vulnerable’ became an increasing anchor for relevance and legitimacy (Bäckstrand and Lövbrand, 2016).

‘Ecological modernization’ converged upon the same characteristics. The marrying of economic imperatives and environmental ambitions through the Kyoto Protocol's carbon-accounting and trading ‘flexible mechanisms’ (e.g. emissions trading schemes and the Clean Development Mechanism, CDM) took on the trappings of emerging ‘green economy’ conversations, emphasizing low carbon transitions as part of co-benefits with health and energy security, to be executed by an ecosystem of clubs and networks, and with increased reference to civil society and ‘the most vulnerable’ as part of the new polycentricism (Bäckstrand and Lövbrand, 2016). It remains unclear if and how market governmentalities (Hajer, 1995; Bernstein, 2001; Paterson & P-Laberge, 2016) are adapting outward from Kyoto's focus on carbon accounting and trading. Michaelowa, Shishlov and Brescia (2019) notes that carbon markets have not, since a 2012–2014 crash due to the financial crisis, excess credits, and low governmental support, recovered in visibility. ‘Ecological modernization’ might be ripe for a new mode that prioritizes low-carbon transitions. Yet, for many, the long-term trend is less optimistic: because the Paris Agreement institutionalizes the ‘voluntarism’ of Copenhagen, market mechanisms, reliance on private sector funding, innovation-facing rhetoric coupled with regulatory softening, and club-based decision-making can only intensify (Bernstein et al., 2010; Krüger, 2017; Ciplet and Roberts, 2017; Blum and Lövbrand, 2019).

The prevalence of both governmentalities is reflected in various literatures. The top-down, regulatory model of Kyoto is broadly acknowledged (Gupta, 2010; Held and Roger, 2018), and came to be the subject of critique as action endemically fell short of pledges (Prins and Rayner, 2007); the potentials of a turn towards polycentric governance remains debated (Ciplet and Roberts, 2017; Bernstein and Hoffmann, 2019). The market rationality in climate governance reflecting carbon capitalism as a hegemonic social system (Oels, 2005; Lövbrand and Stripple, 2011) is also the subject of liberal environmentalism, which explores norms (Bernstein, 2001), and climate capitalism or commodification, reflecting a vast political economy literature on carbon's marketization (Paterson & P-Laberge, 2016).

A characteristic of these governmentalities – particularly ‘ecological modernization’ – is not tackled by Bäckstrand and Lövbrand, but is the subject of literatures grounded in critical strands of geography, political economy, and STS. Emerging strategies – for example, novel carbon sinks, or sunlight reflection methods – are argued to present systemic disincentives for reducing emissions (McLaren, 2016) or reflect politics and discourses of delay (Carton, 2019; Lamb et al., 2020), by acting as ‘fixes’ for the carbon economy and its preferred modes of climate governance (Markusson et al., 2018; McLaren and Markusson, 2020). McLaren et al. (2019) issues a provocation to inquire after these structural imperatives beyond recent debates on ‘climate engineering’; this forms a strong motivation behind our study. According to this perspective, the animating logic of numerous climate governance strategies has arguably been to provide a functional, short-term ‘technical fix’: to circumvent deep-lying societal and economic structures through technical or biophysical solutions (Nightingale et al., 2019; an original definition comes from Weinberg, 1966). Such fixes, in effect, prolong the systemic ‘lock-in’ of the carbon economy at a variety of sites and scales (Unruh, 2000; Urry, 2014; Røttereng, 2018; Nightingale et al., 2019).

A number of recent works build on Harvey's (1982) interpretation, which considers how ‘spatio-temporal’ fixes ‘reconfigure geographies’ to delay global capitalism's tendencies toward crises. Carton (2016) makes the case for carbon markets as an exemplary fix, and notes that carbon removal and sunlight reflection suites of climate engineering similarly promise to ‘slow the rate of decarbonization’ (Carton, 2019). Markusson et al.’s (2018) ‘cultural political economy’ model makes significant contributions. New fixes (e.g. novel carbon sinks) are arguably conditioned by and preserve the rationalities of pre-existing ones (e.g. carbon accounting and trading); moreover, the promissory nature of an imagined sociotechnical system, as much as implemented, scaled-up systems, can play as great a role in reflecting, legitimizing, and entrenching market environmentalism (ibid). Røttereng (2018) calls this ‘symbolic signalling’, where new tracks of signaled ambition substitute for actual implementation. The array of imagined and immature strategies of the Copenhagen era can, following Carton (2019), thus be seen as a ‘mobilization of the future to legitimise and reproduce the present’ (p.764).

Literatures on ‘lock in’ and ‘fixes’ follow critical (often, post-Marxist) traditions, but we see value in a looser adherence to their generalizable insights, and seek a working definition to that effect. We note several intersecting criteria through which a sociotechnical strategy – imagined, immature, or scaled – can embodying logics of fixing. Firstly, a fixing strategy primarily maintains infrastructures and rationalities for the exploitation and usage of carbon resources, often referencing the pragmatism of avoiding or easing profound changes to the carbon economy. Examples range from the sectoral to the systemic; in later sections, we specify ground-level, tangible examples whenever possible. Secondly, sociotechnical strategies can be as operative through framings (via projections and promises), as through implementation in industry practice or institutionalization in governmental policy (Markusson et al., 2017; Røttereng, 2018; Carton, 2019). Thirdly, strategies benefit from dovetailing with dominant market-facing rationalities entrenched during Kyoto Protocol era. Carbon accounting and trading mechanisms in particular, and certain emerging fuels and technologies, became or are becoming prominent because they are calculated as cost effective, and create additional opportunities for hype and the accumulation and redistribution of capital (ibid). Fourthly, fixing strategies perform two kinds of ‘substitutions’ in climate ambitions. One presents nearer-term opportunities for the reduction of a palette of greenhouse gases (GHG), emerging proxies defined by global temperature increase, or kinds of climate-related harms – but that functionally put off strategies for long-term, comprehensive reductions in the use of conventional carbon fuels. The other comes from the emergence of seeking co-benefits with other areas of governance: success no longer stems solely from achieving goals and metrics defined by the climate regime, but from a hazier balance of interests between dilemmas and trilemmas of global issues.

Drawing upon these works, we developed a set of preliminary analytical concepts, as outlined in Table 1, to conduct a consolidative mapping of how governance rationalities and logics of fixing manifested in sociotechnical strategies geared towards climate governance between 2005 and 2015. The following section outlines our

Table 1
Emerging rationalities from Kyoto to Copenhagen eras.

Governmentalities of Kyoto era	Emerging rationalities in the Copenhagen era		'A fixing strategy …'
	Polycentrism or fragmentation of climate governance in a time of austerity; reflects wider governance trends	Rationalities overlap and reinforce each other in ways specific to each sociotechnical strategy – see section 4, table 2.	… primarily maintains infrastructures and rationalities for the exploitation and usage of carbon resources, often referencing the pragmatism of avoiding or easing profound changes to the carbon economy.
Green Governmentality: a post-1970s tradition of centralized and managerial environmental regime design	*Co-benefits* with economy and development, energy and food security, forestry, air pollution		… is operative through projections and promises as well as implementation in industry practice or institutionalization in governmental policy.
Ecological modernization: cost-effective, market facing climate governance based on offsets and credit trading	*Time-buying*: easing carbon transitions, dampening near-term climate impacts, catalyzing more deep-lying mitigation		… benefits from dominant market-facing rationalities entrenched during Kyoto era.
	Relative gains: lower-hanging fruit on the negotiations agenda to sustain momentum		… presents nearer-term opportunities for the reduction of GHG or emerging proxies harms – but that functionally delays deep-lying mitigation.
	Appeals to vulnerable demographics and civil society as anchors for legitimacy		… no longer needs to mark success solely from achieving climate goals and metrics, but from a hazier balance of interests between global issues.

Column 1 describes two governmentalities (ensembles of governance rationalities and sociotechnical strategies) of the Kyoto Protocol era (Bäckstrand & Lövbrand, 2006; 2016). Column 2 describes emerging rationalities in the Copenhagen era, emphasizing that these are not mutually exclusive, and reinforce each other in ways specific to different sociotechnical strategies. Column 3 describes elements of 'fixing' the carbon economy, or carbon 'lock-in' that can be embodied by entwined governance rationalities and sociotechnical strategies.

iterative analytical approach before the results of our analysis are presented.

3. Analytical approach: Interpretative review

For our mapping of the ways in which governance rationalities and logics of fixing manifested in sociotechnical strategies between 2005 and 2015, we conducted an interpretive review of a broad range of secondary analyses – qualitative, multidisciplinary interrogations of the emergence and implications of more limited groupings of strategies (for example, on biofuels alone, or carbon sinks). We sourced these materials via a keyword search of Google Scholar using the general search terms 'sociotechnical strategies', 'sociotechnical systems', 'climate strategies', 'climate governance strategies', and 'climate technologies', as well as search terms specific to each strategy or system (Kyoto's flexibility mechanisms, CCS, REDD+, next generation biofuels, shale gas, SLCPs, CDR, SRM). Analyses on conventional fossil fuels, renewables like solar, wind, and geothermal, energy efficiency, conventional and novel nuclear, and adaptation strategies provided valuable context, but do not form the bulk of analysis. Our data collection process was based on the principle of 'theoretical sampling' borrowed from Grounded Theory (Glaser and Strauss, 1967). According to this principle, data is collected in parallel to analysis and continues until 'theoretical saturation' is reached – the point at which all analytical concepts are well-represented and the addition of new materials begins to reiterate the same information (ibid). We do not claim that this process resulted in a comprehensive meta-review of all literature on this topic. Rather, we present an interpretative review which critically explores how synthesizing insights from governmentality, STS, and political economy can contribute to understanding the emergence and evolution of sociotechnical climate strategies.

Our interpretative review process involved both authors independently undertaking a structured reading of the articles included in the analysis on the basis of the preliminary analytical concepts (Table 1). The review was an iterative process, with the analytical categories being revisited and consolidated as the analysis progressed. Specifically, we mapped how governance rationalities and logics of fixing were reflected in the ways various sociotechnical proposals were framed as part of assessments, projections, and promises; and where relevant, how they were implemented in partially-scaled systems, or institutionalized on resonant policy platforms. We inquired after how the means and ends of a particular system were conceptualised at their upstream stages (e.g. Brown et al., 2000). In doing so, we asked after their promissory roles in climate politics – how sociotechnical proposals backed an envisioned state of climate governance, and how that envisioning was recursively used to rationalize technological development. As an indicator of where certain rationalities and logics became comparatively resonant, we noted if they came to undergird existing policy platforms or projects and infrastructures in the process of being scaled up. Based on the mapping of these individual elements, we then asked if and how these emerging sociotechnical strategies reflected the governmentalities of the Copenhagen era. The following section details the results of this interpretative review process.

4. Analysis: Sociotechnical strategies of the Copenhagen era

In what follows, we undertake a two-part analysis. Here (section 5), we look at the following eight sociotechnical strategies in turn: Kyoto's flexibility mechanisms, CCS, REDD+, next generation biofuels, shale gas, SLCPs, CDR, and SRM. We match them to governmentalities held over from the Kyoto era of 1997–2005 (green governmentality and ecological modernization) as well as rationalities that gained in visibility during the Copenhagen era of 2005–2015 (polycentrism, co-benefits, time-buying, relative gains, and appeals to the vulnerable). The reader can view a more summarized account of this section in Table 1. In section 6, we step back to map overarching patterns of the relationships between these systems.

4.1. Kyoto's flexibility mechanisms

We begin by highlighting the ongoing significance of carbon accounting and trading mechanisms that marshalled much of the Kyoto Protocol's negotiation and operationalization. Dubbed the *'flexibility mechanisms'*, these were framed by the US and its allies as a means to reduce near-term stress on transitioning the carbon economy by incentivizing the most cost-effective ways to reduce emissions, and by allowing actors to trade credits derived therefrom. The result was a widespread use of carbon offsetting. The mechanisms consisted of carbon markets (the most prominent was the EU Emissions Trading Scheme, EU-ETS), alongside Joint Implementation (allowing cooperation between developed states), and the Clean Development Mechanism (CDM), which allowed Annex I countries to receive tradable credits (including the EU-ETS, from 2004 onward) from emissions reductions projects in the developing world.

Carbon offsetting and credit trading was the original manifestation of the cost-effective, market-facing logics of climate governance of the Kyoto period (centrist reviews include Newell and Paterson, 2010; Calel, 2016; Paterson and P-Laberge, 2016; Michaelowa et al., 2019). They leave a complicated and unfinished legacy: engaging industry and finance at multiple levels with climate governance, and keeping heavy carbon consuming and extracting states on board with COP ambitions (Newell and Paterson, 2010). Yet, they may have retarded Annex I efforts to take on more comprehensive domestic emissions reductions. Offsetting and trading served as significant – though not exclusive – means by which Annex I states attempted to meet their commitments under the Kyoto Protocol, enjoying a 'gold rush' period of investment and capital creation between 2006 and 2011 (Michaelowa et al., 2019; Lövbrand et al., 2009), but encouraging 'cheap and easy fixes' with limited potential for sustained, structural change (Calel, 2016; Carton, 2016; Ciplet and Roberts, 2017). Both the EU-ETS and CDM lie dormant currently, following a 2012 collapse due to the aftermath of the financial crisis and a fall in US and EU governmental support (Michaelowa et al., 2019). Some fault, tellingly, lies in abuse of the underpinning rationales of market mechanisms: the EU-ETS was flooded by 'hot air' credits from Russia and Ukraine (ibid). Lack of oversight in the CDM, meanwhile, created perverse incentives for false accounting and generation of credits (Schneider, 2009), and additionally often failed to create projects with development benefits in the hosting country (Olson, 2007).

For a time, some emerging sociotechnical proposals of the Copenhagen era benefited from conforming to neoliberal rationalities, and more concretely, tied into accounting and trading structures. Yet, as conditions pushed climate governance towards polycentrism (recall Ciplet et al., 2015), knock-on rationalities would also be catered to. A suite of climate strategies exemplifying this direction of travel described *new arrangements of carbon sinks*.

4.2. Carbon capture and storage

Carbon capture and storage (CCS) came to prominence around 2005 as the subject of an IPCC Special Report. Portrayed by advocates as proven in (technical) concept, ripe for upscaling, and indispensable for meeting future emissions targets (Hansson, 2011), CCS was from the beginning tied into existing industry, investment, and – importantly – plans for international credit trading (Krüger, 2017). As a supplement that would not fundamentally alter the carbon economy, the idea of CCS was aided by an additional framing as a feasible 'bridging' option for easing, or buying time for, the transition of entrenched carbon infrastructures; and as a catalyst for more ambitious actions in the future (Bäckstrand et al., 2011; Hanson, 2011; Markusson et al., 2017; Krüger, 2017). CCS did not go uncontested: the 'bridging' framing was opposed as an example of 'lock-in': an excuse for continuing carbon dependence, where incentives and resources would be reduced for renewables, and 'like nuclear … [be] a techno-fix for an immediate problem with long-term negative consequences' (Bäckstrand et al., 2011). Indeed, CCS was only included in the (by then, recognizably flawed) CDM in 2011, which coincides with the winding down of the Kyoto mechanisms. This framing juxtaposition becomes – and remains – a theme for many incoming sociotechnical strategies.

A significant aspect of CCS is that it has, for all its alleged potential, never been scaled. The bulk of large-scale CCS projects have emerged as an adjacent suite of *carbon capture and utilization in enhanced oil recovery (CCU in EOR)*, where emitted carbon is reused to expand the operational lives of existing oil fields. CCU in EOR has potential for 'technology spillover' back to CCS; yet it represents a downscaling of the original ambition, operationalised because it extends existing carbon extraction infrastructures (Markusson et al., 2017). For some, policy has failed to support CCS development in carbon markets or taxes (Scott et al., 2012; Haszeldine et al., 2018).

For others, the failure of policy is indicative: CCS serves its purpose as a promise (Markusson et al., 2018; Røttereng, 2018). In rhetoric, CCS is, but for some willpower, a readily-deployable 'bridge'. Yet, a clearer marker of its significance is that in investment and policy (or lack thereof), CCS functions most powerfully as the idea that atmospheric GHGs can be decoupled from the carbon economy (Hansson, 2011; Markusson et al., 2017; Krüger, 2017). Indeed, 'CCS-ready' serves as a legitimizing standard for new plants (Krüger, 2017), and CCS is heavily built into IPCC emissions scenarios that map pathways towards ambitious climate targets (Beck and Mahony, 2018). The latter becomes significant later, as we discuss schemes for carbon dioxide removal.

4.3. REDD+

Another emerging arrangement surrounding carbon sinks was based on 'reducing emissions from deforestation and forest degradation' (REDD+), which evolved into a mechanism for financing the reduction of forest emissions in developing countries.[2] REDD + provides a structure for actors in developed countries to finance 'verified emissions reductions' (VERs) in developing, rainforest-heavy nations for managing a basket of practices that

[2] REDD+, as a project-level instrument, should not be confused with UN-REDD, which is a multi-lateral programme coordinates and builds capacity for various forest management practices.

grew with each COP between 2005 and 2011 – eventually, deforestation, degradation, conservation and enhancement (Hein et al., 2018; Cadman et al., 2016). At the same time, forestry and land-use management is an old thread of conversation at the UNFCCC, with REDD + negotiations (2005–2011) building on preceding negotiations on afforestation and reforestation, and their prospective inclusion in the CDM (2001–2004).

REDD + represented the emergence in the 2000s of 'co-benefits' with other governance issues; here, between climate, local development, and biodiversity (Eliasch, 2008). Co-benefits also dovetailed with economic rationalities: managing forestry, particularly when these manifested as forest carbon projects in the developing world, was less costly and disruptive for developed countries than conventional mitigation efforts (Hein et al., 2018). A sense of pursuing relative gains – lower-hanging fruit on the agenda for sustaining the UNFCCC's visibility and relevance – became more important in the period marking fractious post-Kyoto negotiations; REDD + negotiations and post-Kyoto talks both began in 2005. Moreover, forestry and land-use management had long been a track of UNFCCC negotiation that represented a balance of interests between the US and allied states seeking access to offsets, and forested developing nations seeking access to finance (Boyd et al., 2008).

In that vein, REDD+'s credit accounting structure reflects the resilience of 'market-based conservationism' (Hein et al., 2018). At the same time, REDD+'s VERs cannot (for now) substitute for domestic emissions reductions in donor states; it is unclear whether REDD + will transition to a marketized offset mechanism or remain a financing instrument (Cadman et al., 2016). Recall that afforestation and reforestation had been included in the Kyoto Protocol's CDM; without the offsetting aspect, commentators have questioned the functional benefit of supporting REDD + for developed states. Røttereng (2018) argues that this is evidence of a fix: REDD+ is virtue signalling for carbon consuming and extracting states that distracts from their actual agendas, with the same collection of states showing strong rhetorical support for both REDD+ and CCS as promissory carbon sinks.

4.4. Next-generation biofuels

It was not just (marketized) carbon sinks that reflected these rationalities. Over the turn of the millennium, rising oil prices led to energy security concerns in the global North, which provided context for two strategies with proposed co-benefits for addressing climate change as lower-carbon 'bridging' fuels. The first is biofuels: a sociotechnical strategy with multiple generations, each with unique characteristics. The 'first generation' of biofuels, generated from food crops, had for years been supported by US and EU policy (e.g. the EU's 2003 Biofuels Directive; the Energy Independence and Security Act of 2007 in the US) as a marrying of energy security and climate objectives. Uncommonly amongst the sociotechnical strategies assessed here, first generation biofuels in the mid-2000s represented an internationally scaled system of production and usage across the global North and South. But from 2007 to 2008, a global food crisis threw biofuels' conflicts with food security into sharp relief. A range of studies have since pointed out the effects of biofuels demand in moving production from traditionally food-growing areas into cash crops – although a number of factors, including escalating oil prices, acted in sum to generate food shortages (e.g. Naylor et al., 2007; Clapp and Cohen, 2009; Ajanovic, 2010).

Next generation biofuels – the second is based on non-food residues (prominently, cellulose), and further generations propose the use of algae and other materials – were then proposed to regain co-benefits across the 'biofuel trilemma' (Tilman et al., 2009; see also Hunsberger et al., 2014 on 'sustainable biofuels'). Despite tremendous hype, next generation biofuels remained commercially unscaled through the Copenhagen period, with the 2008 recession reducing incentives for bridging considerable technical gaps. Only towards the present day has some biorefinery infrastructure been approached and growth projected; though these remain far short of original targets (Hayes, 2013; Valvidia et al., 2016; Hassan et al., 2019).

The value of these proposed biofuels over the past decade has, arguably, been as a promissory 'bridge' not only for higher-carbon fossil fuels (e.g. in transport), but for locking-in the older, more controversial version of itself. The idea of 'next generations' was a proxy for an imagined biofuels industry evolved to link climate, energy, and food imperatives – and has thus maintained the political positioning, policy support, and infrastructure of first-generation biofuels precisely by claiming that they would inevitably be substituted (Kuchler, 2014).

4.5. Shale gas

Shale gas, emerging around 2008 in the US, was another form of 'bridging' fuel with co-benefits – we use shale as an imperfect proxy for debates on the potentials of other unconventional, 'tight' fuels. As with biofuels, shale gas was a beneficiary of US energy security goals; its potentials as a new fuel sector during the 2008 recession gave it further visibility. Combined with the refinement of hydraulic fracturing and horizontal drilling approaches, the expansion of shale gas operations in the US has been widely termed a 'revolution'. And like biofuels, shale gas was advertised for its climate co-benefits, a kind of 'green carbon' that would substitute for higher carbon options – in this case, coal in electricity generation (Tour et al., 2010; Howarth et al., 2011). This 'bridge' was premised on shale gas disrupting the political resonance and infrastructures of the coal industry, but analysts were wary that shale gas would substitute for renewables rather than coal in the near term, as well as generate lock-in around its own policy support, structures, and markets in the long term (Schrag, 2012; Levi, 2015).

There is mixed evidence about which kind of substitution is coming to pass. US emissions fell during the scaling up of the shale gas industry, but gas-for-coal substitution was only one contributing factor (Feng et al., 2015), and methane leakage in upstream processes remained an issue (Newell and Raimi, 2014). Without concerted policy 'guardrails' – for example, limiting energy demand growth, reducing methane leakage, ensuring substitution with coal rather than renewables, and restricting low-carbon lock-out (Lazarus et al., 2015; Shearer et al., 2014) – the lock-in of shale gas interests may in the long-run produce comparable climatic impacts to coal, due to a combination of 'fugitive' methane, effects on depressing oil prices, and expanding infrastructure (Waxman et al., 2020). Moreover, shale gas was in this period a US-centered enterprise. With large global reserves and growing markets in Asia and the EU, shale's implications in multiple issues – geopolitical, economic, in energy systems – are still unfolding, from which impetus for its development may ultimately lie (Holz et al., 2015).

4.6. Short-lived climate forcing pollutants

Around 2011, the debate on *short-lived climate forcing pollutants (SLCPs)* repurposed efforts to reduce a heterogeneous range of aerosols from industrial production, agriculture (crop degradation), and other sectors as a co-benefit between air pollution, ozone layer governance, health, food security, vulnerable populations, and climate change (UNEP/WMO, 2011; Shindell et al., 2012). Discussion on SLCPs within the UNFCCC COPs were muted during this period, but as early as 2012, a still-growing Climate and Clean Air Pollution (CCAC) of states, cities, and organizations was lauded as an example of climate governance's new polycentricism. Many saw an opportunity to sidestep the UNFCCC and to generate climate action at less fractious venues. SLCPs, indeed, saw rapid policy expansion at the international level, with the Gothenburg Protocol of the Convention for Long-range Transboundary Air Pollution taking on black carbon (BC) in 2012, the Montreal Protocol on ozone in 2016 addressing hydrofluorocarbons (HFCs), and the Arctic Council adopting BC targets in 2017.

Besides seeking co-benefits and spurring effective polycentrism, a key rationality underpinning SLCP actions was the capacity to reduce warming in the near-term (prior to 2050), since SLCPs remain in the atmosphere for a fraction of the time that carbon does, while in some cases embodying many times carbon's warming potential. Victor, Zaelke and Ramanathan (2015) argued that tangible, feasible action in the near term (recall conversations on CCS, biofuels, and shale oil) might spur heavy carbon emitters to take on more comprehensive actions in the future, and disregarded the prospect SLCPs might distract from long-term carbon reductions as a ‘curious political logic that imagines countries can't focus on more than one thing at a time’ (p.796).

Scientific networks, generally, were circumspect, warning that SLCP reductions could not buy time or provide a bridge for low-carbon transitions. SLCP reductions could slow certain near-term risks (e.g. some ecosystems; sea level rise), but would not halt warming in the long term if carbon was not also reduced. More plainly, SLCPs could not allowed to be fungible with or substitute for carbon, as this might disguise and prolong emissions of the latter (Myhre et al., 2011; Bowerman et al., 2013; Shoemaker et al., 2013; Allen, 2015). Yet, some evidence indicates this is coming to pass in the post-Paris period, where Nationally Determined Contributions (NDC) include SLCPs under a single, economy-wide GHG metric, shading distinctions between actions on near-term SLCPs and long-term carbon in reaching their targets (Ross et al., 2018; Shindell et al., 2017).

4.7. Carbon dioxide removal

A final pair of sociotechnical strategies in this era emerged in the mid-2000s, originally grouped as forms of ‘*geoengineering*’ or ‘*climate engineering*’. The term encompasses two technically dissimilar suites: carbon dioxide removal (CDR) proposes a variety of natural and technological sinks for filtering and storing carbon directly from the atmosphere (unlike CCS, which operates at source), while schemes for solar radiation management (SRM) propose that increasing the albedo of the planet's surfaces could reflect a degree of sunlight and thereby reduce warming and its impacts. The initial pairing of these suites was a function of scale and intent, with early conceptualizing of both CDR and SRM as transboundary, even planetary interventions in the climate system (Keith, 2000; Shepherd et al., 2009), with some harkening to Cold War era weather modifications (Fleming, 2009) or a renewed sense of stewardship as part of the ‘Anthropocene’ zeitgeist (Brand, 2009; see also Rockström et al., 2009).

CDR, or of late, *‘negative emissions technologies (NETs)’*, had a more circuitous rise to prominence. An early-2000s variant, ocean iron fertilization (OIF), was scientifically discredited following initial promise. The upscaling of a technologically-grounded range of direct air capture (DAC) approaches remains held back in part by high energy requirements (Wilcox et al., 2017). The collective prospects of the idea of carbon removal were revived in 2013 by the inclusion of *bioenergy carbon capture and storage (BECCS)* – an immature CDR proposal with a single pilot demonstration – in the vast majority of the IPCC Fifth Assessment Report's emissions scenarios on which the Paris Agreement targets of 2C and 1.5C came to be based. This led to observations that the achievability of global climate targets was functionally propped up by a speculative technology and its underpinning assumptions (Anderson, 2015; Geden, 2016).

BECCS has since been argued to implicitly commit climate governance to ‘the promise of negative emissions’, reflecting the promissory nature of CDR as well as the evolving framings of scientific assessment (Beck and Mahony, 2018). As a discursive totem, CDR or NETs continues to expand, and has come to marshal carbon sinks with diverse backgrounds: from DAC, to BECCS, to forms of terrestrial CDR often recategorized from existing land-use and forestry management practices, to ocean-based approaches. Conversely, CCS debates are referencing CDR to regain visibility (Bui et al., 2018). CDR's original framing as large-scale ‘climate engineering’ or ‘intervention’ is dissipating; the suite is increasingly normalized as carbon sink-based mitigation, and given impetus by platforms that aim at carbon neutrality by 2050 (Geden et al., 2019).

Given CDR's growing profile, many called pragmatically for investment and incentivization (e.g. Lomax et al., 2015; Bellamy and Geden, 2019). Yet, BECCS in 2013 was (and remains) a projection of integrated assessment modeling (IAM) that calculates IPCC scenarios – BECCS was prominently featured in emissions projections because of model assumptions that it would become highly cost-effective post-2050. Moreover, BECCS is a chimera of biomass energy and CCS, two sociotechnical strategies with resilient controversies (Buck, 2016). Suggestions for improving BECCS′ potentials rely on improvements to CCS infrastructures and a turn to next-generation biofuels to reduce land-use trade-offs – in this sense, BECCS is an imaginary that builds on the unfulfilled potential of previous ones (Markusson et al., 2018).

Despite these uncertainties, heavy BECCS deployment in modeling scenarios allows emissions to ‘overshoot’ in the near term before being sequestered later in the century – effectively, a time-buying scheme for climate policy created from modeling parameters (Anderson, 2015; Beck and Mahony, 2018; Markusson et al., 2018; Carton, 2019) that reflects 'a long history' of how carbon sinks have been historically discussed and branded (Carton et al., 2020). The degree to which other novel CDR approaches may reflect similar logics is underexamined. Indeed, BECCS and direct air capture (DAC) share some of ‘the same technical, regulatory, and financing frameworks needed for CCS’ (Haszeldine et al., 2018, p.16) – and by extension, some potentials for prolonging carbon infrastructures. McLaren et al. (2019) proposes policy guardrails against perverse incentives in enhanced oil recovery (recall CCS), industry calls for CDR to serve as a source of (tradable) carbon offsets (recall carbon sinks and market mechanisms), and a hazy substitutability between conventional carbon reductions and negative emissions in setting targets (a similar concern exists for SLCPs).

4.8. Solar radiation management

For most of the Copenhagen era, the idea of *SRM as regional or planetary sunshades* drew greater and more fractious debate than CDR. A 2006 essay by Nobel laureate Paul Crutzen (of ozone layer governance) saw one SRM option as selectively allowing some increase of climate-cooling sulphate pollutants that are already by-products of shipping and industry – an uneasy trade-off between air pollution and climate goals (Crutzen, 2006). These early links with SLCPs would go dormant, with SLCP governance focusing on the co-benefits with reducing climate-heating pollutants. SRM schemes came to be dominated by more novel, earth systems modeling-driven scenarios for a layer of reflective (often, sulphate) particles in the upper atmosphere, dubbed stratospheric aerosol injection, or SAI (Irvine et al., 2016).

SRM became active as a fringe but forceful idea – even now, it has negligible mainstream political support, and scarcely any development or demonstration projects (Doughty, 2018) and engineering beyond proof-of-concept calculations (Smith and Wagner, 2018). The perceived technical strength of SRM – using volcanic eruptions as a proxy – has been its potential to cool the climate within weeks or months (Crutzen, 2006). A ballooning amount of assessment pointed out that sunlight reflection, as modeled, could reduce warming and many attendant harms (Irvine et al., 2016) while presenting a systemic range of environmental and political challenges (Blackstock and Low, 2018 collects articles written 2012–2016). 'Cheap, fast, and imperfect' became a resonant shorthand particularly of SAI (Parson and Keith, 2013), as did a 'risk vs. risk' framing – SRM perhaps made sense only in comparison to the risks of poorly-mitigated climate change (Linner and Wibeck, 2015).

Scientific networks sounded many cautious notes. An early framing of SRM as an 'emergency' mechanism was warned against for scientific uncertainties and playing into the politics of panic (Markusson et al., 2014; Sillmann et al., 2015). Deployment schemes by coalitions were studied but warily regarded (e.g. Ricke et al., 2013), and an initial assessment focus on regulation of prospective deployment (Victor, 2008; Virgoe, 2009) pivoted to a more polycentric governance of research itself (Nicholson et al., 2018). The most prevalent defense of SRM potentials came to be (and still is) as a time-buying strategy (Neuber and Ott, 2020), underpinned by scenarios that model SAI's capacity to reduce a broad spectrum of climate harms, especially if coupled with strong mitigation (e.g. MacMartin et al., 2014). These conclusions were accompanied by appeals to SRM's capacity to blunt impacts for vulnerable populations (Horton and Keith, 2016), that SRM could spur stronger recognition of and action on conventional mitigation (Reynolds, 2014), and calls for more enabling, mission-oriented research programs (Victor et al., 2013; Keith, 2017). Others described these scenarios as the use of modeling parameters to create as rose-tinted a depiction of deployment as possible, questioning benefits for the vulnerable as well as the capacities of a certain kind of model (and scientist) to set the terms of debate (Stilgoe, 2015; Flegal and Gupta, 2018; McLaren, 2018) in critique that mirrors that of BECCS in integrated assessment models.

Much contention existed over SRM's potential – due particularly to the 'cheap, fast, and imperfect' trope' – to reduce incentives for comprehensively reforming the carbon economy, as both an idea and as a sustained deployment. Recognition of these potentials remain pragmatic and prevalent; since the debate's earliest days, researchers have issued warnings is that SRM only masks warming, and cannot substitute for carbon reductions. For some, this so-called 'moral hazard' is ambiguously systemic and therefore unhelpful (Hale, 2012); for others, it is overstated (Reynolds, 2014). Of late, critical geography has revived SRM and its moral hazard as exemplary of a carbon economy fix, 'buying time for market-driven [mitigation] policy and reducing near-term risk' (Surprise, 2019; Gunderson et al., 2019) with a comparable logic to that of CDR and CCS (Carton, 2019). More concrete readings see moral hazard as forms of 'substitution' or 'deterrence' in mitigation efforts grafted onto existing sociopolitical issues and policy platforms, for which pre-emptive policy guardrails must be constructed (Lin, 2013; McLaren, 2016).

5. Analysis: Governmentality patterns

We previously noted how Copenhagen era (2005–2015) climate strategies were framed, how they embodied evolving governmentalities, and how they were beginning to appear as practices that prolong the near-term stability of the carbon economy. Here, we draw more systematic insights. We observe distinct patterns in how these sociotechnical strategies referenced governance rationalities and engendered forms of fixing, and in how strategies built upon the rationalities and infrastructures of those that came before (see column 4 of Table 2, as well as Table 3). Markusson et al. (2017, 2018) describe the latter as 'defensive fixes' – a path dependency of techno-fixes.

We observe a transition and continuity, rather than a clean break, between governmentalities of the Kyoto (1997–2005) and Copenhagen (2005–2015) periods. Fledgling strategies entrenched the carbon economy and mode of climate governance dominant during the Kyoto period in three ways: generating carbon credits, repurposing existing carbon infrastructures, and capitalizing on energy security.

The first shows the resilience of the market-facing practices of 'ecological modernization'. CCS, REDD+, and to a less clear degree, CDR, arose as *carbon sinks linked to offsetting, accounting, and trading mechanisms* (Røttereng, 2018). CCS was included in the CDM; as was the grouping of 'afforestation and reforestation' that is an antecedent to REDD+, which follows a similar logic of generating emissions credits. Strategies also *maintained infrastructures of carbon fuel extraction and usage* more directly. Fuels comparatively lower in carbon content – biofuels and shale gas – were argued to be substitutable for higher carbon variants in ostensibly limited circumstances, but in the process presented opportunities for lengthening the use of existing carbon infrastructures (e.g. the promise of next generation biofuels prolonging first-generation use; shale gas substituting for renewables as much as for coal, and expanding the long-term oil and gas economy), and for co-optation by industrial interests. Many argue that CCS and kinds of CDR (e.g. direct air capture), through deployment in enhanced oil recovery, are beginning to follow in these tracks (Markusson et al., 2017; McLaren, 2019; Carton, 2019). BECCS is exemplary of path dependencies, linked to biomass energy and CCS, and further on to the logics of marketized carbon sinks (Buck, 2016; Markusson et al., 2018; Carton et al., 2020). The third positions climate goals as a *co-benefit with the pressing demands of energy security* (particularly in the US) emerging over the early 2000s, with the clearest examples being biofuels and shale gas.

At the same time, the shape of Copenhagen-era strategies shows the marks of emerging regime fragmentation in the mid-2000. A loss of confidence in the UNFCCC's centralized, managerial mode of governance in the fractious post-Kyoto negotiations, and an ensuing openness towards a *polycentrism of seeking climate-related goals* through adjacent UN regimes, minilateral coalitions, and multilevel arrangements of states, municipalities, industries, and civic organizations, became the Copenhagen era's prevailing rationality. The need to keep the climate regime alive took form as a strengthening of rationalities for seeking relative gains, co-benefits, and bridging strategies, which trickled down into the appeals to viability and legitimacy made of new sociotechnical strategies. At the same time, rationalities of co-benefits and time-buying in particular presented opportunities for locking in carbon structures in less direct ways than entrenchment of cost- and market-friendly governance, or governance directly coupled to systems of carbon extraction and use.

References to *co-benefits for legitimizing climate strategies* with energy security (biofuels, shale gas) and development (the CDM) were joined by the linked issues of land-use, forestry, and agriculture (REDD+ and various kinds of terrestrial CDR), and air pollution (SLCPs and biofuels). Food security became significant – as a minimization of trade-offs – for hyping new biofuels after the 2007 food crisis; this issue was newly raised for BECCS as a combination of biomass energy and CCS systems. Mayrhofer and Gupta (2016) point out that the 'co-benefits' rationality's main potential is to incorporate climate objectives into more immediate processes of local and global governance. At the same time, there are dangers in treating climate goals as 'side effects of another goal that might be higher on the political agenda' (ibid, p.27). The perception and

Table 2
Sociotechnical strategies.

Sociotechnical strategy	Arrival period & circumstances	Degree of scaling	Match with Kyoto and Copenhagen governmentalities
Flexible mechanisms	1997 Kyoto Protocol	Kyoto Protocol 'flexibility mechanisms'	• Ecological modernization: cost-effective, market facing climate governance based on offsets and credit trading
CCS	2006-2010 debate on CDM inclusion	Permitted in CDM in 2011 but never scaled	• Ecological modernization: carbon markets, prolonging carbon infrastructures • Relative gains: sustaining carbon markets • Time-buying for easing carbon transitions
REDD+	Negotiated between 2005-2013; preceded by forestry and land-use debate	Modest number of projects, remains a financing mechanism.	• Ecological modernization: carbon accounting and credit generation • Relative gains: financing for forest nations • Co-benefits: development, biodiversity
Next gen biofuels	After 2007 food crisis, built upon early 2000s 1st gen biofuels	Only first-generation (food crop-based) scaled	• Co-benefits: energy and climate goals; pivoted to reducing trade-offs with food security
Shale gas	2005-2011, driven by energy security and industry innovations	Rapidly expanded in US; markets and reserves mapped in EU and Asia	• Co-benefits: energy and climate goals • Time-buying for easing carbon transitions based on gas-for-coal substitutions, catalyze more deep-lying mitigation
SLCPs	2011 recognition of air pollutants as climate heaters	BC, HFCs and methane listed in various platforms, including Paris NDCs	• Co-benefits: air pollution, ozone layer governance, health, food security, development and vulnerable populations, • Time-buying: accompany and catalyze more deep-lying mitigation
CDR	Early 2000s, with ocean fertilization; 2013 with BECCS in AR5	Increasing attention as part of Paris targets, but unscaled	• Ecological modernization: carbon markets, prolonging carbon infrastructures • Time-buying for easing carbon transitions based near-term carbon emissions overshoot
SRM	2006 Crutzen essay on sulphate forcing	Nascent small-scale mechanics tests	• Time-buying for easing carbon transitions by dampening climate impacts particularly for vulnerable populations, catalyze more deep-lying mitigation

Column 1 names emerging sociotechnical strategies of the Copenhagen era (2005-2015). Column 2 describes the period of arrival, while column 3 describes the degree of infrastructure scaling. Column 4 notes how sociotechnical strategies reflected evolving governmentalities of the Kyoto and Copenhagen eras, including logics of lock-in and fixing.

Table 3
Governmentality patterns.

Kyoto era →	Copenhagen era
Green governmentality	**Polycentrism and fragmentation**
Ecological modernization	
Flexible mechanisms – carbon markets, Joint Implementation, Clean Development Mechanism (1997-2012 heyday).	Reduced activity (2012-present)
	Credit generating carbon sinks (CCS and increasingly forms of CDR)
	Financing mechanism for less-developed countries (REDD+)
Co-benefits: energy security	
	Food security (next generation biofuels)
	Air pollution (SLCPs)
	Relative gains
	Co-benefits with development for most vulnerable (REDD+, biofuels, SLCPs)
	Funding (REDD+) or protecting vulnerable populations (SRM)
Buying time / Bridging	
Substitution of lower-carbon fuels for high carbon variants (shale, biofuels)	
	CCS and CDR in enhanced oil recovery
	Claiming to catalyze future mitigation instead of de-incentivizing it (CCS, CDR, SRM)
	Substituting for long-term carbon emissions with a different emissions basket (SLCPs) or a proxy measure of harm (SRM)
	Overshoot of near-term carbon emissions (CDR; functionally, SLCPs)

We show the emergence or consolidation of governance rationalities and strategies of the Kyoto and Copenhagen eras (bolded script, dark grey), alongside variations of those rationalities (light grey) as they emerged with various sociotechnical strategies.

advocacy of a co-benefit can fade as contradictions surface during operationalization – REDD+ and development, or biofuels and food security, or shale gas and energy-related imperatives – and balancing interests between governance issues becomes subject to scientific uncertainties and political horse-trading. Indeed, a co-benefits agenda might also be understood partly as trying to reframe critiques of harmful side effects. In some cases, if the driving forces of a climate strategy come from rationales external to climate governance – for example, shale gas – 'co-benefits' actually disguises trade-offs.

Another manifestation of the regime's fragmentation was an *increased openness towards relative gains* in the negotiation agenda that might maintain some momentum at the UNFCCC. Though it stands outside the scope of our investigation, Khan and Roberts (2013) point out that adaptation funding received much needed support (at least on paper) under this rationale. Negotiations for REDD + as a financing mechanism for forest nations (2005–2013), and including CCS in the CDM (2006–2010), similarly benefited in the post-Kyoto process. Dovetailing with these rationalities were resurgent appeals to demographics apart from governments and industry to sustain climate action – Bäckstrand and Lövbrand (2016) note that the visibility of civic and non-governmental organizations in this period rose as part of a move to polycentrism. Some of this manifested as appeals to the *welfare of 'most vulnerable'*: as presenting co-benefits (or at least minimizing trade-offs) with development (next-generation biofuels, REDD+, SLCPs), or for SRM, as a measure that might alleviate climate harms and buy time for developing adaptive capacities (Horton and Keith, 2016).

The emergence of the *'time-buying' or 'bridging'* rationality – easing the near-term strain for economies and societies on route to comprehensive low carbon transitions – came with many varieties, and displays the strongest potentials for lock-in. Some tied clearly into the cost-effective, market-facing climate governance of the Kyoto era. An ostensibly transitory low-for-high carbon fuel substitution (biofuels and shale) has been noted. CCS tied into the structures of tradable carbon credits, and was exemplary of the promise to ease transitions for carbon infrastructures; a logic expanded for CDR (e.g. BECCS) in permitting near-term 'overshoot' of emissions trajectories due to the promise that emitted carbon can be sequestered from the atmosphere in the future. SLCP reductions are projected to reduce certain near-term impacts, and SRM scenarios promise the same by slowing or halting temperature increase.

In debates that accompanied the growth of each of these proposals, scientific networks were careful to preface that none of these options can or should in the long run substitute for reducing emissions by replacing conventional fossil fuels. Advocates (for example, in CCS) extended the idea of a 'bridge' to argue that feasible compromises might catalyze more systematic reductions in the future (Bäckstrand et al., 2011); a variation of this for SRM argues that the prospect of a planetary sunshade might shock actors into stronger mitigation (Reynolds, 2014). Nevertheless, it is already clear that the bridging rationality presents opportunities for prolonging carbon structures. CCS has yet to be implemented at scale despite a decade and a half of investment and hype, indicating that its function is served as ambition signalling (Markusson et al., 2018), and Røttereng (2018) notes this for REDD + as well. US shale gas production (and biofuels, though this is not a fossil fuel) was deployed more due to energy security and intra-industry innovation rather than for climate objectives, and already displays self-sustaining logics (Lazarus et al., 2015; Kuchler, 2014). SRM and SLCPs present perverse opportunities for climate ambition based on proxies for comprehensive carbon emissions reductions: (rates of) temperature increase for SRM, or a more feasibly manageable basket of GHGs (e.g. HFCs) in SLCPs. Many countries, for example, combine HFC and methane reductions with carbon reductions through an economy-wide emissions target in the Paris Agreement's Nationally Determined Contributions (Ross et al., 2018); others warn that fungibility must not be emerge between conventional carbon reductions and negative emissions (McLaren et al., 2019).

6. Conclusion

A bird's eye view reveals what smaller scale analyses might not. Most studies of climate's sociotechnical strategies are based on single examples or smaller groupings, and when linking these systems, qualifications abound at eye-level. But taken as a whole, patterns emerge. The Copenhagen era's proposals and systems navigated emerging rationalities that responded to the increasing fragmentation of the global regime. However, they strongly reproduced entrenched structures and rationalities of the Kyoto era, presenting numerous outlets for signalling climate ambition while delaying more deep-lying forms of decarbonization.

Our intent is not to denigrate considerable advances that have been made in mitigation efforts, nor to declare all incoming climate strategy hopelessly compromised. Indeed, we leave out a number of sociotechnical strategies from our assessment, particularly renewable energy and efficiency, nuclear energy, and adaptation strategies. When assessing how the near-term carbon economy is 'fixed' by emerging efforts, omitted systems may offer countering logics. Rather, we sound a cautionary note about hype and advocacy regarding immature and imagined sociotechnical strategies. From CCS to SRM, each debate in the course of emergence saw myopic claims made about that system's potentials, and even that they present opportunities for avoiding or altering conditions that hampered previous efforts. A longer and wider arc of climate governance – even limited to the decade between 2005 and 2015 – indicates that these proposals, for all their different technical specifications, filed into comparable and often well-worn political usages. Structure – governmentalities built around the carbon economy – does matter.

Yet, structure need not be deterministic. Pointing to these governmentalities has been accompanied by avenues for altering them, in the form of proposed policy incentives and safeguards – see Chhatre et al. (2012) for REDD+, Lazarus et al. (2015) for shale gas, Shindell et al. (2017) for SLCPs, McLaren et al. (2019) for CDR, and McLaren (2016) and Reynolds (2019) for SRM. The question is whether these guardrails can be constructed, as we move into a period of governance marked by the implementation of the Paris Agreement, spurred further by carbon neutrality platforms, the European Green Deal, and of late, the opportunities and constraints set in motion by plans to restart the global economy in the aftermath of Covid-19. Whether these sociotechnical strategies come to 'repackage' Copenhagen governmentalities in a laissez-faire mode of climate polycentrism (Bernstein et al., 2010; Held and Roger, 2018; Ciplet and Roberts, 2017; Blum and Lövbrand, 2019) or offer opportunities for catalyzing a low-carbon transition, depends on our collective determination that the past assessed here need not be prologue.

CRediT authorship contribution statement

Sean Low: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Miranda Boettcher:** Formal analysis, Writing - review & editing.

Declaration of competing interest

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

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References

Ajanovic, A., 2010. Biofuels versus food production: does biofuels production increase food prices? Energy. https://doi.org/10.1016/j.energy.2010.05.019.
Allen, M.R., 2015. Short-lived Promise? the Science and Policy of Cumulative and Short-Lived Climate Pollutants. Oxford Martin Policy Paper.
Anderson, K., 2015. Duality in climate science. Nat. Geosci. 8 (12), 898–900.
Aykut, S.C., 2016. Taking a wider view on climate governance: moving beyond the 'iceberg,' the 'elephant,' and the 'forest'. WIREs Climate Change 7, 318–328.
Bäckstrand, K., Lövbrand, E., 2006. Planting trees to mitigate climate change: contested discourses of ecological modernization, green governmentality and civic environmentalism. Global Environ. Polit. 6 (1), 50–75.
Bäckstrand, K., Lövbrand, E., 2016. The Road to Paris: contending climate governance discourses in the post-Copenhagen era. J. Environ. Pol. Plann. https://doi.org/10.1080/1523908X.2016.1150777.
Bäckstrand, K., Meadowcroft, J., Oppenheimer, M., 2011. The politics and policy of carbon capture and storage: framing and emergent technology. Global Environ. Change 21, 275–281.
Bain, P.G., Milfont, T.L., Kashima, Y., Bilewicz, M., Doron, G., Gardarsdottir, R.B., et al., 2015. Co-benefits of addressing climate change can motivate action around the world. Nat. Clim. Change 6, 154–158.
Beck, S., Mahony, M., 2018. The politics of anticipation: the IPCC and the negative emissions technologies experience. Global Sustainability 1 (8), 1–8.
Bellamy, R., Geden, O., 2019. Govern CO_2 removal from the ground up. Nat. Geosci. 12, 874–876. https://doi.org/10.1038/s41561-019-0475-7.
Bernstein, S., Hoffmann, M., 2019. Climate politics, metaphors and the fractal carbon trap. Nat. Clim. Change. https://doi.org/10.1038/s41558-019-0618-2.
Bernstein, S., 2001. The Compromise of Liberal Environmentalism. Columbia University Press.
Bernstein, S., Betsill, M., Hoffman, M., Paterson, M., 2010. A tale of two Copenhagens: carbon markets and climate governance. Milennium 39 (1), 161–173.
Blackstock, J.J., Low, S. (Eds.), 2018. Geoengineering Our Climate? Ethics, Politics, and Governance. Earthscan from Routledge, London.
Blum, M., Lövbrand, E., 2019. The return of carbon offsetting? The discursive legitimation of new market arrangements in the Paris climate regime. Earth System Governance 2, 100028.
Bowerman, N.H.A., Frame, D.J., Huntingdon, C., Lowe, J.A., Smith, S.M., Allen, M.R., 2013. The role of short-lived climate pollutants in meeting temperature goals. Nat. Clim. Change 3, 1021–1024.
Boyd, E., Corbera, E., Estrada, M., 2008. UNFCCC negotiations (pre-Kyoto to COP-9): what the process says about the politics of CDM-sinks. International Environmental Agreements 8, 95–112.
Brand, S., 2009. Whole Earth Discipline: an Ecopragmatist Manifesto. Viking Press, New York.
Brown, N., Rappert, B., Webster, A. (Eds.), 2000. Contested Futures: A Sociology of Prospective Techno-Science. Ashgate, Aldershot.
Buck, H.J., 2016. Rapid scale up of negative emissions technologies: social barriers and social implications. Climatic Change 139, 155–167.
Buck, H.J., Martin, L.J., Geden, O., Kareiva, P., Koslov, L., Krantz, W., Kravitz, B., Noël, J., Parson, E.A., Preston, C.J., Sanchez, D.L., Scarlett, L., Talati, S., 2020. Evaluating the efficacy and equity of environmental stopgap measures. Nat. Sustain. https://doi.org/10.1038/s41893-020-0497-6.
Bui, M., Adjiman, C., Bardow, A., Anthony, E.J., Boston, A., Brown, S., et al., 2018. Carbon capture and storage (CCS): the way forward. Energy Environ. Sci. 11, 1062.
Cadman, T., Maraseni, T., Ma, H.O., Lopez-Casero, F., 2016. Five years of REDD+ governance: the use of market mechanisms as a response to anthropogenic climate change. For. Pol. Econ. https://doi.org/10.1016/j.forpol.2016.03.008.
Calel, R., 2016. Carbon markets: a historical overview. WIRES Climate Change 4, 107–119.
Carton, W., 2016. Fictitious Carbon, Fictitious Change? Environmental Implications of the Commodification of Carbon. Lund University.
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.
Carton, W., Asiyanbi, A., Beck, S., Buck, H.J., Lund, J.F., 2020. Negative emissions and the long history of carbon removal. Wiley Interdiscipl. Rev. Clim. Change. https://doi.org/10.1002/wcc.671.
Chhatre, A., Lakhanpal, S., Larson, A.M., Nelson, F., Ojha, H., Rao, J., 2012. Social safeguards and co-benefits in REDD+: a review of the adjacent possible. Current Opinion in Environmental Sustainability 4 (6), 654–660.
Ciplet, D., Roberts, J.T., 2017. Climate Change and the transition to neoliberal environmental governance. Global Environ. Change 46, 148–156.
Ciplet, D., Roberts, J.T., Khan, M., 2015. Power in a Warming World: the New Global Politics of Climate Change and the Remaking of Environmental Inequality. MIT Press, Cambridge, MA.
Clapp, J., Cohen, M.J. (Eds.), 2009. The Global Food Crisis. Centre for International Governance Innovation and Wilfred Laurier Press, Waterloo.
Crutzen, P.J., 2006. Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? Climatic Change 77, 211–219.
Dimitrov, R.S., 2010. Inside Copenhagen: the state of climate governance. Global Environ. Polit. 10 (2), 18–24.
Dorsch, M.J., Flachsland, C., 2017. A polycentric approach to global climate governance. Global Environ. Polit. 17 (2), 45–64.
Doughty, J., 2018. Past forays into SRM field research and implications for future governance. In: Blackstock, J.J., Low, S. (Eds.), Geoengineering Our Climate? Ethics, Politics and Governance. Earthscan from Routledge, London, pp. 100–106.
Eliasch, J., 2008. Climate change: financing global forests. In: The Eliash Review. The Stationary Office Limted, UK.
Falkner, R., 2016. The Paris Agreement and the new logic of international climate politics. Int. Aff. 92 (5), 1107–1125.
Feng, K.S., Davis, S.J., Sun, L.X., Hubacek, K., 2015. Drivers of the US CO2 emissions 1997-2003. Nat. Commun. 6, 7714. https://doi.org/10.1038/ncomms8714.
Flegal, J.A., Gupta, A., 2018. Evoking equity as a rationale for solar geoengineering research? Scrutinizing emerging expert visions of equity. International Environmental Agreements 18, 45–61.
Fleming, J.R., 2009. Fixing the Sky: the Checkered History of Weather and Climate Control. Columbia University Press, New York.
Geden, O., 2016. The Paris Agreement and the inherent inconsistency of climate policymaking. Wiley Interdisciplinary Reviews: Climate Change 7 (6), 790–797.
Geden, O., Peters, G.P., Scott, V., 2019. Targeting carbon dioxide removal in the European Union. Clim. Pol. 19 (4), 487–494.
Glaser, B.G., Strauss, A.L., 1967. The Discovery of Grounded Theory. Strategies for Qualitative Research. de Gruyter, New York.
Gunderson, R., Stuart, D., Petersen, B., 2019. The political economy of geoengineering as Plan B: technological rationality, moral hazard, and new technology. New Polit. Econ. 24 (5), 696–715.
Gupta, J., 2010. A history of international climate change policy. WIRES Climate Change 1, 636–653.
Hajer, M., 1995. The Politics of Environmental Discourse: Ecological Modernization and the Policy Process. Oxford University Press, London.
Hale, B., 2012. The world that would have been: moral hazard arguments against geoengineering. In: Preston, C. (Ed.), Reflecting Sunlight: the Ethics of Solar Radiation Management. Rowman and LittleField, Lanham MD.
Hansson, A., 2011. Colonising the future: the case of CCS. In: Markusson, N., Shackley, S., Evar, B. (Eds.), The Social Dynamics of Carbon Capture and Storage. Routledge, London, pp. 98–114.
Harvey, D., 1982. The Limits to Capital. University of Chicago Press, Chicago.
Hassan, S.S., Williams, G.A., Jaiswal, A.K., 2019. Moving towards the second generation of lignocellulosic biorefineries in the EU: drivers, challenges, and opportunities. Renew. Sustain. Energy Rev. 101, 590–599.
Haszeldine, R.S., Flude, S., Johnson, G., Scott, V., 2018. Negative emissions technologies and carbon capture and storage to achieve the Paris Agreement commitments. Philosophical Transactions of the Royal Society A 376, 20160447.
Hayes, D.J.M., 2013. Second-generation biofuels: why they are taking so long? WIRES Energy and Environment 2, 304–334.
Hein, J., Guarin, A., Fromme, E., Pauw, P., 2018. Deforestation and the Paris climate agreement: an assessment of REDD+ in the national climate action plans. For. Pol. Econ. 90, 7–11.
Held, D., Roger, C., 2018. Three models of global climate governance: from Kyoto to Paris and beyond. Global Policy 9 (4), 527–537.
Holz, F., Rickter, P.M., Egging, R., 2015. A global perspective on the future of natural gas: resources, trade, and climate constraints. Rev. Environ. Econ. Pol. 1–22, 0(0).
Horton, J.B., Keith, D.W., 2016. Solar geoengineering and oblications to the global poor. In: Preston, C.J. (Ed.), Climate Justice and Geoengineering: Ethics and Policy in the Atmosphertic Anthropocene. Rowman & Littlefield, London, pp. 79–92.
Howarth, R., Ingraffea, A., Engelder, T., 2011. Should fracking stop? Nature 477, 272–275.
Hulme, M., Mahony, M., 2010. Climate change: what do we know about the IPCC? Prog. Phys. Geogr. 34 (5), 705–718.
Hunsberger, C., Bolwig, S., Corbera, E., Creutzig, F., 2014. Livelihood impacts of biofuels crop production: implications for governance. Geoforum 54, 248–260.
Irvine, P.J., Kravitz, B., Lawrence, M.G., Muri, H., 2016. An overview of the Earth system science of solar geoengineering. WIRES Climate Change. https://doi.org/10.1002/wcc.423.
Jasanoff, S. (Ed.), 2004. States of Knowledge: the Co-production of Science and Social Order. Routledge, New York.
Jasanoff, J., Kim, S.H., 2015. Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power. University of Chicago Press, Chicago.
Keith, D.W., 2000. Geoengineering the climate: history and prospect. Annu. Rev. Energy Environ. 25, 245–284.
Keith, D.W., 2017. Toward a responsible solar geoengineering research program. Issues Sci. Technol. 33 (3).
Keohane, R.O., Victor, D.G., 2011. The regime complex for climate change. Perspect. Polit. 9 (1), 7–23.
Khan, M., Roberts, J.T., 2013. Adaptation and international climate policy. WIRES Climate Change 4, 171–189.
Krüger, T., 2017. Conflicts over carbon capture and storage in international climate governance. Energy Pol. 100, 58–67.
Kuchler, M., 2014. Sweet dreams (are made of cellulose): sociotechnical imaginaries of second-generation bioenergy in the global debate. Ecol. Econ. 107, 431–437.

Lamb, W.L., Mattioli, G., Levi, S., Roberts, J.T., Capstick, S., Creutzig, F., Minx, J.C., Müller-Hansen, F., Culhane, T., Steinberger, J.K., 2020. Discourses of climate delay. Glob. Sustain. 3 (e17), 1–5. https://doi.org/10.1017/sus.2020.13.
Lazarus, M., Tempest, K., Klevnäs, P., Korsbakken, J.I., 2015. Natural Gas: Guardrails for a Potential Climate Bridge. New Climate Economy Contributing Paper. Stockholm Environment Institute, Stockholm, Sweden, and Seattle, WA, US. Retrieved from. http://newclimateeconomy.report.
Levi, M., 2015. Fracking and the Climate Debate. *Democracy*. Retrieved from. https://democracyjournal.org/magazine/37/fracking-and-the-climate-debate/.
Lin, A.C., 2013. Does geoengineering present a moral hazard? Ecol. Law Q. 40 (3), 673–712.
Linner, B.O., Wibeck, V., 2015. Dual high stake emerging technologies: a review of the climate engineering research literature. WIREs Climate Change 6, 255–268. https://doi.org/10.1002/wcc.333.
Lomax, G., Lenton, T.M., Adeosun, A., Workman, M., 2015. Investing in negative emissions. Nat. Clim. Change 5, 498–500.
Lövbrand, E., Stripple, J., 2011. Making climate change governable: accounting for carbon as sinks, credits and personal budgets. Crit. Pol. Stud. 5 (2), 187-100.
Lövbrand, E., Rindefjäll, T., Nordqvist, J., 2009. Closing the legitimacy gap in global environmental governance? Lessons from the emerging CDM market. Global Environ. Polit. 9 (2), 74–100.
MacMartin, D.G., Caldeira, K., Keith, D.W., 2014. Solar geoengineering to limit the rate of temperature change. Philosophical Transactions of the Royal Society A372, 20140134.
Markusson, N.O., Ginn, F., Ghaleigh, N.S., Scott, V., 2014. 'In case of emergency press here': framing geoengineering as a response to dangerous climate change. WIRES Climate Change 5, 281–290.
Markusson, N.O., Dahl Gjefson, M., Stephens, J.C., Tyfield, D.P., 2017. The political economy of technical fixes: the (mis)alignment of clean fossil and political regimes. Energy Research & Social Science 23, 1–10.
Markusson, N.O., McLaren, D., Tyfield, D., 2018. Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs). Global Sustainability 1 (10), 1–9.
Mayrhofer, J.P., Gupta, J., 2016. The science and politics of co-benefits in climate policy. Environ. Sci. Pol. 57, 22–30.
McLaren, D.P., 2016. Mitigation deterrence and the 'moral hazard' of solar radiation management. Earth's Future 4, 596–602. https://doi.org/10.1002/2016EF000445.
McLaren, D.P., 2018. Whose climate and whose ethics? Conceptions of justice in solar geoengineering modelling. Energy Research & Social Science 44, 209–221.
McLaren, D.P., Markusson, N., 2020. The co-evolution of technological promises, modelling, policies and climate change targets. Nat. Clim. Change 10, 392–397. https://doi.org/10.1038/s41558-020-0740-1.
McLaren, D.P., Tyfield, D.P., Willis, R., Szerszynski, B., Markusson, N.O., 2019. Beyond "net-zero": a case for separate targets for emissions reduction and negative emissions. Frontiers Climate Change 1, 4. https://doi.org/10.3389/fclim.2019.00004.
Michaelowa, A., Shishlov, I., Brescia, D., 2019. Evolution of international carbon markets: lessons for the Paris Agreement. WIRES Climate Change 613, 1–24.
Miller, C.A., 2004. Climate science and the making of a global political order. In: Jasanoff, S. (Ed.), States of Knowledge: the Co-production of Science and the Social Order. Routledge, London.
Myhre, G., Fuglestvedt, J.S., Berntsen, T.K., Lund, M.T., 2011. Mitigation of short-lived heating components may lead to unwanted long-term consequences. Atmos. Environ. 45, 6103–6106.
Naylor, R.L., Liska, A.J., Burke, M.B., Falcon, W.P., Gaskell, J.C., Rozelle, S.D., Cassman, K.G., 2007. The Ripple Effect: biofuels, food security, and the environment. Environment 49 (9), 30–43.
Neuber, F., Ott, K., 2020. The buying time argument within the solar radiation management discourse. Appl. Sci. 10. https://doi.org/10.3390/app10134637.
Newell, P., Paterson, M., 2010. Climate Capitalism: Global Warming and the Transformation of the Global Economy. Cambridge University Press, Cambridge.
Newell, R.G., Raimi, D., 2014. Implications of shale gas for climate change. Environ. Sci. Technol. 48, 8360–8368.
Nicholson, S., Jinnah, S., Gillespie, A., 2018. Solar radiation management: a proposal for immediate polycentric governance. Clim. Pol. 18 (3), 322–334.
Nightingale, A.J., Eriksen, S., Taylor, M., Forsyth, T., Pelling, M., Newsham, A., et al., 2019. Beyond technical fixes: climate solutions and the great derangement. Clim. Dev. https://doi.org/10.1080/17565529.2019.1624495.
Oels, A., 2005. Rendering climate change governable: from biopower to advanced liberal government? J. Environ. Pol. Plann. 7 (3), 185–207.
Okerere, C., Bulkeley, H., Schroeder, H., 2009. Conceptualizing climate governance beyond the international regime. Global Environ. Polit. 9 (1), 58–78.
Olson, K.H., 2007. The clean development mechanism's contribution to sustainable development: a review of the literature. Climatic Change 84, 59–73.
Parson, E.A., Keith, D.W., 2013. End the deadlock on governance of geoengineering research. Science 339, 1278–1279.
Paterson, M., P-Laberge, X., 2016. Political economies of climate change. WIRES Climate Change 9. https://doi.org/10.1002/wcc.506.
Prins, G., Rayner, S., 2007. Time to ditch Kyoto. Nature 449, 973–975.
Reynolds, J.L., 2014. A critical examination of the climate engineering moral hazard and risk compensation concern. The Anthropocene Review 2 (2), 174–191. https://doi.org/10.1177/2053019614554304.
Reynolds, J.L., 2019. The Governance of Solar Geoengineering: Managing Climate Change in the Anthropocene. Cambridge University Press, Cambridge.
Ricke, K.L., Moreno-Cruz, J.B., Caldeira, K., 2013. Strategic incentives for climate geoengineering coalitions to exclude broad participation. Environ. Res. Lett. 8, 014021.
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E., et al., 2009. Planetary boundaries: exploring the safe operating space for humanity. Ecol. Soc. 14 (2), 32. Retrieved from. http://www.ecologyandsociety.org/vol14/iss2/art32/.
Ross, K., Damassa, T., Northrop, E., Waskow, D., Light, A., Fransen, T., Tankou, A., 2018. Strengthening Nationally Determined Contributions to catalyze actions that reduce short-lived climate pollutants. Working Paper. World Resources Institute and Oxfam.
Røttereng, J.-K.S., 2018. The comparative politics of climate change mitigation measures: who promotes carbon sinks and why? Global Environ. Polit. 18 (1), 52–75.
Schneider, L., 2009. Assessing the additionality of CDM projects: practical experiences and lessons learned. Clim. Pol. 9 (3), 242–254.
Schrag, D.P., 2012. Is shale gas good for climate change? Daedalus 2, 72–80.
Scott, V., Gilfillan, S., Markusson, N., Chalmers, H., Haszeldine, R.S., 2012. Last chance for carbon capture & storage. Nat. Clim. Change. https://doi.org/10.1038/NCLIMATE1695.
Shearer, C., Bistline, J., Inman, M., Davis, S.J., 2014. The effect of natural gas supply on US renewable energy and CO2 emissions. Environ. Res. Lett. 9, 094008.
Shepherd, J., Caldeira, K., Cox, P., Haigh, J., Keith, D.W., Launder, B., et al., 2009. Geoengineering the Climate: Science, Governance and Uncertainty. The Royal Society, London.
Shindell, J., Kuylenstierna, J. C. I., Vignati, E., van Dingenen, R., Amann, M, Klimont Z, et al. Simultaneously mitigating near-term climate change and improving human health and food security. Science 13: 183-189.
Shindell, J., Borgford-Parnell, N., Brauer, M., Kuylenstierna, J.C.I., Leonard, S.A., Ramanathan, V., et al., 2017. A climate policy pathway for near- and long-term benefits. Science 356, 493–494.
Shoemaker, J.K., Schrag, D.P., Molina, M.J., Ramanathan, V., 2013. What role for short-lived climate pollutants in mitigation policy? Science 342, 1323–1324.
Sillmann, J., Lenton, T.M., Levermann, A., Ott, K., Hulme, M., Benduhn, F., Horton, J.B., 2015. Climate emergencies do not justify engineering the climate. Nat. Clim. Change 5, 290–292.
Smith, W., Wagner, G., 2018. Stratospheric aerosol injection tactics and costs in the first 15 years of deployment. Environ. Res. Lett. 13 (124001). https://doi.org/10.1088/1748-9326/aae98d.
Stilgoe, J., 2015. Experiment Earth: Responsible Innovation in Geoengineering. Routledge, New York.
Stripple, J., Bulkeley, H. (Eds.), 2014. Governing the Climate: New Approaches to Rationality, Power and Politics. Cambridge University Press, Cambridge.
Surprise, K., 2019. Preempting the second contradiction: solar geoengineering as spatiotemporal fix. Ann. Assoc. Am. Geogr. 108 (5), 1228–1244.
Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., et al., 2009. Beneficial biofuels: the food, energy, and environment trilemma. Policy Forum 325, 270–271.
Tour, J.M., Kittrell, C., Colvin, V.L., 2010. Green carbon as a bridge to renewable energy. Nat. Mater. 9, 871–874.
UNEP/WMO, 2011. Integrated Assessment of Black Carbon and Tropospheric Ozone. Report, United Nations Environment Programme and World Metrorological Organization. Retrieved from. https://www.ccacoalition.org/en/resources/integrated-assessment-black-carbon-and-tropospheric-ozone.
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Pol. 28, 817–830.
Urry, J., 2014. The problem of energy. Theor. Cult. Soc. 31 (5), 3–20.
Valvidia, M., Galan, J.L., Laffarga, J., Ramos, J.L., 2016. Biofuels 2020: biorefineries based on lignocellulosic materials. Microbial Biotechnology 9 (5), 585–594.
Victor, D.G., 2008. On the regulation of geoengineering. Oxf. Rev. Econ. Pol. 24 (2), 322–336.
Victor, D. G., Zaelke, D., & Ramanathan, V. Soot and short-lived pollutants provide political opportunity. Nat. Clim. Change 5: 796-798.
Victor, D.G., Morgan, M.G., Apt, J., Steinbruner, J., Ricke, K.L., 2013. The truth about geoengineering: science fiction and science fact. Foreign Aff. 92, 1–8.
Virgoe, J., 2009. International governance of a possible geoengineering intervention to combat climate change. Climatic Change 95, 103–119.
Waxman, A.R., Khomaini, A., Leibowicz, B.D., Olmstead, S.M., 2020. Emissions in the stream: estaimating the greenhouse gas impacts of an oil and gas boom. Environ. Res. Lett. 15, 014004.
Weinberg, A., 1966. Can technology replace social engineering? Bull. At. Sci. 22 (10), 4–8.
Wilcox, J., Psarras, P.C., Liguori, S., 2017. Assessment of reasonable opportunities for direct air capture. Environ. Res. Lett. 12 (6), 065001.