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# The practice of responsible research and innovation in “climate engineering”

Sean Low<sup>1,2</sup>  | Holly Jean Buck<sup>3</sup>

<sup>1</sup>Institute for Advanced Sustainability Studies, Potsdam, Germany

<sup>2</sup>Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, Netherlands

<sup>3</sup>Institute of the Environment and Sustainability, University of California, Los Angeles, California

**Correspondence**

Sean Low, Institute for Advanced Sustainability Studies, Berliner Str. 130, 14467 Potsdam, Germany.  
Email: sean.low@iass-potsdam.de

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**Abstract**

Sunlight reflection and carbon removal proposals for “climate engineering” (CE) confront governance challenges that many emerging technologies face: their futures are uncertain, and by the time one can discern their shape or impacts, vested interests may block regulation, and publics are often left out of decision-making about them. In response to these challenges, “responsible research and innovation” (RRI) has emerged as a framework to critique and correct for technocratic governance of emerging technologies, and CE has emerged as a prime case of where it can be helpfully applied. However, a critical lens is rarely applied to RRI itself. In this review, we first survey how RRI thinking has already been applied to both carbon removal and sunlight reflection methods for climate intervention. We examine how RRI is employed in four types of activities: Assessment processes and reports, principles and protocols for research governance, critical mappings of research, and deliberative and futuring engagements. Drawing upon this review, we identify tensions in RRI practice, including whether RRI forms or informs choices, the positionalities of RRI practitioners, and ways in which RRI activities enable or disable particular climate interventions. Finally, we recommend that RRI should situate CE within the long arc of sociotechnical proposals for addressing climate change, more actively connect interrogations of the knowledge economy with reparative engagements, include local or actor-specific contexts, design authoritative assessments grounded in RRI, and go beyond treating critique and engagement as “de facto” governance.

This article is categorized under:

Policy and Governance > Private Governance of Climate Change  
Social Status of Climate Change Knowledge > Climate Science and Decision Making

**KEYWORDS**

assessments, climate engineering, governance, research practices, responsible research and innovation

**Abbreviations:** BECCS, bioenergy carbon capture and storage, a CDR approach; CDR, carbon dioxide removal, or carbon removal; CE, climate engineering, or geoengineering; IAM, integrated assessment modeling; RRI, responsible research and innovation; SRM, solar radiation management, or sunlight reflection methods; STS, science, technology, and society studies.

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## 1 | INTRODUCTION

In March 2019, the Swiss delegation sponsored a resolution at the United Nations Environment Assembly (UNEA) for the UN Environment Programme to undertake a vaguely defined assessment process of “geoengineering and its governance.” In the proposal, geoengineering (we use the synonym “climate engineering,” or CE) encompassed both novel, planetary-scale sunshades (sunlight reflection methods, SRM) and carbon sinks (carbon dioxide removal, CDR; of late, negative emissions, NETs). The resolution’s failure was attributable to a number of reasons, including timing, terminology, and the broader implications of assessment for governance (Jinnah & Nicholson, 2019). It was ultimately stymied by United States and Saudi Arabia-led efforts to keep discussion of CE under the auspices of the Intergovernmental Panel on Climate Change (IPCC). Under the IPCC, analysis would be constrained to science rather than governance (Economist, 2019).

The failed UNEA proposal reflects challenges around assessing technologies and climate pathways. “Authoritative assessments” continue to be important for establishing benchmarks in both scientific and political arenas, and have steering effects in future activity (Gupta & Möller, 2018). Struggles are still playing out around the shape and scope of such assessment: when it is appropriate to assess it? By whom it should be assessed? What purpose does assessment serve?

These are central questions for scholars and practitioners informed by “Responsible Research and Innovation,” or RRI—and this includes ourselves. RRI is described by its practitioners as a wide-ranging set of philosophies and procedures for aligning the governance of novel fields of science and technology with societal values (Burget, Bardone, & Pedaste, 2017; Ribeiro, Smith, & Millar, 2017). Informed by science, technology, and society studies (STS), RRI is concerned with “governance” as more than risk management through regulatory policy. Rather, RRI sees governance as maintaining a dialog with society about how a field’s envisioned trajectory and risks are constructed, shaped by oft-hidden politics of scientific assessment and technological innovation. RRI seeks to not only generate but incorporate societal concerns into future assessment and regulation. “Deliberative” conversations, often within “mini-publics,” are seen as an ideal vehicle for developing alternative conceptions of risks that challenge technocratic narratives and pose reparative measures. In principle, RRI can inform governance from the laboratory and research program to the funding agency and the patent regime. In practice, RRI-informed activity—at least in CE fields—is pragmatically slanted toward academic spheres of critique and engagement.

One can think of RRI as the latest in a range of frameworks—versions of “Technology Assessment” (Schot & Rip, 1997); “Post-Normal Science” (Funtowicz & Ravetz, 1993); “Transdisciplinarity” (Lang et al., 2012)—that have sought to turn longstanding STS insights on the constructed and political nature of scientific knowledge into engaged practice within contemporary scientific and technological governance. There is an element of old wine in new bottles. The term can be seen as a politically invented attempt to bring together a heterogeneous set of practices and interventions; at the same time, the added value of RRI comes arguably from its mobilization of ideas re-purposed from antecedent frameworks and literatures (Ribeiro et al., 2017). Concurrent with “Anticipatory Governance” (Guston, 2014), RRI has become popularized in European contexts due in part to strong reference in Horizon 2020, the European Commission’s research and innovation program (de Saille, 2015).

RRI and climate engineering are a mutually foundational pairing of governance theory and case study—Stilgoe, Owen, & Macnaghten, 2013, a resonant prospectus of RRI, is grounded in an episode of SRM research governance. RRI interrogations have argued that the CE research ecosystem has often reflected and reinforced a particular paradigm: technical assessment of costs and risks as “actionable evidence”; a separate and secondary examination of societal dimensions; and treatment of stakeholder engagement as communication of scientific results. RRI, then, sets itself up broadly as a set of corrective measures to the practice and politics of technocracy. But RRI has not been questioned itself to a similar and corresponding degree. As climate engineering continues to be discussed—and as carbon removal gains interest from companies and policymakers—it is crucial that we understand the present context of RRI with regards to climate responses, including its limitations. This paper reviews how RRI has been employed in CE conversations, identifies tensions embedded in its practice, and make recommendations for future RRI-informed work. In doing so, we intend for the paper to reflect the thing it reviews: a critical examination of science and innovation governance informed by the traditions of STS. For greater ease of reference, we have included a brief list of acronyms and commonly referenced concepts preceding the main text.

## 2 | A REVIEW OF RRI PRACTICE IN CLIMATE ENGINEERING

RRI was first brought into CE conversations in the early 2010s by practitioners who had pioneered its application in United States and United Kingdom-based nanotechnology initiatives. RRI's initial anchor was the development of an advisory panel and “stage-gate” process around the testing of a deployment mechanism (a large balloon) in a small-scale SRM outdoor experiment hosted by a university consortium in the United Kingdom (the “test-bed” of the SPICE Project). The SPICE test-bed's travails and eventual cancellation in 2012 serves as the underpinning case study of Stilgoe et al. (2013), which lays out RRI's principles for enacting responsibility in science governance (see also Owen, 2014; Stilgoe, 2015).

In this decade of climate engineering research, we can trace RRI-informed activity in four overlapping areas—noting that “RRI” is not a unified tribe implicated in the same aims and actions. What constitutes an “RRI-informed” activity? In straightforward cases, the activity—which could be an intellectual product, a study, a deliberative event, or a line of scholarship—is defined as informed by RRI by the author(s). But often, principles of RRI are implicit in a study's intent and process, and we include such works in our review. We are wary that various works of engagement, discourse analysis, sociology, anthropology, and foresight can thereby be claimed in retrospect as examples of RRI practice, but there is reason to take account of them. RRI, first, draws upon these disciplines. And even if studies do not mention RRI as a motivating framework, they may dovetail with its intents; they may cite, and be cited by, RRI studies to reinforce mutually agreeable points.

### 2.1 | Assessment processes and reports

The first body of RRI-informed critique addresses the gray literature of assessment reports, exploring how experts setting the terms of debate has framing effects as part of “de facto governance”—the privileging of particular objectives for assessment, risk dimensions, areas of expertise and epistemology, and avenues for action that serve as informal but resonant conventions for bounding research (e.g., Gupta & Möller, 2018; see also Rip, 2014). Owen (2014), Morrow (2017), Gupta and Möller (2018), and Foley, Guston, and Sarewitz (2018) critique a perceived “actionable evidence” paradigm in seminal reports, as well as a countering mode of “responsible” or “anticipatory” assessment. All four highlight the seminal Royal Society report (Shepherd et al., 2009) as laying out a template followed in most subsequent assessments. The paired National Academies of Science reports on CDR and SRM (NAS, 2015a, 2015b) are argued to be especially technocratic and physical science-based, and in particular to set in motion a framing of SRM as a security issue at the deployment level, but as an issue of technical assessment at smaller level—this seeks to enable SRM at lower scales in “allowed zones” (Gupta & Möller, 2018; Morrow, 2017). Assessment, then, should explore societal and ethical concerns via deliberative engagements, rather than place ontological primacy on technical and physical risk via modeling and engineering calculations. It should engage in open-ended questioning, rather than normalize CE approaches via metrics of “costs” and “effectiveness” that make it digestible for policy. It should engage society as co-designers of research objectives and process, rather than as mere sources for data or audiences for results. And it should highlight the responsibilities of expert communities in shaping knowledge, rather than transfer responsibility for “using” that knowledge to society (Foley et al., 2018; Owen, 2014).

Accordingly, some reports, due to participation of RRI-informed scholars, attempt to formulate more deliberative assessment processes and governance recommendations. The Bipartisan Policy Center's report (Long et al., 2012) calls for exploratory foresight, substantive engagement, and collaborative, multidisciplinary approaches arguably due to the presence of “Anticipatory Governance” practitioners (noted by Foley et al., 2018). The Forum for Climate Engineering Assessment's report on SRM governance was generated by an Academic Working Group of social scientists and policy analysts; the report (Chhetri et al., 2018) emphasized “responsible knowledge creation” as a core objective, and devoted 6 of its 12 governance recommendations to concrete ideas for infusing principles and methods associated with RRI practice into existing governance systems at multiple levels.

### 2.2 | Principles and protocols

Most RRI-informed activity, however, takes place in the wider research ecosystem, where work is not coordinated as part of a commissioned assessment, but within which authorship networks, frames and received wisdoms, and “de

facto” governance can nevertheless be observed. We begin with what has evolved in later communications as variants of “principles and protocols” (e.g., Bellamy & Healey, 2018).

The seminal example here is the “Oxford Principles.” A set of five short research guidelines (regulation as a public good; public participation in decision-making; disclosure of research; independent impacts assessment; governance before deployment) generated in 2009 by a multidisciplinary group of UK-based academics, the Oxford Principles’ value has been argued by its creators to be as a “bottom up and incremental approach” with sufficient room for future activities to fit into, and as such, to be appropriate for an ever-evolving debate (Rayner et al., 2013). The Oxford Principles inspired a wave of such efforts: see the lists of principles contained in Asilomar Scientific Organizing Committee (2010), Long et al. (2012) and Schäfer, Lawrence, Stelzer, Born, and Low (2015).

Informal “principles” can also be seen in terms of both governance frameworks and guidelines for knowledge production. When it comes to governance, Stilgoe et al. (2013) describe RRI to be informed by “Anticipation, Reflexivity, Inclusion, and Responsiveness”; this resembles and is clearly mutually informed by “Foresight, Engagement, Integration, and Ensemblization,” the guiding principles of the concurrent framework of “Anticipatory Governance” (Barben, Fisher, Selin, & Guston, 2009; Foley et al., 2018; Guston, 2014). Bellamy (2016) draws on both, calling for “reflexive foresight,” judgment of CE based on “robustness” across multiple worldviews rather than technical optimality, and “legitimacy” as decided by societal debate. The key takeaway is although a premium is placed on understanding the political economy of futures-making, RRI practice must do more than map context—it must create engagements, reflect upon them, and tie the insights to concrete governance. Scholarship informed by RRI and STS also suggests informal principles for knowledge production, juxtaposing modes of instrumental knowledge production against an arguably more participatory and reflexive mode. These modes are phrased as “technocratic vs. democratic” (Owen, 2014), as “deductive” or “deliberative” activity (Low & Schäfer, 2019), as “solutionist” against “experimentalist” research and governance (Asayama, Sugiyama, Ishii, & Kosugi, 2019), or, resonantly, as a matter of “opening up” rather than “closing down” technology appraisal (Chilvers & Kearnes, 2019; Stirling, 2008).

### 2.3 | Critical analyses of research

A number of ethnographies or critical examinations of discourse in research practice have applied these principles piecemeal, as part of individual studies (in contrast to a sustained assessment or governance process). Many such studies are not conducted under RRI’s banner. However, they perform a kindred function of exposing the substance of arguments and power dynamics in the research landscape. Moreover, they are cited by studies, and provide background context for anchoring deliberative engagements, that explicitly invoke RRI.

A key example of this is the large literature of content mapping and discourse analyses of frames and narratives from media, academia, and policy that assess how CE is packaged and received (Porter & Hulme, 2013; Scholte, Vasileiadou, & Petersen, 2013; Huttunen, Skyten, & Hilden, 2014; Oldham et al., 2014; Harnisch, Uther, & Boettcher, 2015; Linner & Wibeck, 2015; Himmelsbach, 2017). These analyses include maps of moral positionings (Betz & Cacean, 2011); framings of advocacy, detraction, and appropriate governance (Anselm & Hansson, 2014a, 2014b; Boettcher, 2019; Cairns & Stirling, 2014); metaphors with medical, mechanistic, and military connotations (Luokkanen, Huttunen, & Hilden, 2013; Nerlich & Jaspal, 2012); and kinds of “catastrophism” (Asayama, 2015).

Later studies explicitly informed by STS explore how scientific “knowledge” of CE’s potentials is constructed, though from a more systemic than specific (e.g., an actor’s or institution’s) point of view. Low and Schäfer (2019) argue that different modes of research practice (e.g., technical modeling vs. deliberative engagements) emphasize particular types of risk, and entrench the status and biases of actors with relevant expertise. Talberg, Thomas, Christoff, and Karoly (2018) examine underpinning assumptions and signaling implications of different kinds of “scenarios” (both modeling and more qualitative imaginings); Gupta and Möller (2018) explores “normalizing” frames set in motion by authoritative assessment reports as *de facto* governance.

This literature strongly interrogates modeling practice. One half of this work focuses on the modeling of SRM deployment schemes and impacts via earth systems models. Wiertz (2015) provides the earliest interrogation in the CE literature of evidence construction and validation within modeling structures; Flegal (2018) is a comprehensive update, with an emphasis on the advocative tendencies of actors who rely on modeling results. Flegal and Gupta (2018) and McLaren (2018) argue that dimensions of (in)equity and (in)justice are set in motion by SRM scenarios, while Schubert (2019) traces how the forceful numeracy of modeling has shaped the discussion of SRM in the US.

The other half unpacks the origins and ongoing implications of “bio-energy carbon capture and storage” (BECCS) in scenarios calculated by integrated assessment models (IAMs) for the IPCC’s Fifth Assessment Report (AR5). BECCS is integral to scenarios that keep temperatures at century’s end below 2C; a threshold that would, a year later, be adopted in the Paris Agreement. BECCS, as well as the IAM research community, have since been interrogated for their roles in underpinning otherwise improbable climate targets, with scrutiny given to the normalization of BECCS and carbon budget “overshoot” in expectations for future climate politics (Beck & Mahony, 2018a; Haikola, Hansson, & Anshelm, 2019; Haikola, Hansson, & Fridahl, 2019); the quid pro quos and tensions between IAM work and political imperatives (Beck & Mahony, 2018b; Geden & Beck, 2014); and the history, practices, and perspectives of the IAM community in producing what Jasanoff (2004) calls “regulatory science” (Cointe, Cassen, & Nadaï, 2020; Guillemot, 2017; Haikola, Hansson, & Fridahl, 2019; Low & Schäfer, 2020).

## 2.4 | Deliberative engagement and futuring

If critical analyses map the knowledge and political economies with an eye to inequities, RRI also generates engagements with those missing constituencies, and develops “futures” that represent under-investigated discourses and profiles of risk and uncertainty. The objective is to be explicitly “generative” (Vervoort, 2019), and not simply to recognize the (perverse) signals and effects of existing imaginaries, but to create alternative narratives (Stilgoe et al., 2013; van der Duin, 2018; Vervoort & Gupta, 2018). Current efforts to do so are limited; we can do more to make them specific to actor and region, and especially to connect them to conclusions of critical mapping studies.

One resonant body of deliberative engagement work has been conducted by a UK-based network of practitioners who align themselves strongly with the RRI program. Bellamy and Lezaun (2017) summarizes a “second wave” of engagements; key examples include Corner, Parkhill, Pidgeon, and Vaughan (2013), Bellamy, Chilvers, Vaughan, and Lenton (2013), Macnaghten and Szerszynski (2013), and the secondary analysis of McLaren, Parkhill, Corner, Vaughan, and Pidgeon (2016). These works pose themselves as a course correction to a first wave of engagement studies argued to highlight facilitative frames from modeling work, and lock SRM and CDR in as policy options (e.g., Ipsos MORI, 2010; Mercer, Keith, & Sharp, 2011; regard the framing language of Burns et al., 2016). “Second wave” engagements, then, are kin to critiques of the “actionable evidence” paradigm of authoritative assessments (see Section 3.1, and Owen, 2014), with the same efforts to refocus attention on society’s right to be involved in defining the feasibility, risks, and aims of CE. The results of these studies tend to portray public perceptions as critical of CE in comparison to more established mitigation options (particularly of SRM), and as placing a stronger focus on social dimensions of risk to which technical modeling is less amenable. Many other engagements exist that do not self-identify with this normative project, although they—to a less forceful degree—share conclusions regarding perceptions of CE (e.g., Wibeck et al., 2017; Wibeck, Hansson, & Anshelm, 2015), as well as problematize procedures of deliberation and constitution of publics (Cairns, 2019; Sugiyama et al., 2017).

A less visible body of work draws inspiration from older branches of “future studies,” as well as the practice of foresight in planning (see Barben et al., 2009; Guston, 2014; Selin, 2008). Several “single-author scenarios” leverage the logic of experimental futuring to consider contingencies (Bodansky, 2013; Morton, 2015; Rabitz, 2016; Sweeney, 2014). An adjacent literature is tied more to RRI principles, using deliberative stakeholder engagements to generate “explorative” scenarios that link the imagination of risks to the concerns of participants present (e.g., Banerjee, Collins, Low, & Blackstock, 2013), as well as to possible governance mechanisms (Bellamy & Healey, 2018; Low, 2017). Further efforts are emerging in forms of gaming and role-playing (Matzner & Herrenbrück, 2016; Suarez & van Aalst, 2017). There continue to be calls for this brand of foresight to be applied further (Chhetri et al., 2018; Vervoort & Gupta, 2018). But for now, foresight (and gaming) studies are less visible when compared to scenarios generated by modeling, or even other deliberative engagement activity—possibly because of internal debate over the truth-value of scenarios with deliberately rich fictions, and by connection, whether scenarios can act as tool of projection for strategic guidance, or only as a platform for deliberation.

Future engagement work should unlock the potential of deliberative formats currently marshaled under wider RRI practice (Ribeiro et al., 2017, p. 93; Chilvers & Kearnes, 2019, p. 10). Typical variations of focus groups and participatory forums are low-lying fruit. The potential of games (Mendler de Suarez et al., 2012; Vervoort, 2019) and fiction (e.g., “climate fiction,” Milkoreit, 2017) are underapplied as engagement, role-playing, and futuring tools (see Buck, 2019a, which combines elements of both). The resonance of modeling epistemology and scenarios in SRM and CDR assessments should especially motivate RRI to treat modeling not only as a realm of critical inquiry (Section 2.3), but as

a learning and generative tool (Salter, Robinson, & Wiek, 2010; van der Sluijs, 2002) for which we are already beginning to see initiatives (Carton, n.d.; DIPOL, n.d.; FCEA, n.d.-b). One of these (FCEA, n.d.-b) leverages the insights and practices of science fiction, foresight-based scenarios, and integrated assessment modeling for policy information.

### 3 | TENSIONS IN RRI PRACTICE

RRI practice contests the bounds of debate in climate engineering, but it does so in particular ways. How have some practitioners attempted to reinforce assessment and discourse in their image? How has RRI itself been shaped by activities within climate engineering research and assessment? In what follows, we turn our attention to the effects of this RRI-inspired work, as well as draw out some of the underlying tensions and inconsistencies.

#### 3.1 | Informing versus forming social choices

First, there is a tension in RRI practice between what Stirling (2008) distinguishes as “commitments,” or the inevitable “*forming* of social choices” on a novel technology that then manifests as forms of policy, funding, regulation, and liabilities; and “appraisal,” or the *informing* of those choices. RRI practice is dedicated to “opening up” appraisal, but is less vocal and specific on the formation of commitments. RRI does not preclude the emergence of dominant narratives and ensuing policies—as long as these are not perverse, inequitable, or recklessly enabling; or that they reflect a considered consensus that emerges from sustained engagement with publics and stakeholders deemed relevant (e.g., Stirling, 2008, p. 284). And much thinking is dedicated to “Responsiveness,” or adjusting regulatory policies and structures (within governance activities writ large) in light of insights gleaned from “anticipatory, reflexive and inclusive” assessments (Stilgoe et al., 2013). Yet, this is more a matter of establishing a process for “responsible” science governance, rather than throwing (or even implying) support behind particular trajectories or visions of development. “Closing down” can seem like a state of affairs held in abeyance.

Several contexts lend themselves to the slipperiness regarding when the “right” commitments would and should become entrenched. The generally stated reason is that it is ultimately up to “society,” howsoever defined, to decide. This bears merit, but the shaping role of the researcher in reaching or rejecting such a conclusion is certainly underplayed. The second is pragmatic: RRI activity in CE is currently staffed largely by social scientists with stronger collective expertise in mapping knowledge than policy formation or regime reform, and may not be geared against “forming” as much as comparatively geared toward “informing.” A third reason might lie at the heart of RRI as a project descended from STS. What would happen if engagements began to comprehensively reproduce enabling, technocratic frames? To what degree must the RRI practitioner maintain, in the critical tradition, that “it could be otherwise”?

How are these tensions manifesting in CE discourses? At the broadest level, efforts to forestall the specter of “mission-driven research” for policy formation may have some partial influence in impeding the formation of concrete policy or trajectories of development. In the absence of policy, RRI studies also give an incomplete portrayal of contestations over “de facto” governance that primarily assess the activities of a technology’s advocates (we return to this later). But RRI work is also showing signs of divergence in the fields of SRM and CDR, reflecting escalating trends that reject the coherence of the “climate engineering” umbrella.

#### 3.2 | Enabling CDR, disabling SRM?

Research in SRM and CDR has co-evolved, with overlapping actors and discourses. But while RRI work on SRM remains a cross between generating open appraisal and critical commitments, some RRI engagement in CDR is beginning to reflect enabling frames generated by “net negative” and “net zero” emissions in policy conversations. Bellamy (2018), for example, reframes the language of RRI around “responsible incentivization” with specific regard to CDR, and calls for such incentives “as an explicit policy goal”—compare this to the language of Bellamy et al. (2013) and Bellamy (2016), which implies extreme caution for framing SRM as an object of policy. The emergence of policy-oriented frames on kinds of CDR in RRI-informed work is—regardless of whether CDR policy might eventually be restrictive or enabling—a stage of permissiveness yet to be granted to SRM.

Several factors may have been facilitative. Heterogeneous arguments for disaggregating the umbrella term of “climate engineering” (e.g., Heyward, 2013; Boucher et al., 2014; NAS, 2015a; Pereira, 2016; Keith, 2017) have had a functional effect

in separating carbon removal from the more controversial baggage of sunlight reflection. Long (2017), Morrow (2017) and Gupta and Möller (2018) argue that the increasing SRM-CDR split in assessment reports has had the steering effect of presenting SRM as a more uncertain prospect than CDR, with the effect that critical social science came late to the latter. The emergence of BECCS in 2C and 1.5C emissions pathways in prominent IPCC reports is also normalizing the promise of CDR through the concept of “net negative emissions” (Beck & Mahony, 2018a; Haikola, Hansson, & Anshelm, 2019), with salutary effects for the preceding concept of “net zero emissions,” or carbon neutrality (Geden, Peters, & Scott, 2019).

Moreover, there is an increased awareness of BECCS in climate policy, particularly in light of growing aspirations toward carbon neutrality by 2050. This could be a reason for comparatively permissive frames in CDR research. However, there is neither indication of policy uptake beyond target-setting, nor of much literacy in climate decision-making on the shape of carbon removals needed to make “net zero” plausible. Much assessment is dedicated to filling this knowledge gap, but many studies might not identify as RRI-informed, framing themselves as exploring barriers to—or implications of—rollout of BECCS at scale (e.g., Fridahl & Lehtveer, 2018; Gough, Mabon, & Mander, 2018). These are not necessarily “reflexive” analyses of knowledge economy as much as sociopolitically oriented supplements to calculations of techno-economic and biophysical barriers to CDR deployment (e.g., Minx et al., 2018; Rickels, Merk, Reith, Keller, & Oschlies, 2019; Smith et al., 2015).

There is an opportunity for RRI-informed activity to ensure that research that does treat CDR as a “policy object” (Owen, 2014) is not recklessly instrumentalized. We should engage with policy-oriented metrics as an imperfect step in debating the challenges of scaling such systems, but practitioners should step up explorations of whether envisioned terrestrial, marine, or technological CDR approaches meet appropriate variations of societal acceptance. RRI and STS engagements with CDR are just beginning. Prior to the BECCS debate, there were few societal and political studies of CDR's implications and knowledge economy, though there is significant empirical research on particular techniques such as forest carbon sequestration and carbon capture and storage (Buck, 2016), and a little on ocean iron fertilization (a discredited form of marine CDR, see Buck, 2019b; Gannon & Hulme, 2018). RRI and STS engagements currently coalesce around terrestrial CDR such as BECCS. One discernable strand of research consists of STS-informed studies on the knowledge economy of IAM work that has led to BECCS' current visibility (Beck & Mahony, 2018a, 2018b; Cointe et al., 2020; Haikola, Hansson, & Anshelm, 2019; Haikola, Hansson, & Fridahl, 2019; Low & Schäfer, 2020).

The second relies on analogical comparisons, or surveying and (deliberative) engagement exercises, to source socio-political and ethical concerns. The sprawling UK-based “Greenhouse Gas Removal from the Atmosphere” program contains a project investigating scenarios under which CDR approaches might reinforce the carbon economy (“mitigation deterrence,” Markusson, Jarvis, Szerszynski, & Tyfield, n.d.) with stakeholder groups. Bellamy, Lezaun, and Palmer (2019) map perspectives on BECCS policy instruments. Buck (2018a) also explores how (here, rural Californian) perspectives on CDR may come to be shaped by uniquely local, entrenched interests on renewables, and (2016) draws upon analogies with biofuels and forest carbon controversies to point out potentials for land-use conflicts, cash-crop dilemmas for smallholder farmers, or the rise of artificial economies regarding BECCS.

The conduct of RRI in CDR debates, however, could learn positive and cautionary lessons from a comparatively earlier set of RRI engagements in SRM, including the only such concrete governance mechanism—the SPICE “stage gate” (Stilgoe et al., 2013). More forthright disagreement can be observed between RRI-informed work, and those they perceive as proponents of SRM research who subscribe to an “actionable evidence” paradigm. These are: stages of research defined by environmental and technical thresholds that demarcate allowed zones for field tests (Parker, 2014; Parson & Keith, 2013), “mission-driven” climate modeling for assessing physical risk to inform further discussion (Keith & Irvine, 2016; MacMartin & Kravitz, 2019), questioning the certitude of a “slippery slope” toward deployment, the “moral hazard” or “mitigation deterrence,” and the ungovernability of a technology with systemic effects (Keith, 2017; Reynolds, 2014), developing governance tenets with a wider focus on technology development (e.g., intellectual property and patenting governance) and deployment (e.g., liability and compensation) (Reynolds, 2019), and research programs with a systems engineering approach (Keith, 2017).

RRI-informed work contests these assumptions on every front. A quick retour is valuable: These emphasize that the technical distinctions between stages and scales are clouded when mapping societal concerns (Stilgoe, 2015), that modeling functionally brackets of sociopolitical dimensions and sets skewed notions of risk, equity and justice in play (Flegel & Gupta, 2018; Low & Schäfer, 2019; McLaren, 2018), that there are strong indications of “mitigation deterrence” (McLaren, 2016), or that the characteristics of SRM as projected cannot be managed by democratic processes (Hulme, 2014; Macnaghten & Szerszynski, 2013). Still others highlight the tendency of engaged stakeholders to emphasize socio-political concerns over technical viabilities (Bellamy, 2016; Bellamy et al., 2013; McLaren et al., 2016), that engagement work has to deliberately “unframe” SRM as a policy object (Corner et al., 2013), and that proponents of

SRM research are conducting “boundary work”: setting up the questions such that they are themselves best suited to deliver the answers (Owen, 2014).

At the same time, there are tensions in these critiques. For example, one study—Macnaghten and Szerszynski (2013)—has been critiqued for double standards in characterizing SRM as incompatible with democracy, and for not asking if SRM is any less governable than previous case studies of comparable problem structure that have become accepted regimes of global governance (Heyward & Rayner, 2013; Horton et al., 2018; Keith, 2017). In what follows, we ask if RRI practitioners are engaged in their own boundary work, and how this is shaping activity in SRM and CDR.

### 3.3 | Positionalities

Positionality is difficult to grapple with—we ourselves have sympathies toward RRI critiques that can be observed in our respective works.<sup>1</sup> That said, RRI in CE is not even-handed in its pursuit of reflexivity, tending to interrogate—and thereby emphasize—actors outside of their own practice: modelers, engineers, perceived technophiles, the media, and policy and civic participants. The shaping roles of RRI practice in CE discourses, or self-examination by practitioners in individual studies, are more often caveated than examined in-depth (e.g., Bellamy, 2016; Owen, 2014 p.217).

RRI practitioners engage in the activities that they observe. van Oudheusden (2014) notes that RRI is typically presented as procedure (where deliberation and democracy lead to more socially robust results) rather than politics (how RRI practitioners intentionally or functionally influence sociotechnical regimes, in the manner of the technically focused communities they examine). RRI can be seen as efforts to shape “de facto governance,” the informal but forceful norms of scientific conduct (Rip, 2014), which can be linked to “performativity” (a concept used across the social sciences to inquire after how actions and ideas have imperfectly self-fulfilling effects). Indeed, when RRI's practitioners emphasize the political over the technical in mapping CE's potentials, this is “boundary work” (Star & Griesemer, 1989), where expert communities contest what is at stake (“benefits and risks” is a popular formulation) and with whom responsibility ultimately lies, by defining problems and solutions in a manner that reflects their own identities and agendas.

RRI's boundary work reverses the polarity of technical, policy-coupled research in three connected trends of “de facto” governance. First, RRI reformulates definitions of technology performance or viability not as questions of cost, feasibility, and physical impact, but rather in terms of legitimacy gleaned from democratic consent. Second, RRI emphasizes socio-political and ethical questions instead of technical ones; furthermore, pointing out that there is a limited degree to which societal questions can be shaped by technical knowledge. Third, RRI argues that societal concerns must be explored through open-ended deliberation and imaginative futuring, rather than shaped by proxy via modeling parameters and results. In this way, RRI-informed work (especially in SRM) redefines the terms of debate in such a manner that technical disciplines, or technology advocates, possess less authority to speak to what is at stake than arenas more amenable to RRI-based expertise: stakeholders, “publics,” “democracy,” worldviews, and the social sciences. An important caveat is that these contestations take place to a more forceful degree in SRM conversations, where networks and positionings are more coherent and entrenched.

The argument, certainly, goes both ways: technical, policy-focused networks do this in reverse. The point is that RRI activities in CE rarely reflect on the degree to which key insights—often portrayed as emerging naturally from stakeholder engagements—coincide with the wider aim of producing governance that counters technocratic pressures, or more uncomfortably, with institutional or personal positionings. We are supportive of RRI's aims and wonder if exploring its politics provides ammunition for instrumentalists. But stronger awareness and disclosure of positionality should not erode RRI's value (see Footnote 1).

There is, however, an element of speaking to the converted. RRI is currently more successful at marshaling the engagement efforts of critical social scientists, than substantively altering the activities of modeling and engineering communities, industry professionals, policy-makers, or social scientists with more positivistic methods for risk assessment or enabling stances toward R&D. Indeed, it is questionable whether the loose structure of RRI's concepts and approaches is seen as coherent outside of its own community (Ribeiro et al., 2017), and the theoretical and practical challenges of “deliberation” continue to be debated (Lenzi, 2019; Lövbrand, Pielke Jr., & Beck, 2011). On questions of positionality and influence, RRI would benefit from increased exchange with practitioners from forms of Technology Assessment (and other longer-running frameworks) that have in the past grappled with relevance and identity, becoming institutionalized or instrumentalized, and the elided politics of their own practice (e.g., Van Est, 2017 and special issue).

This remains a partial review of RRI's constitutive effects in CE. Spaces to watch may include the “responsible incentivization” of CDR approaches; we might observe if RRI work begins to re-produce or reject the “policy object” frames currently endowed on BECCS, or if these are inherited by marine-based CDR or direct air capture. RRI, since the SPICE project, has not been re-applied as a concrete governance mechanism, and whether it re-surfaces as part of (small-scale) field tests and pilot projects of SRM or CDR would say much about its resonance. For now, we might note that the concept of “responsibility” itself becoming the object of boundary work. “Responsible” research and innovation (or incentivization) claims the word and the opening move in framing it (Stilgoe et al., 2013, p. 1569). Keith (2017), however, labels as “responsible” an SRM research program centered around systems engineering and stress-testing development and deployment scenarios. Assessments with no inclination toward RRI have used “responsibility” to reframe governance to their favor (e.g., NAS, 2015a on “responsible” deployment of SRM, see critique of Morrow, 2017); others invoke RRI tenets, but recommend governance that is still of the mode that RRI criticizes (see Foley et al., 2018).

## 4 | SOME FUTURE STEPS FOR RRI PRACTICE IN CE

Beyond acknowledging positionality, we propose some steps that can be taken in future RRI practice in SRM and CDR conversations, with the goal of asking practitioners to further confront challenges noted earlier.

### 4.1 | Use RRI as a lens on the long arc of climate governance

First, we should apply RRI concepts to the definitional politics of CE. This means treating SRM and CDR approaches not strictly as separate, nor holistically as “climate engineering,” but as the latest steps in lineages of sociotechnical climate strategies that were in their time seen as novel. For example, we would not be talking about BECCS if not for land-use management, carbon sinks, and biofuels (Buck, 2016), carbon capture and storage (Markusson, Dahl Gjefson, Stephens, & Tyfield, 2017), the legacy of eco-neoliberalism (Carton, 2019), or if CDR and SRM had not been framed together for a time as novel interventions in the global climate. The way all these current and historic components have been discussed and managed informs us about BECCS' political economy, as well as avenues for governance. And not only have SRM and CDR co-evolved or been influenced by antecedent sociotechnical systems in climate governance; they have overlapping spheres of actors, concepts, institutions and discourses in the same post-Paris Agreement governance and policy space.

It is increasingly argued that SRM and CDR approaches should be assessed separately, and even as individual approaches, due to different technological, climatic, and political characteristics, and that “climate engineering” is a term that has lost coherence. RRI-informed assessment should resist fostering an amnesia about “climate engineering” because it facilitates an instrumentalist tendency toward defining risks and opportunities for particular approaches (e.g., NAS, 2015a, 2015b); it should also resist wholly separate treatment as this “forfeits an opportunity to think about a holistic climate strategy” (Long, 2017).

Rather, exploring SRM and CDR approaches more as “novel climate strategies” (the concept matters more than the name) allows us to de-emphasize the rigidity of the “climate engineering” moniker, or, for that matter, SRM and CDR, while recognizing their framing roles. It allows us to more fluidly situate these approaches (and how they are labeled) as their fits with established suites of mitigation and adaptation are negotiated, and it opens up a wider conversation on these approaches' connections to past, present, and future climate strategies. This may seem vague to the reader, who may find a continuing need to scrutinize categorizations obvious, but remain unsure about the usefulness of specific demarcations.

Yet, consider that there are multiple such examples in current climate governance besides what are now termed types of SRM and CDR. A similar kind of uneasy and unfinished fitting has been happening to carbon capture and storage (Krüger, 2017), “bridging” or “clean” fossil fuels (Lazarus, Tempest, Klevnäs, & Korsbakken, 2015), and short-lived climate forcing pollutants (Victor, Zaelke, & Ramanathan, 2015)—as was once the case for “adaptation” (Schipper, 2006). What have the politics of assessment and categorization been in these cases; how have they been performative in policy? To what degree might novel climate strategies be captured by interests in the carbon economy, following examples in the past (McLaren, Tyfield, Willis, & Markusson, 2019)? How would proposals for kinds of sunshades and carbon sinks unfold alongside these avenues and others in a Paris Agreement era of governance—described as bottom-up,

polycentric, and catalytic in intent (Held & Roger, 2018), but potentially be *laissez faire*, driven by markets and clubs, and rife with externalities (Ciplet & Roberts, 2017)?

## 4.2 | Reparative, generative, and situated engagements

In the future, we must more actively connect mappings and interrogations of the knowledge economy with engagements which seek to repair the shortcomings which they map and implicitly critique, and include local or actor-specific contexts. These are already in RRI's mission statement; our suggestion is to emphasize them for incoming SRM and CDR assessment.

The research mapping the landscape of discourses, actors, institutions, and agendas contesting CE governance has a generally emancipatory intent (Section 2.3). These critical analyses, however, can play a more purposefully corrective role, if RRI practitioners more systematically connect them to initiatives that generate narratives and include constituencies based on inequities in knowledge construction (Section 2.4), especially in projects emphasizing national or local contexts that would shape particular concerns and avenues for effective governance. Such connection should motivate RRI practice to grapple with the tensions of explicitly generative work, especially between providing a platform for deliberation or for application in concrete governance or technology development processes (Low & Schäfer, 2019, p. 8). Foresight work, in particular, comes to RRI from government and business planning, and RRI-informed futuring has to learn how to negotiate with instrumentalist interpretations of its value. Similarly, connections between mapping and generative work in local contexts would more tightly focus the latter. Deliberative engagements based in northern Europe (however unintentionally) give the impression of delivering generalizable insights from some globalized public, while the much smaller set of foresight and scenarios activities has often taken a catch-all, global approach to mapping concerns. Engagement might take different shapes in different contexts; the northern European context has tended to favor mini-publics (e.g., Bellamy & Lezaun, 2017), while the American context shows a stronger tendency toward engaging interest groups (e.g., FCEA, n.d.-a).

In general, we make a plea for RRI practice to operate more often under guiding questions relevant to a specified political context and audience. Modeled deployment schemes, risk scenarios, and governance recommendations are often conceptualized at a global scope; unspecified users of these works are treated functionally as “benevolent global planners.” High-level and parsimonious approaches have benefits (e.g., Long, 2017; Rayner et al., 2013), but can also create insights divorced from specific politics, as well as policy, funding, and innovation processes (Vervoort & Gupta, 2018). This is not an argument for solution-oriented assessment, or against emancipatory research, or against studies of systemic scope. Rather, a “hosting” set of structures, worldviews, policy platforms, and political agendas presents a sandbox within which one can pose context-driven but RRI-informed activities, bounding the plurality of imaginaries and stakeholders, and coming down explicitly on the side of embeddedness rather than divorced critique. Morrow (2019), for example, argues that calls for a “mission-driven” research program (in this case, proposals for SRM research in the US—see Keith, 2017) have to be engaged, and bridging spaces between informing policy and exploring societal legitimacy can be designed. “Situated” engagement can take place at all levels in contexts that are locally meaningful, whether they be in governmental settings, or community centers, educational institutions, and religious organizations.

We can imagine these activities taking place as part of an assessment or a research program. Recall the UNEA resolution in the introduction. The status quo in assessment is a multidisciplinary agglomeration of work packages on technical definitions, modeling, politics, legal mechanisms, and governance that are “separate but equal” (Foley et al., 2018), and that typically treats RRI-informed activity as a segregated component filed into the “governance” section under “upstream,” “sub-state,” or “bottom up” processes (e.g., Schäfer et al., 2015; Shepherd et al., 2009). An assessment process grounded entirely in RRI, then, might contain the twinned streams of mapping and generative activities highlighted earlier, and the framework of Barben, Beck, Matzner, and Wittstock (n.d.) provides a valuable template. Such assessment would be made relevant to international bodies (the UNFCCC or UNEA), firms and industry (Shell, fossil fuel extractors), national contexts, and regions with histories of coordination (the European Union [EU], or small island states). For example, within the context of the European Union (where both authors have studied and worked), the mapping stream would have to account for specific historic discourses and commitments (e.g., support of the 2C target, the precautionary principle), contextual politics (e.g., heterogeneous energy landscapes within the bloc; trends toward pluralism and fragmentation), and review actors and perspectives both privileged and missing. Engagement and futuring activities would account for the fact that assessments have largely taken place within a handful of

wealthy northern European states with comparatively strong climate ambitions (Bellamy & Geden, 2019; Biermann & Möller, 2019; Stephens & Surprise, 2020). Tying these insights to concrete governance would require understanding the EU's coordination of research funding, and policy in climate, energy, and innovation (2050 Long-term Strategy, n.d.; Policy for Research and Technological Development, 2019), as well as the relevance and agendas of its national and regional regulatory structures.

One can ask, given the emphasis of RRI on the situated, how such processes are scalable. How might an ecosystem of context-specific, embedded conversations be put together in a systemic manner? Most RRI practitioners would argue that engagement does not need to be universal to improve the quality, robustness, and social attunement of research, but scaling engagement is perhaps important for securing planetary legitimacy. There are precedents here; context-specific assessment in climate governance is frequently incorporated into larger summaries. We can point to the IPCC's Working Group II on impacts and vulnerabilities—which not only have to be highlighted as specific to region and capacity, but in metrics and concepts that allow comparability across context, and be communicable at an imperfect aggregate level. Indeed, few insights are so unique as to have no wider relevance. Perspective mapping done among Finnish Laplanders (Buck, 2018b) might, for example, have broader generalizability for rural communities, the indigenous, or Arctic polities. (Buck (2018b) also argues that concerns explored here were reflective of a global imaginary rather than a specifically local one.

### 4.3 | Design governance beyond research and assessment

The first clear engagement of RRI in climate engineering debates—the “stage gate” of the SPICE “test bed” (Stilgoe et al., 2013)—was a concrete governance mechanism and process. It might seem odd that there have since been no further examples. In SRM, there has been a lack of field demonstrations since SPICE to direct such efforts, and an upcoming small-scale experiment planned by Harvard researchers (Dykema, Keith, Anderson, & Weisenstein, 2014) appears less engaged by RRI practitioners. CDR, through BECCS, has overtaken SRM as a topic of policy-oriented conversation, but RRI practice has similarly not engaged with (the albeit limited number) of projects and pilots that develop the hardware and components of CDR (e.g., BECCS or direct air capture) systems.

Rayner (2017) described the state of CE as a “research impasse,” where technologists were waiting for a more permissive climate, while social scientists concerned themselves with mapping imaginaries. This formulation is generous to technologists and unkind to social scientists, but it seems accurate that RRI practice has since SPICE pragmatically treated *research itself as a form of governance*. There is, in our estimation, nothing wrong with this avenue of activity—imaginaries are resonant, and interrogating the evidence and actors that underpin them is, as we have noted, its own form of “de facto” governance.

But there is also room to explore proposals for concrete governance mechanisms and processes—these should not be seen as facilitative, but anticipatory. “Principle and protocols” remain an adaptable governance suite: the “Code of Conduct” of Hubert (2017) integrates principles of “responsible” research with international legal norms and is a living document iteratively developed with stakeholder engagements. We can re-examine the value of information clearing houses and other kinds of disclosure mechanisms (Craik & Moore, 2014). RRI practice must also develop processes that grapple with specifics of technical hardware development, such as tying R&D to incentives that prevent fudging on mitigation (McLaren et al., 2019), or patents and intellectual property rights (Parthasarathy, Avery, Hedberg, Mannisto, & Maguire, 2010; Reynolds, Contreras, & Sarnoff, 2017). Not enough attention has been paid, since the SPICE “stage gate,” to concrete “provisions to detect, slow, or stop lock-in” at stages from conception to implementation (McKinnon, 2018). And all of these questions can be similarly be linked to and informed by the insights of engagement and critique, and adapted to particular institutional, sectoral, or political contexts and agendas.

## 5 | CONCLUSION

RRI activity has appeared in climate engineering over the past decade in the forms of assessment processes, principles and protocols, critical mappings, and deliberative engagements. Right now, SRM in particular faces a research impasse, and has no governance. The recent 2019 attempt at the UN Environment Assembly highlighted the challenge of even agreeing to assess it. But it is possible this will change: the IPCC is considering SRM in its Sixth Assessment Report,

and the US National Academies of Sciences are studying a research agenda. Carbon dioxide removal, meanwhile, is gaining in research and attention.

The stakes are thus high for developing responsible research and innovation in both these climate response approaches. RRI has arguably been moderately successful as a corrective in the previous decade's context—when SRM was a fringe idea with very little research funding, and climate change was not yet considered an “emergency” by mainstream thinkers. We cannot take for granted, however, that it will be successful in opening up debate or foregrounding social dimensions of these climate responses in future contexts. Long and Blok (2017), for example, suggest that the values associated with current forms of populism conflict with values central to RRI, and even suggest that a lack of RRI may have aided the populist rise, critiquing RRI scholars for being inadequately critical of the economic system. They call for a “resurgent RRI,” more critical and assertive, which can question the political economic context in which RRI is performed (Long & Blok, 2017). Indeed, climate engineering research in particular would benefit from a “recalibrated” RRI. Going forward, applying RRI to climate intervention can help to produce assessments that are grounded in RRI which map not just technologies and narratives, but actors involved. It can help to produce concrete governance mechanisms, not just serve as de facto governance by governing research. And an RRI approach can help in the holistic assessment and discussion of all climate responses, not just solar geoengineering or carbon removal discretely. This can inform a more intelligent and robust climate response strategy than when SRM and CDR are evaluated without relationship to each other, or to either mitigation, or adaptation.

## CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

## AUTHOR CONTRIBUTIONS

**Sean Low:** Conceptualization; data curation; formal analysis; writing-original draft; writing-review and editing. **Holly Buck:** Conceptualization; writing-review and editing.

## ENDNOTE

<sup>1</sup> A note on our own positionalities regarding SRM and CDR is warranted. Low is wary that these proposals—as concepts as much as scaled systems—may be captured by the carbon economy, following antecedents such as the Kyoto Protocol's “flexibility mechanisms”. He believes that the resonance of SRM and CDR approaches lies less in the heterogeneous calculations of their technical capacities, and more in what they promise as ideas (e.g., expanding the carbon budget) that trickle down systemically into politics. Buck has a similar concern about capture by the carbon economy/carbon management, especially with direct air capture coupled with enhanced oil recovery, but is also interested in exploring alternative pathways to large-scale carbon removal, as explored in Buck (2019a), *After Geoengineering*. She views SRM as worthy of research from a risk management standpoint.

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