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Key Points:

- Appeals to the future drive the discourse, science, and policy of climate engineering in the present.
- Future claims are implicit in framings and models; a prominent example is the inclusion of negative emissions in IPCC scenarios.
- Foresight methods can provide a platform for structured communication on future claims under conditions of deep uncertainty.

Corresponding author:
S. Low, sean.low@iass-potsdam.de

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The futures of climate engineering

Sean Low[1]

[1]Institute for Advanced Sustainability Studies, Potsdam, Germany

Abstract This piece examines the need to interrogate the role of the conceptions of the future, as embedded in academic papers, policy documents, climate models, and other artifacts that serve as currencies of the science–society interface, in shaping scientific and policy agendas in climate engineering. Growing bodies of work on framings, metaphors, and models in the past decade serve as valuable starting points, but can benefit from integration with science and technology studies work on the sociology of expectations, imaginaries, and visions. Potentially valuable branches of work to come might be the anticipatory use of the future: the design of experimental spaces for exploring the future of an engineered climate in service of responsible research and innovation, and the integration of this work within the unfolding context of the Paris Agreement.

1. Introduction

In the past decade, scholarly and popular discourse has made much of the potential of engineering planetary sunshades or carbon sinks. Therein lies an under-investigated component of the field's evolution, for "potential" describes future possibilities made meaningful in the present. There are no end-of-pipe technologies, with cemented strategies for deployment and institutions for governance. The field remains a set of early proposals, prototypes, and research practices under constant re-evaluation as new voices continue to enter the narrative battleground.

What drives the most concerted debate is not the mundane reality of what climate engineering is, but the promises and pitfalls of what it could be. And these are often incorporated into richly detailed narratives in which research or deployment has altered the landscape of the near-term or far-off future, for both good and ill. Conceived outcomes range from the reduction or reconfiguration of climate risks, to influences on the carbon economy, state and human security, intellectual property, dynamics between North and South, and civilization's relationship to the natural world in the context of the Anthropocene.

Herein lies two dynamics of significance. Firstly, our capacity to predict or even project the future is limited—especially if those futures are systemic in scope. Calculating costs and feasibilities or modeling climatic impacts produce their shares of uncertainty, but envisioning additional societal repercussions—with crosscutting environmental and human dimensions and cascading sequences of events—is an exercise in educated guesswork that relies not only upon expertise but imagination, and even bias and agenda.

Secondly, engagement with the future is not politically neutral. Futures emphasize different baskets of risk and benefit, and thereby contain embedded claims—sometimes implicit, sometimes instrumental—on the viability of climate engineering, and in turn, upon the proposed direction of scientific and policy agendas today. Recognizing that engagement with the future shapes the present, and that a wide array of stakeholders and perspectives (including, and perhaps especially, those of academic researchers) play constitutive roles in doing so, has implications for research—both past and future—into the intellectual economy of climate engineering.

2. Framing and Modeling

Although it is intuitive that conceptions of the future have shaped the discourse, science and policy of climate engineering, such dynamics have yet to be investigated in depth. Here, we can leverage growing bodies of work on how climate engineering has been communicated in academic papers, media articles, policy documents, climate models, works of fiction and art, and other artifacts that serve as currencies of the science-society interface.

Two literatures deserve special mention. The first is a number of discourse analyses on framings and narratives [*Bellamy et al.*, 2013; *Corner et al.*, 2013; *Scholte et al.*, 2013; *Anshelm and Hansson*, 2014a, 2014b; *Cairns and Stirling*, 2014; *Huttunen et al.*, 2014; *Harnisch et al.*, 2015; *Linner and Wibeck*, 2015] and metaphors [*Nerlich and Jaspal*, 2012; *Luokkanen et al.,* 2013] that map how information on climate engineering can be packaged by experts and processed by audiences; ranging from the need to conduct risky research in the face of the prospectively greater risk of climate change, to climate management as part of an emerging anti-conservationist brand of environmentalism, to a wariness of "leaving science to scientists" and a democratic deficit in deciding on climate engineering's means and ends, to a rejection of the entire enterprise in light of its potential to perpetuate the carbon economy and its inequities. The (much smaller) second is on earth systems models as an experimental space for gauging the geophysical processes and impacts of climate engineering, but as an imperfect mapping bound not only to limitations in the models but also to the preferences—and even the biases—of modelers in their choices of the type, scale, and duration of climatic perturbation [*Heyen et al.*, 2015; *Wiertz*, 2015].

Both literatures provide an early accounting of the politics of climate engineering, the actors that contest them, and the textual and visual media by which they are transmitted. However, we can also extend these strands of inquiry to examine the effects that framings and models have had—and will have going forward. Here, a (re)orientation of these literatures to emphasize the shaping influences of the future would be a valuable exercise. One obvious justification is that framing and modeling the contours of an engineered climate is inherently future-oriented. More significantly, this allows a beneficial integration with concepts developed in science and technology studies (STS) on expectations, imaginaries, visions, and other "creatures of the future tense" [*Selin*, 2008] in emerging technologies.

3. Futures Made Present

The sociology of expectations [*Brown et al.,* 2000; *Borup et al.*, 2006] and related literatures [*Grin and Grunwald*, 2000; *Adam and Groves*, 2007; *Selin*, 2008; *Jasanoff and Kim*, 2015] note that emerging technologies rely upon compelling appeals to the future to drive support for a particular shape and momentum of development, precisely because of irresolvable uncertainties surrounding their eventual impacts. These claims upon the future (e.g., expectations, imaginaries, visions) are made present by artifacts (e.g., papers and patents) and practices (e.g., of discourse, R&D, and governance); they shape how technologies are conceptualized, funded, developed, and regulated by marshaling stakeholders across science and society around shared reference points on risks and benefits, benchmarks in the innovation process, and actors and activities relevant to achieving them.

Nor are all futures of a kind. One dichotomy that may become useful lies between feasible but exaggerated long-range futures that incorporate a wide range of societal, technological, and environmental dimensions and that judge entire pathways of knowledge and development, and shorter-range, more technically focused futures that nudge existing innovation paths—a distinction between "high" and "low" expectations (compare *Borup et al.*, 2006 to *Gardner et al.*, 2015, or see *Grunwald*, 2004 for an alternative comparison between "intermediate" and "guiding" visions). Assessing the fit between the dynamics of antecedent cases and those of climate engineering can yield rich gains for understanding how the field has evolved, and continues to.

An example might illustrate the importance of applying these concepts. Bioenergy with carbon capture and storage (BECCS)—a kind of carbon dioxide removal, or negative emissions approach—forms an integral part of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report's Representative Concentration Pathway (RCP) 2.6, which is currently the only envisioned emissions pathway that might limit the increase in global average temperature to 2°. The necessary scale and speed of implementation proposed by these modeling scenarios is belied by the fact that BECCS—like most other approaches currently grouped under the term "climate engineering"—faces huge unknowns in material and political support, and in human and ecological impact [*Anderson and Peters*, 2016]. The incorporation of an imaginary technological base to meet a politically negotiated goal that would otherwise be unfeasible has been interrogated as "magical thinking" [*Rayner*, 2016] and "policy-based evidence-making" [*Geden*, 2015], and brought under renewed questioning the processes by which the demands of politics can drive scientific expertise toward speculative conclusions.

In other words, the prospective deployment of BECCS (a claim upon the future) embedded within RCP 2.6 (an influential artifact) already anchors expectations and motivates actors in climate governance. Researchers must ask not only how BECCS — and by extension, the promise of negative emissions — came to achieve a prominent place in the IPCC scenarios underpinning the global community's climate targets, but how BECCS and other similarly speculative technologies might influence the development of strategies to address climate change in the unfolding context of the post-Paris process.

The Paris Agreement is ostensibly silent on climate engineering. Yet, an assessment of its articles, procedures and institutions by international legal scholars *Craik and Burns* [2016] concludes that "the building blocks for an internationally integrated approach to climate engineering law and policy are faintly present," though more so for negative emissions than sunlight reflection. A concrete point of entry — or entrenchment — may be the IPCC's slated special report on options for achieving the 1.5° target. Already, there are calls for the IPCC to openly acknowledge and assess the potentials of solar climate engineering alongside approaches for negative emissions, mitigation, and adaptation, to forestall a repetition of BECCS' "inclusion by stealth" [*Nature Geoscience*, 2016; *Parker and Geden*, 2016]. How and where these suites of technology are integrated into public discourse, industry, and governmental policy will reinforce a spectrum of options between prolonging and re-orienting our carbon dependence — and the spaces at which science meets policy in executing the Paris Agreement need to be watched.

4. Anticipatory Foresight

In recognizing the dynamics set in play by past and contemporary conceptions of the future, a second opportunity emerges for researchers. This is the use of scenarios and other foresight methods to design experimental futures, as a sandbox within which to provoke thought on a diverse range of possibilities and options for response, structure communication between different actors and perspectives, and subject conceptions of the future to critical reflection [*Selin*, 2008].

This kind of "anticipatory foresight" is a component of several related frameworks derived by STS scholars for the governance of emerging technologies — anticipatory governance [*Barben et al.*, 2009; *Guston*, 2014], future-oriented technology assessment [*Grunwald*, 2004] and responsible research and innovation [*Stilgoe et al.*, 2013] — whose tenets are being gradually imported into the climate engineering discourse (mostly) by researchers familiar with their application in the field of nanotechnology [*Foley et al.*, 2015; *Stilgoe*, 2015]. A shared idea between these frameworks is that if the future is more easily claimed than predicted in potentially game-changing technologies, technology governance can map and even steer these dynamics by maintaining and highlighting lines of communication between different futures, bodies of disciplinary knowledge and stakeholders, and by informing decision-making with its conclusions.

Efforts to apply scenarios and foresight for anticipatory purposes in climate engineering are still young, consisting largely of workshops with predominantly academic participation. Many use "explorative" scenarios — sets of juxtaposed futures with alternative developments, actors and contingencies — to reflect on the causes and consequences of those developments, as well as on the underlying perspectives and assumptions that participants bring with them. Some aim at the long-term in order to capture structural changes [50–100 years in *Banerjee et al.*, 2013], others aim at near-term dynamics [15 years in *Boettcher et al.*, 2015]. Still others extend the use of explorative scenarios to inform the design of governance options in a range of climate engineering approaches [*Bellamy and Healey*, 2014] or sunlight-reflecting methods in particular [*Haraguchi et al.*, 2015; *Boettcher et al.*, 2016]. And the range of potential applications remains wide, with suggestions for gaming and role-playing simulations to stress-test proposed pathways for technology development and governance [*Keith et al.*, 2010; see also *Milkoreit et al.*, 2011 and *Matzner and Herrenbrück*, 2016), or — in a more normative bent — envisioning futures towards or against which planning can be guided (*Lin*, 2015).

5. Studying Futures, Making Futures

Researchers from across the natural, applied, and social sciences — at least for now — play constitutive roles in framing issues and setting agendas at the boundary spaces between science, society, and policy, in which the steering momentum of future imaginaries plays an under-examined part. The inclusion of negative emissions approaches in IPCC modeling scenarios may be a prominent indication of this, and they are hardly the only speculative technologies emerging in the climate governance landscape. Scholarship must recognize that in assessing future-oriented technologies, experts are implicated in claiming and making the future—and help render these dynamics transparent (a useful starting point is *Stilgoe* [2015], an STS-grounded account of the evolution of climate engineering, and that calls for a mode of reflective "slow science").

Beyond studying imaginaries as they are translated into tangible policies, prototypes, and practices, researchers can apply the tenets of foresight as mediators in the construction of experimental futures, as part of anticipatory governance frameworks. Despite its growth in recent years, climate engineering is a young discourse that has yet to achieve mainstream resonance. Anticipatory foresight represents a proactive approach for engaging incoming stakeholders and demographics, and mapping the concerns and agendas that underpin their conceptions of the future under conditions of deep uncertainty. Perhaps most importantly, anticipatory foresight emphasizes the explorative and critical aspects of future-making; an appropriate approach for an emerging discourse with limited predictive capacity, strong political pressures, and a multitude of possible outcomes. As the next decade of research unfolds, it will be important to recall that exposing tomorrow's landscape is really an investigation of today's politics.

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