Geoengineering Governance, the Linear Model of Innovation, and the Accompanying Geoengineering Approach

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Climate Geoengineering Governance Working Paper Series: 020.

Published online 16 February 2015

Climate Geoengineering Governance (CCG)

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KEYWORDS: *Geoengineering, the Collingridge Dilemma, the Linear Model of Technology Innovation, Technology Accompaniment, Ethics of Technology*

Geoengineering Governance and the Two Lessons from Science and Technology Studies

Geoengineering has gained some attention over the last 5-10 years as a potential climate policy option and, not least, research agenda (Royal Society 2009; Fleming 2010; Rayner *et al.* 2013). It has come with promises of capabilities to control the climate and to resolve climate policy dilemmas (POST 2009; Bickel and Lane 2009), but it has also come with warnings of unwanted, even disastrous, effects – on the climate as well as on society (ETC 2010; Gardiner 2011; Macnaghten and Szerszynski 2013). This situation has raised questions, familiar from other areas of science and technology, about our ability to stop, direct or steer technology innovation in such a way as to avoid or ameliorate potential drawbacks.

Such discussions tend to draw on analyses of other technologies and our past experience with them. In the discourse informed by science and technology studies (STS), these discussions often refer to the Collingridge dilemma (Collingridge 1980; Liebert and Schmidt 2010; Shackley and Thompson 2012; also, see Rayner 2010), stating that at early stages of technology innovation it is hard to know what the outcomes will be and what the outcomes of any interventions in it will be, whereas at later stages of the innovation process the technology may have become so stabilised, entrenched and ubiquitous that it is hard to change.

Another lesson from STS tends to be forgotten, however. Much of the discussion around the future of geoengineering and how to govern it has relied on a linear conceptualisation of technical innovation. The linear model of technology innovation holds that technology develops through a set of stages, denoting distinct kinds of activities, each temporally and causally dependent on the completion of previous stages. The model typically includes at least a distinction between a research stage and a deployment stage, and sometimes with further stages in between, like development, testing, demonstration, marketing, etc. (Godin 2006).
The linear model also implies an identity between what is being researched, developed, deployed, etc. across the stages, i.e. that it is the same object that recurs in each stage, albeit in different states of development or completion. The linear model has been thoroughly critiqued in technology and innovation studies since at least the 1970s (see, e.g. Godin 2006), for reasons as described below, but is still a common trope in both academic and policy discourse on geoengineering. For example, the metaphor of a stream is frequently used to evoke this identity, when speaking of upstream research and downstream deployment.

This paper aims to address the lack of critique of the linear model in geoengineering governance discourse, and to illustrate different considerations for a geoengineering governance framework that is *not* based on a linear model of technology innovation. Finally, we set to explore a particular approach to geoengineering governance based on Peter-Paul Verbeek's notion of 'technology accompaniment'.

The Linear Model in Geoengineering Discourse

As compared to geoengineering *research* proposals, there is a paucity of geoengineering *technology* development plans, or analyses and assessments at all informed by any models of technology innovation. A few contributions can be identified, and they tend to be linear in character. The NOVIM (2009) report goes some way to set out a plan for the development of stratospheric aerosol injection, and is a good example of a strongly linear conceptualisation of innovation.

The NOVIM report projects five progressive phases of research, development and deployment: (I) non-invasive laboratory and computational research; (II) field experiments; (III) monitored deployment; (IV) steady-state intervention and (V) disengagement. Each phase is seen to offer distinct challenges and objectives with successively higher levels of risk (NOVIM 2009, 29). The report presents these phases as cumulative, with new phases adding to on-going efforts in previous ones, rather than replacing them. Feedback from later phases to earlier ones and any need to retreat to earlier phases from later ones are not discussed, nor is there any recognition that later phase activities might precede earlier ones.

Alongside these phases, an argument is developed about the need for better knowledge from science to be used by decision-makers. The report also makes a strong distinction between what *can* and what *should* be done, and defines the latter question being outside of the scope of the report (NOVIM 2009, v). This delimitation rests on the assumption that non-natural-science concerns are not necessary for designing a valid innovation strategy and that scientists can legitimately proceed to produce such plans separately from experts on economics, social science, ethics, etc. as well as participation from other concerned parties. The linear model lends itself well to arguments about the ethical and political neutrality of a science happening in isolation from other disciplines, actors and interests.

The 2011 geoengineering technology assessment from the US Government Accountability Office (GAO) offers another example of distinctly linear conceptualisation of geoengineering. The report sets out to assess a range of geoengineering technologies, choosing to focus on four dimensions: maturity, effectiveness, "cost factors", and "potential consequences" (2011, 77). Maturity is here rated according to so-called technology readiness levels (TRL), with reference to their use by NASA and the European Space Agency and their wider circulation as a standard tool (2011, 77). The version of the TRL model used encompasses nine levels of readiness, ranging from "basic principles observed and reported" to "actual system has been proven in successful mission operations" (2011, 78-79). These levels are depicted as sequential.[1]

These two examples are somewhat different in that the NOVIM report sets out a plan for future technology innovation, and the GAO seeks to assess the *status quo*. Also, the GAO report is oriented towards the future in that the purpose of the assessment is to guide decisions on research funding and to direct our exploration of potential geoengineering futures. However, in both cases we are presented with ideas about the distance from imagined future states as well as some contours of a route towards it. A key attraction of the linear model is that it allows us to promote (and critique) current science with reference to specific, imagined technological futures.

The linear model – or versions thereof – is commonplace in the literature on geoengineering. We will not attempt any exhaustive review here, but a few examples will go some way towards backing this claim up. McLaren (2012) uses TRLs (referencing GAO 2011) to assess the maturity of negative emissions technologies. The authors of the Oxford principles refer to stages of development in elaborating the principles (Rayner *et al.* 2013). So does the Royal Society report (2009), and it even goes so far as to offer predictions of when the technologies will have progressed through them to maturity.

[1] Interestingly, the GAO applies the model only to the artefacts needed to deliver the intervention (e.g. mirrors and the means to place them into space), rather than to a bigger socio-technical system that includes the mechanisms through which the intervention is to have effects (e.g. a designed atmosphere) and the tools we use to analyse these mechanisms. The maturity of climate modelling and our ability to predict effects and side-effects are not assessed in this report.

It is worth noting that the linear model not only affects the way we conceptualise geoengineering technology innovation; it also affects the way that we conceptualise how it should be governed. For instance, it sets up a temporal and causal distinction between early and late parts of the innovation process. Understood this way, we can formulate a choice between intervening early or late (Collingridge 1980), upstream or downstream (Corner *et al.* 2012; Macnaghten and Szerszynski 2013; Carr *et al.* 2013), before or after deployment (Rayner *et al.* 2013). The linear model also associates "early" with science and "late" with use, and so the model enables the formulation of a choice between choosing to intervene early in science or later in use (deployment). Discussions about whether to intervene in science have been framed as a decision about how far upstream, i.e. how far removed from the use context, intervention should be made.

David Collingridge (1980) articulated this as a matter of the early uncertainty about the later form and impact of emerging technologies versus later certitude, in combination with early freedom of choice and malleability, and later locking-in to specific forms and less scope for change. Again, early stages are conceived as happening at a distance from societal contexts, and – unlike deployment – not embedded in and locked-in with societal structures or impacted by interests, or at least much less so.[2]

The linear model can be a discursive tool for both the promotion and constraint (as interventions) of geoengineering-related activities. In either kind of intervention, it is a matter of attaching scenarios (be they promises or threats) of technology futures to current science.[3] Moreover, the politics of using linear models varies by context, and needs to be evaluated in reference to it. However, any use would tend to reproduce to

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[2] To be fair, this is how the Collingridge dilemma is often presented, whereas Collingridge himself transcended this simple model of early stage malleability as the unrestricted agency of apolitical expert-scientists, to analytically include (and advocate) multiple knowledges, values, and diverse actors (although primarily policy makers, rather than technology users) throughout the innovation process (Liebert and Schmidt 2010).

[3] For an example of the latter, see Macnaghten and Szerszynski (2013), who argue that the 'social constitution' of geoengineering is knowable and allows us to predict threats pertaining to solar radiation management.

some degree the privileged position of scientists in making choices about research priorities, pertaining to their assumedly early, societally isolated domain[4] as well as reproducing the faith in science as the predominant and ethically and politically neutral mechanism of socio-technical change.

Critiques of the Linear Model in Technology and Innovation Studies

As mentioned above, the linear model has been thoroughly critiqued in technology and innovation studies. A classic debate framed it in terms of a choice between science "push" and demand "pull" as the main explanation of technology innovation (Di Stefano *et al.* 2012; Godin and Lane 2013), thus reifying the two stages. This was superseded by models allowing for feedbacks between different stages (e.g. Kline 1985) and models that abandoned the notion of stages altogether in favour of interaction between a set of activities that are not by necessity ordered in a sequence.

Substantively, studies have shown that the linear model seriously underplays uncertainty and contingency (including scope for setbacks/failure as well as otherwise surprising outcomes), in that it suggests an ordered progression from research stage to later 'completion', and, relatedly, that it tends to underplay the scope for choice and agency in favour of a pre-determined and predictable technology innovation outcome (Rip 1995). A single starting point is thought to lead to a single outcome, or at least a very restricted set of outcomes. By placing science at the start of the innovation process, and assuming that subsequent stages are determined (or strongly shaped) by it, the linear model tends to highlight science as the primary locus and source of novelty and creativity (MacKenzie and Wajcman 1999). This downplays contributions of actors and knowledges seen as being 'downstream', for example 'users' (Fleck 1994) or policy makers (Jasanoff 2004). The allocation of agency mainly to the realm of science serves to simplify the social and political processes involved. Most actors apart from scientists can in this way be made to seem external, as part of the

[4] We believe that is why the term 'upstream engagement' is inherently limiting when arguing for the democratisation of science and technology.

context, and with mainly a reactive role to play. Politics can be deferred to downstream deployment, located elsewhere and later in relation to the upstream science, which has now been purified and made to seem untouched by politics (Russell and Williams 2002).

It may be worth commenting briefly on why the linear model persists in the face of decades of thorough critique. The use of science in technology innovation (Latour 1985; Gibbons *et al.* 1994) has undoubtedly created a demand for ways of thinking about how technology futures are implicated in current science. As long as discussions and analyses focus on science, the ways in which it is taken up or connected with technology innovation can often remain obscure without problem. In fact, linear promises of future technology may be most valuable to scientists and their sponsors, if left unscrutinised. To develop technologies, it is frequently necessary to build up expectations and hype (Brown and Michael 2003; Bergek *et al.* 2008; van Lente *et al.* 2013), so as to attract resources and good will.

There is also the opposite but analogous need and desire to think through possible negative outcomes. And such efforts need to attract attention and resources too. Again, linear predictions (Williams 2008) are useful, albeit about doom rather than salvation. This interplay between technology promoters and their detractors contributes to a process of social learning about specific technologies (Rayner 2004) and about the role of technology in society more widely. Whilst the linear conceptualisations of technology development thus have their uses, we should be wary of the way they shape our understanding of what might be the result of current research and development efforts, and our evaluation of those efforts and the actors involved with them.

Non-Linear Models of Technology Innovation

There is a wide variety of models for the analysis of technology innovation available in the STS and technology and innovation studies literatures. This section of the paper will set out one perspective, without claiming to represent the full variety, but in a way that will produce a useful contrast with the linear model, with the aim of opening up the discussion rather than to pronounce on any one right way of doing so.

A dominant theme in social science theorising on technology over the last three decades is that of interaction in networks. Models have tended to emphasise distributed agency across sets of actors and artefacts (see, e.g. Pinch and Bijker 1984; Latour 2005), in a process that can be more or less coordinated but rarely completely determined by any one agent, and at least in part emerges through contingent interactions. This perspective highlights the limits to prediction and central management, and so presents a messier object of analysis and governance than does the linear model.

A second key result has been recognition of the heterogeneity of technology, i.e. the view that technology not only consists of a particular kind of object, or one particular kind of knowledge, but a heterogeneous range of elements, including also actors and institutions (Hughes 1983). Metaphors such as system building (Hughes 1983) or bricolage (Garud and Karnoe 2003) are used to refer to the process in which such elements are aligned and mutually adjusted (co-produced) in attempts at making a technology work and potentially stabilised for reliable performance. This challenges, in particular, models where science is the sole root of any technology, and emphasises instead their multiple origins. A heterogeneous model, in contrast with a linear one, would emphasise scientific knowledge as one kind of knowledge among several, amongst yet other kinds of building blocks.

In this view, actors are to be seen as part of the technology, and as part of the heterogeneous networks that make up socio-technical arrangements that work. Beyond this, we may also talk of the socio-technical contexts in which technologies are developed, and how they are shaped by those contexts and so implicated in wider political struggles (Winner 1980). The stability of any network is therefore in part dependent on how it fits with its contexts (cf. Geels 2005), with their structures and power relations (Hård 1993).[5] In contrast, the linear model tends towards being self-contained, with internal dynamics determining outcomes.

Geoengineering Governance without the Linear Model

Rejecting the linear model and replacing it with a non-linear alternative, however, does not by itself resolve the Collingridge dilemma. Current activities invoking technology futures may well contribute to socially, ethically, and politically undesirable outcomes, and we might want to pre-empt them by intervening in the technology innovation process. As such, we are *not* arguing that the Collingridge dilemma will be mysteriously dissolved once geoengineering governance frameworks adopt a non-linear model of technology innovation, or that we cannot – or should not – care about future outcomes of geoengineering at the present. We do, however, insist that the Collingridge dilemma and the responses to it have to be reconsidered when the other lesson from STS, i.e. the problems of the linear model, is being taken seriously. In the following, we outline several implications of the rejection of the linear model for the discussions on geoengineering governance.

Firstly, it is important not to assume any naturally occurring stage, levels of development, or streams of development in geoengineering, at least not without being aware of the theoretical choices being made and of the problems that go with it. In other words, it is necessary for researchers and policy makers to be reflective about 'linearity' in the language of and framings in geoengineering governance, and they should also be wary of arguments and debates that fall unreflectively into the frames of the linear model. For instance, such arguments and debates have already appeared in the form of slippery slope arguments stating that geoengineering research will lead to its deployment because of cultural beliefs and vested interests permeated in geoengineering research (Jamieson 1996, 333; Long and Scott 2013), or because of the 'institutional momentum' created by geoengineering research (Gardiner

[5] Although models and theories diverge strongly. For some there can be no *a priori* and sustained analytical distinctions between levels, and so not between technology and its context. For others, the important thing is to avoid *a priori* distinctions between humans and artefacts. The position set out here, allows for structurally determined levels and focuses on human agency.

2010, 289). By rejecting the linear model, we can reject the crudely determinist arguments suggesting inevitable movement along a path, trajectory, etc. in research and deployment of geoengineering. Technical change is not necessarily predictable and unmanageable. It is *not* often the case that technology is completely out of control after an initial tentative formulation even if it is not necessarily easy to control it. Again, this is *not* to assert that concerns about the slippery slope arguments and other related problems are unreal, but only to state that it is important not to conceptualise and formulate them with the language and frames of the linear model, which would easily lead to determinist arguments. Similarly, by rejecting the linear model, we should also abandon the assumption that there is *one* stable, homogenous object being researched, developed, deployed, etc. across different stages. In this respect, we can too reject essentialist arguments suggesting the future of geoengineering is entirely inherent in the technology itself (see, e.g. Macnaghten and Szerszynski 2013).

Secondly, if there are no stages, there is no obvious sense in which intervention in geoengineering can or should be 'early', and the assessment of and intervention in geoengineering need to be reconceptualised as an *on-going process*, 'now' is always a good time to act. In other words, a shift is required from the emphasis on 'early stages' or 'upstream' in geoengineering to the on-going process in which geoengineering is being researched, developed, and deployed (see Joly and Kaufmann 2008). In effect, it is important to be reminded that technologies continue to evolve in and with society when they are made available to the public or being put into use (Leonard-Barton 1988; Rip and Kemp 1998), and thus the 'later stages' and 'downstream' will be as important as the 'early stages' and 'upstream' in a comprehensive geoengineering governance framework. There are various analytic approaches available that aim to account for the processual dimension of technology innovation, and are not restrict to 'early stages' or 'upstream', e.g. real-time technology assessment (Guston & Sarewitz 2002), the technology-as-social-experiment approach (van de Poel 2009, 2011, 2013), the technology accompaniment approach (Verbeek 2006, 2010, 2011, 2013). Using one of these approaches should enable geoengineering governance to take seriously the non-linear characteristic of geoengineering.

Thirdly, one ought to be reminded that science (and technology) is only one site of intervention, and there are other sites as well. If the activities of the linear model are not sequential stages, they can instead be seen as parallel activities, and thus there are multiple sites of possible intervention. Intervention can target not just research, but also experimentation, deployment, use, ventures, regulation, policy-making, and the discourse of geoengineering. In short, the context in which geoengineering emerges is as an important site of intervention as much as the science and technology of geoengineering (see, e.g. Gardiner 2010, 2011, 2014). Here, it is instructive to refer to research in the area of nanotechnology governance with the approach of midstream modulation (Fisher *et al.* 2006; Schuurbiers and Fisher 2009; Schuurbiers 2011). The midstream modulation approach views the laboratory itself as an important site of intervention, as it is where scientists and engineers shape nanotechnology and bring it into being, and it is also where social, ethical, and political values already being imparted into technology through their decisions. For the proponents of midstream modulation, then the labs and relating settings where research takes place should too be opened up as sites of intervention. Insofar that upstream engagement on geoengineering has tended to rely on dedicated institutional set-ups that are separate from the labs, it will be insufficient to account for the multicity of the innovation processes.

Fourthly, whilst the linear model tends to separate science from issues of ethics and politics and support understanding of it as apolitical, we argue that assessment and intervention need to take into account of the values that are at stake in innovation. Intervention should not just focus on scientific and technical details, but also on the values that are inevitably present. In short, the assessment and intervention ought to be *socio-*

technical, i.e. they have to take into account the values situated in the broader context of which geoengineering emerges.[6]

Accompanying Geoengineering

We have already noted that the model of technology innovation assumed in the discussions will affect the approach to technology governance envisioned, and our brief review of the literature on geoengineering governance has shown that the current discourse tends to emphasise the importance of 'early stage' or 'upstream' intervention, 'governance before deployment', etc., which could be seen as supported by the linear assumption that the assessment of and intervention in geoengineering at the early stages could predict its outcome and alter its course, and thus avoid or alleviate the socially, ethically, and politically inacceptable outcomes of geoengineering at the later stages; or, at least, the early assessment of and intervention in geoengineering is considered to be an important exercise to reveal possible social, ethical, and political problems in geoengineering futures, and thereby opening up the discussions on those issues, and raising our preparedness for them.

Technology innovation, however, is *non-linear*; and, technology governance frameworks based on the linear model are at best insufficient and at worst misleading. Philosophers of technology have argued that the intended outcomes of technology in the research context might not always realise in the use context (Albrechtslund 2007; Ihde 2008; cf. Kiran 2012). This is, in part, due to outcomes of technology are *not* only determined by scientists and engineers in the research context, but *also* by users in the use context.[7] For geoengineering governance, this argument implies that the significance of early assessment and intervention could be limited: without experience of the use context, the (normative) conclusions from the early assessment of geoengineering

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[6] Accordingly, our visions of a geoengineering world, which (re)present our values of and about geoengineering, are perhaps more appropriate as the object of critical reflection. See Ferrai (2013) for a similar argument in favour of the inclusion of technological visions in the assessment and governance of nanotechnology.

[7] Ihde (2008) calls this "the designer fallacy", and the challenge is to bridge the gap(s) between the research (and design) context and the use context, see e.g. Kiran (2012), Wong (2013).

could be unrealisable in the use context; and, the intervention in the "early stages" or "upstream" also could not guarantee the expected results in the use context. This is so because users of geoengineering – and, the society as a whole – can diverge from the intended uses or respond to the expected consequences of geoengineering differently, and thereby render early assessment of and intervention irrelevant. In effect, without emphasising the heterogeneity of geoengineering, the focus on the "early stages" and "upstream" could (inadvertently) impose an essentialist view of geoengineering, and mistakenly take the object of analysis and evaluation to be the same throughout the innovation process. As technology innovation is a heterogeneous, unfolding and multi-sited process where human agency matters alongside material agency, and the overall assemblage is only predictable to a degree, experimenting and learning will be integral to understand what we are doing and what can be achieved.
To be sure, this is *not* a decisive argument for abandoning assessment and intervention in this manner altogether, but the argument clearly signpost the need to go beyond the "early stages" and "upstream" in a geoengineering governance framework.[8] Indeed, we view this as one of the major challenge to approach geoengineering governance without the linear model of technology innovation. In the following, we shall explore one approach in ethics of technology offered by Peter-Paul Verbeek (2006, 2010, 2011, 2013), and discuss how it can inform geoengineering governance frameworks that forgo the linear model of technology innovation.

Verbeek (2010; also, see 2011) observes that ethics of technology has predominantly been viewed as a safeguard of humanity against the transgression of technology, and so the aim of ethics of technology is to analyse and evaluate technologies and their impacts on individuals, and to reject them if they oppose our social, ethical, and political values. Against this background, Verbeek proposes an alternative approach to ethics of technology he calls 'technology accompaniment'. Drawing from actor-network theory (see, e.g. Latour 1992, 2005; Law 2009; Sayes

[8] Our argument, therefore, should not be considered as an argument against 'opening up' the geoengineering debate (see, e.g. Stirling 2008; Bellamy *et al.* 2013). In effect, 'opening up' the debate on geoengineering can be valuable if it is not based on a linear model of technology innovation.

2014) and postphenomenology (see, e.g. Ihde 1993, 2009; Verbeek 2005), Verbeek argues that human experience is *always* mediated by technology, and thus there is no external (or, non-technological) standpoint from which technology can be evaluated. Moreover, he argues that technology is not only value-laden, but it is *co-constitutive* of our morality. Accordingly, Verbeek argues that ethics of technology should *not* be evaluating whether some technologies are socially, ethically, or political permissible with a particular normative standard isolated from technology, as it will overlook the role of technology in shaping and transforming the moral concepts individuals use in evaluating technologies (also, see Swierstra *et al*. 2009; Boenink *et al*. 2010; Swierstra 2013); instead, ethics of technology should be devoted to examine various forms of human-technology-world (and, human-technology) relations and their quality. More specifically, the technology accompaniment approach examines how technology can interact with our moral concepts and how it can transform human experience, and explores different ways to shape technologies *and* our involvement with them. As such, it open up the conceptual space for the inclusion of the contingencies *in* and *from* the use context, as human (and the broader context) is an integral part of the human-technology-world relations.

Central to the technology accompaniment approach, therefore, is a shift from the evaluation of technology with an external standpoint to accompanying technology innovation with an internal standpoint; and, from the normative reflection on technology to the normative reflection on the quality of human-technology-world (and human-technology) relations. In doing so, it also requires us to reconceptualise ethics of technology as a *task* that requires continuous efforts from individuals to build, reflect, and maintain the technologically-mediated relations. For Verbeek, the aim of ethics of technology is no longer to pronounce social, ethical, and political (un)acceptability of technology, but to examine the much broader question of "what is a good way of living with technology?" (Verbeek 2011, 158).

The technology accompaniment approach thus entails a de-centring of the analysis from the technology to our technologically-mediated relations with the world. However, this leaves a problem of delimitation: in the case of geoengineering, it would after all not only be geoengineering technologies that mediated our relation(s) with the world. By taking a further step towards de-centring the technology, we suggest that useful questions also include: what will adding geoengineering to existing sets of technologies – for example, energy, agricultural, or military, etc. – mean for our technologically-mediated relation(s) with the world? If we do so, we could more competently answer the questions: whether, why, and how we should continue with developing geoengineering technologies.

Applying the technology accompaniment approach to geoengineering technologies shifts the emphasis of geoengineering governance away from the questions about whether geoengineering is socially, ethically, and politically acceptable to the questions about if and how geoengineering might contribute to the good life. In other words, instead of (only) probing social, ethical and political issues in geoengineering futures and searching for solutions to them, this approach explores different technologically-mediated relations presented by geoengineering technologies, and examines the quality of those technologically-mediated relations as well as geoengineering technologies' contribution (or subtraction) to the existing sets of technologies we already have. This shift is important, as it requires us not only to question geoengineering *technology*, but also the background condition of which geoengineering comes into prominence and the kind of life we *should* live with (or without) geoengineering (cf. Gardiner 2011). In this way, the technology accompaniment approach also move away from focusing on 'early stages' and 'upstream' to a much broader context of inquiry.

It is not our intention to spell out the technology accompaniment approach to geoengineering governance in full detail here. However, a recent analysis of solar radiation management by Maialen Galarraga and Bronislaw Szerszynski (2012) offers an illustrative example of how it could be applied.[9] In their analysis, Galarraga and Szerszynski examine

[9] Galarraga and Szerszynski have not referred to the technological accompaniment approach in their analysis, but their emphasis on various forms of human-world relation presented by implementation of solar radiation management provides an interesting example of how the technologically-mediated relations of geoengineering technologies can be analysed.

different ways in which implementation of solar radiation management can be conceptualised. They distinguish three different accounts of ‘making climates’, i.e. producing, educing, and creating; and, introduce three types of climate makers corresponding to each account of ‘making’: climate architect, climate artisan, and climate artist. What is novel and interesting about their analysis is their attempt to understand different technologically-mediated relations in the implementation and the human-world relations associated with them.

More specifically, Galarraga and Szerszynski show that the implementation can be understood via the notion of production, i.e. “the imposition of an existing form onto formless matter” (2012, 225), and the ideal-type of human-world relation corresponds to this notion is the climate architect, i.e. an agent who attempts to impose a new form onto the matter of climate. Alternatively, they note that the implementation can be understood via the notion of educing in which “form is drawn out from the potentialities of matter itself” (2012, 226); and, corresponding to this notion is the climate artisan who focuses on the process in which the en-forming of climate occurs, and facilitates the form’s coming into being. Finally, the notion of creation, which is about “the capacity a create a new *eidos* [i.e. essence, ideal] that is not wholly determined by anything that pre-exists it” (2012, 227), is associated with the climate artist who views climate-making to be inevitably involved in creating climatically novel states.

Galarraga and Szerszynski have offered an illustrative example of how to analyse the human-technology-world (and human-technology) relations presented by geoengineering: geoengineering allows human beings to produce, educe or create climate, and it engenders different types of role (or relation) we have to the world, i.e. architect, artisan and artist.[10] For the technology accompaniment approach, the normative question will be the desirability of the human-technology-world relations made possible by geoengineering, and the role (or, relation) human beings ought to have to

[10] Their analysis is based on solar radiation management technologies but not carbon dioxide reduction technologies. It is, however, plausible that the human-technology-world relations and the ideal-types Galarraga and Szerszynksi suggest have identified are also applicable to carbon dioxide reduction technologies.

the world. In the case of Galarraga and Szerszynski, they believe that neither ‘production’ nor ‘educing’ is suitable to characterise the human-technology-world relation in geoengineering; it is the ‘creation’ relationship, and thus the role of climate artist, they think can enable us to deal with the novelty of the geoengineered climate system. Whether Galarraga and Szerszynski is correct or not requires further discussion, but if they are correct about the desirability of the ‘creation’ relationship, the technology accompaniment approach will assert that geoengineering ought to be developed (and implemented) with this account of making. At the same time, it will also recommend people to *become* climate artists too. It should be clarified that the technology accompaniment approach does *not* imply we have to accept any one way of doing geoengineering. We may find *all* forms of geoengineering unpalatable. Yet, it does remind us of the possibility to (re)configure the human-technology-world relations of geoengineering, instead of rejecting geoengineering outright.

In short, accompanying geoengineering means that we should redirect our attention from the science and technology of geoengineering to the quality of human-technology-world (and human-technology) relations of geoengineering. And, geoengineering governance needs to understand how geoengineering can (re)shape our morality and transform human experience, and concerns with shaping both geoengineering technologies and individuals’ involvement with them. Ultimately, the questions for geoengineering governance should be about geoengineering’s contribution to the good life, the good society, and the good climate. Of course, we have not touched on the more fundamental questions concerning what is the good life, the good society, or the good climate, and thus the questions about what is considered to be a *good* technologically-mediated relation of geoengineering remains to be answered. Yet, we believe the technology accompaniment approach provides us the impetus to re-open the dialogue on the *normative* questions not only about geoengineering, but about the good life, the good society, and the good climate in general.

Conclusion

In this paper, we have argued that the discourse on geoengineering and its governance is problematically characterised by a strong but implicit reliance on the linear model of technology innovation. We have also sought to point out alternative, non-linear ways in which we can conceptualise geoengineering innovation, and pointed to some consequences of such a re-conceptualisation for geoengineering assessment and governance.

We have thus contributed a new perspective to the discussion of geoengineering innovation, assessment and governance. Moreover, we have outlined some governance implications, including the need to see intervention as an on-going activity, the need to intervene in sites beyond science labs and dedicated engagement forums, the necessity to evaluate and debate social and ethical commitments alongside and together with scientific and technical facts, and the need to de-centre geoengineering technology in assessments and instead re-focus on what geoengineering – among other technologies – does to our relations with the world. Further work could usefully specify and test practical forms for these abstract implications.

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