GEOENGINEERING GOVERNANCE RESEARCH

BACKGROUND BRIEFING

Geoengineering: issues of path-dependence and socio-technical lock-in

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Introduction

In recent years there has been growing academic and policy interest in geoengineering – the large scale, intentional manipulation of climate system in order to attempt to counteract the effects of climate change (Belter & Seidel 2013). Alongside a number of other important policy issues, concerns have been raised over the potential for geoengineering technologies to contribute to so-called 'carbon lock-in' (Unruh 2000), or to become 'locked-in' themselves (CBD, 2012; Shepherd et al., 2009; Rayner et al., 2013). In particular, the scale of infrastructures that geoengineering interventions would require, and the issue of the so-called 'termination effect' (Jones et al. 2013) (whereby the termination of a programme of stratospheric aerosol injection would result in rapid heating of the planet) have been discussed in these terms. Dynamics of 'lock-in' have been raised even in relation to the more purely discursive aspects of these challenges, where (despite the emergent and somewhat ill-defined nature of the field), it has been suggested that the extant framings of geoengineering in academic and policy literatures may already demonstrate features recognisable as forms of cognitive lock-in, likely to have profound implications for future developments in this area (Bellamy et al. 2012). This review paper, prepared in advance of an academic and policy workshop on the topic, is intended to give participants a brief overview of the theoretical literature on lock-in and path-dependence, to summarise the ways in which these concepts have been invoked in the existing literature on geoengineering, to highlight some on-going theoretical debates around these concepts, and to examine the generic, and more geoengineering-specific challenges of assessment of these processes.

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A version of this manuscript was submitted to the journal WIREs Climate Change in January 2014 and is currently under review. Other presentations from the workshop can be found in a special section of the outputs part of the CGG website.

Contents

Section 1. Theoretical background: path-dependence and lock-in

Path-dependence and lock-in (Arthur 2007; Collingridge 1980; David 1997) are concepts with roots in evolutionary economics and the history of technology, that are now widely used across a range of social and political sciences to describe and theorise the ways in which technologies, or more broadly socio-technical systems (Geels 2004), develop and endure or disappear. In addition to technological developments, processes at work in political and other social systems have also been described in these terms (Pierson 2000). Path-dependence refers, at the most basic level, to the fact that 'history matters' in understanding socio-technical development. The original conceptualisation of path-dependence in the economics literature emphasized that path-dependent processes emerge initially from contingent (chance, random) circumstances that confer an initial advantage on a particular technology, followed by self-reinforcing processes or positive feedback, such as cumulative cost reductions and learning effects linked to increasing returns to adoption (David 1985; Arthur 2007). Within path-dependent processes, the sequencing of events is held to be particularly important, with earlier events mattering more than those occurring later. As Pierson puts it:

> 'Specific patterns of timing and sequence matter; starting from similar conditions, a wide range of social outcomes may be possible; large consequences may result from relatively "small" or contingent events; particular courses of action, once introduced, can be virtually impossible to reverse.' (Pierson 2000, p.251)

Lock-in is a way of conceptualising the outcomes of path-dependent processes, and describes how particular technologies – through their co-evolution with social, institutional, cultural and political systems - may become resistant to change, 'closing down' or constraining possibilities for the development of alternative (possibly superior or more socially/environmentally desirable) socio-technical configurations. In addition to the aforementioned processes such as cumulative cost reductions, identified in the original economics literature on path-dependence and lock-in, a growing body of work has identified a number of additional drivers and processes linked to path-dependent outcomes. These include cognitive or epistemic processes, such as the effects of technological paradigms (Dosi, 1982; Nelson & Winter, 1977), the importance of path-dependent processes in institutions (North 1990; Foxon 2002; Setterfield 1993), which can range from legal systems (Hathaway 2001) to less rigidly defined culturally accepted 'ways of doing things', or everyday practices (Quitzau 2007); and notions such as the 'technological regime', defined as the 'the whole complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of a technology' (Rip & Kemp 1998). A classic example of a 'locked-in' socio-technical regime is the transport system based around the use of the private motor car. As Shackely and Green explain:

> 'the private car has had a profound influence on the structure of the city and its surrounding region, but it is no readily reversible effect as the mass availability of the car becomes part and parcel of everyday lifestyles and patterns of social and economic activity' (Shackley & Green 2007, p.223).

The potentially negative impacts of technological lock-in – also sometimes referred to as entrapment (Walker 2000), or entrenchment (Collingridge 1980) – include a host of environmental and social problems such as climate change, ecological degradation, resource depletion, pollution, health and social problems, impacts which in general are only 'belatedly discovered after the system is well established' (Konnola et al. 2006, p.241). Other paradigmatic examples of instances of socio-technical lock-in accompanied by undesirable impacts that are difficult to ameliorate, can be found in the fossil fuel energy generation and distribution system (Unruh 2000), nuclear industry (Walker 2000; Cowan 2008), systems of industrial agriculture (Cowan & Gunby 1996), automobile transport (Heffernan 2003) and urban infrastructures (Hommels 2005) such as sewage systems (Quitzau 2007).

Given that lock-in of particular socio-technical configurations can act to constrain future choices in profound ways, understanding path-dependent processes and lock-in of different types has important implications for democracy and social justice. For example, it has been observed that the proximate social forces shaping early configurations of artefacts and technologies (as well as routines, practices and paradigmatic ways of thinking) ‘typically reflect the ‘needs’ preferences, normativities and interests of rather restricted social groups’ (Stirling 2009), with the result being that the diversity and direction of technological change in areas as diverse as agriculture, pharmaceuticals, energy, the military, and communication, has historically been constrained by powerful socio-economic and institutional-political pressures.

Maintenance of the social control of technology and the prevention or amelioration of negative impacts of technological development are the normative drivers of the broad field of Technology Assessment (TA). Much work in this area builds on the work of Collingridge (1980), who famously described the question of societal control over technological development in terms of a ‘dilemma’ whereby in the early stages of a technology’s development while the technology is still relatively easy to control, the impacts of technologies are largely unpredictable/unknowable; but by the time impacts are known, control is often impossible or very difficult. Collingridge argued that maintenance of flexibility in the face of unpredictability was a means of mitigating the negative impacts associated with lock-in, and that ‘the essence of controlling a technology [was] not in forecasting its social consequences, but in retaining the ability to change a technology, even when it is fully developed and diffused’ (Collingridge 1980, p.20).

It has been observed that lock-in of a particular technology is likely to imply ‘lock-out’ of others (Delrio & Unruh 2007), and hence the erosion of diversity (Stirling, 2007), which may happen by chance, or through the deliberate actions of advocates for particular technologies (Walker 2000). Hence, it has been suggested that one way in which flexibility can be sustained (and damaging lock-in avoided) is through the maintenance of diversity (Konnola et al. 2006; Walker 2000; Stirling 2009). For example, Walker’s case study of the nuclear re-processing industry provides evidence of the negative effects of a loss of diversity leading to entrapment, and for the need to ‘ensure that alternatives survive and develop, that switching costs are not held unnaturally high, and that extrication is given due and timely attention’ (Walker 2000, p.846).

Section 2. Concepts of lock-in and path-dependence in geoengineering discourse

The term 'lock-in' features relatively prominently in the academic and policy discourse around geoengineering thus far. However, reflecting its diverse usage in the academic literature, exactly what is meant by the term is not necessarily consistent, and it has been invoked to refer to a number of different processes or give voice to a number of different kinds of concerns. Within the academic and policy literature on geoengineering, two broad levels of analysis can be discerned: a focus on particular technologies or classes of technology and the potential mechanisms and consequences of lock-in that might result from their development and deployment; and a focus on the broader context of existing fossil fuel dependence or so-called 'carbon lock-in', and the ways in which particular technologies might disrupt or reinforce this. In the former category, the issue of socio-technical lock-in has been cited as a policy concern in a number of high-profile reports on geoengineering, including the Royal Society Report (Shepherd et al. 2009), the UK House of Commons report on the Regulation of Geoengineering (House of Commons 2010), and the 2012 report by the Convention on Biological Diversity (CBD, 2012). The need for assessment of the risk of lock-in was also a component of one of the so-called 'Oxford Principles' for the governance of geoengineering (Rayner et al. 2013). Some authors (Rayner et al. 2013) distinguish between technical and social lock-in with technical lock-in referring to kinds of commitments that would accompany particular technological approaches such as stratospheric aerosol injection due to the existence of the so-called 'termination effect' (a term used to refer to the fact that if an SRM technology such as stratospheric aerosol injection were to be implemented but then discontinued, there would be a rapid spike in temperature that would likely be more damaging than the more gradual temperature increases that would have taken place in the absence of such an intervention). Social lock-in, in this case is used to refer to the ways in which many of the proposed technologies (e.g. direct air capture), would be dependent on the existence of a highly capital-intensive physical infrastructure, the large sunk costs in which would create vested interests in keeping facilities operational, and hence would lead to various types of inertia and lock-in (Hamilton 2013a).

Other work has drawn attention to the importance of framing effects and what could be called 'cognitive lock-in'. For example, Bellamy et al. carried out a review of appraisals of geoengineering methods. They highlight the ways in which instrumental framing effects impact on the outcome of appraisals in important ways, acting to promote apparently preferable decision options given those framing effects that are privileged. In particular they illustrate the impact on outcomes of the choice of contextual problem frame within which appraisal of geoengineering takes place (e.g. the idea of climate emergency or the failure of mitigation), the choice of appraisal methods applied (e.g. the use of expert-analytic methods such as computer modelling, economic assessment and expert opinions), and the particular options appraised (e.g. the choice to focus on a limited number of geoengineering options, or to compare geoengineering options in contextual isolation rather than with the wider portfolio of responses to climate change). They draw on the concept of lock-in to argue that:

> 'As an upstream suite of technology proposals, [geoengineering proposals] are particularly sensitive to…instrumental framing effects and could easily be quickly and prematurely closed down, locking us in to certain technological trajectories but not others (David, 1985; Arthur, 1989). Ultimately, potentially unsung divergent values and interests in such a lock-in could cause controversy' (p.26)(Bellamy et al. 2012).

In a related vein, work on 'upstream' public engagement has highlighted the ethical concern that 'the very act of studying and engaging with geoengineering could generate a momentum of its own—an intellectual 'lock-in'—that might also have a dramatic impact' (A Corner et al. 2012). This is related to the so-called 'slippery slope' argument (Hamilton 2013b; Jamieson 1996; Hulme 2012; Banerjee et al. 2013) that 'even very basic and safe research … could be a first step onto a 'slippery slope' towards deployment' (SRMGI 2011, p.21). Conversely, the oft-cited argument in favour of research is that without research,

> 'if and when geoengineering becomes necessary, we will lack knowledge about which approaches are more or less effective and more or less dangerous. So there will be a greater chance that geoengineering efforts will fail or cause serious collateral damage (Bodansky 2013)'.

However, the implication that research is a neutral activity has been critiqued. For example Jamieson draws attention to what he calls the 'cultural imperative' that holds that if something can be done it should be done, and suggests that this results in technologies developing 'a life of their own that leads inexorably to their development and deployment'. He draws on the history of medical research to suggests that one of the central reasons for this is that '[a] research program often creates a community of researchers that functions as an interest group promoting the development of the technology that they are investigating' (Jamieson 1996, p.333). The report on geoengineering by the US Congressional Research Service made a similar point, by highlighting the fact that '[i]nnovative and entrepreneurial organizations seldom mobilize themselves to put complex technologies "on the shelf"' (Bracmort & Lattanzio 2013, p.8), which may result in a the premature and possibly dangerous promotion and deployment of particular technologies. Likewise a recent report from the Yale Climate and Energy Institute highlighted similar concerns around the slippery slope by pointing to the ‘propensity for technologies to be developed once conceived of, and then used once developed’ (Banerjee et al. 2013, p.6).

On the other hand, some have argued that with regard to geoengineering research there is a risk that regulatory lock-in to particular commitments (e.g. a total ban on testing), might be regretted or have unintended consequences in limiting possible responses to emergency climate change (Keith et al. 2010).

Another area of growing interest to assessment of geoengineering, is the role that Intellectual Property (IP) might play in shaping the development of these technologies (Parthasarathy et al. 2010). Although not specifically referring to the terminology of ‘lock-in’, Parthasarthy and colleagues argue that 'in the absence of any significant regulatory framework, the patent system has become the de facto method of controlling technological development' (p.7), and suggest that this is likely to shape its development in profound and irreversible ways. They find that in the field of geoengineering,

> ‘while relatively few patents have been granted to date, certain trends – including the provision of broad patent language, dramatically increasing numbers of applications, and the concentration of patent ownership – suggest that patents will play an important role in how this technology develops’ (p. 3).

As well as the above-mentioned work which is concerned with the various processes that might impact on the future development (and potential lock-in) of proposed geoengineering technologies, the concept of lock-in also features as descriptive of the broader context within which these geoengineering interventions are being discussed – for example, the idea that the world is currently ‘locked in to the highest emissions trajectory envisaged by the IPCC’ (Rayner 2011, p.2). The concept of carbon lock-in (Unruh & Carrillo-Hermosilla 2006; Unruh 2000) has been used to describe the apparent inertia in industrialised highly carbon dependent economies due to the stability of the techno-institutional complexes responsible for the bulk of carbon emissions (encompassing both physical infrastructure and social and cultural practices and institutions). Some geoengineering technologies such as direct air capture (DAC) have been examined within the context of carbon lock-in, and it has been suggested that these technologies may ‘exacerbate carbon-based path dependency and intensify the lock-in of fossil fuels in the near term’ (Unruh & Carrillo-Hermosilla 2006, p.1193). This might also act to ‘lock-out’ other technologies. Potentially relevant to understanding the types of lock-in processes associated with certain geoengineering technologies is the literature on Carbon Capture and Storage. For example it has been argued that lock-in of Carbon Capture and Storage (CCS) might contribute to fossil fuel lock-in (albeit low carbon), *and* to a process of lock-out of renewable alternatives (Greenpeace, 2008; Shackley & Thompson, 2011).

Conversely, geoengineering is seen by some as a way of 'unlocking the mitigation puzzle' and providing a way out of what is seen to be a gridlock[2]. Allenby, for example, has suggested that the UNFCCC process itself is a form of 'cultural lock-in' (Allenby 2012), with existing policy structures (however ineffectual) being unlikely to change because of the institutional and psychological commitments of the participants to the process, and that geoengineering can best be understood as a *response* to this lock-in. It is interesting then that existing carbon lock-in may well form the basis of an argument both for and against geoengineering, as has occurred in arguments for and against CCS (Hansson & Bryngelsson 2009).

Likely as a result of their relatively more developed status, carbon-based geoengineering techniques such as Bio-Energy with Carbon Capture and Storage (BECCS) have been examined in more detail than solar radiation management methods, particularly with relation to possible impacts on fossil fuel lock-in (Vergragt et al. 2009; Gough & Upham 2010), and there is potentially relevant literature for some carbon based geoengineering techniques to be found in literature on mechanisms of lock-in around Carbon Capture and Storage (CCS) (Markusson & Haszeldine 2009; Shackley & Thompson 2011). It is notable that some of this empirical work on CCS actually suggests that

> 'there is little evidence at the current time that CCS is 'crowding-out' the alternatives, and it may even be a factor in realising some of those alternatives through sharing underlying technologies. This would suggest that the risk of low-carbon lock-in may be relatively modest' (Shackley & Thompson 2011, p.112).

The concept of lock-in has also featured in debates around biochar, with disagreement apparent about the degree to which biochar should be considered a 'disruptive technology' (Shane Tomlinson 2009) to incumbent political economic regimes locked into unsustainable pathways, or whether the promotion of biochar and its linkage into carbon markets etc, might itself result in 'lock-in to routes and styles that favour scale and profit at the expense of local livelihoods and landscapes' (Leach et al. 2010).

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[2] For example: http://www.american.com/archive/2010/march/what-role-for-geoengineering

Section 3. On-going theoretical debates and challenges of assessment

While the concepts of lock-in and path-dependence have proven useful across a range of disciplines, and are invoked widely within the emerging discussions of geoengineering, there are a number of on-going areas of debate, and the degree to which path-dependence is understood to constitute a theory, is contested (Vergne & Durand 2010, p.736). It has been argued that the original path dependence explanation for the persistence of particular sub-optimal solutions may be 'too simple, too generic' (Guy Peters 2009, p.68) to contribute greatly to understanding persistence in other areas (e.g. public policy), and that other explanations such as first-mover advantage or organizational inertia may be equally or better able to explain persistence (Vergne 2013). The issue of the sub-optimality or otherwise of path-dependent outcomes is also the subject of long standing academic debate (David, 1985, 1997; Liebowitz, S & Margolis, 1990), often fuelled, it has been claimed (e.g. Arthur 2013), by ideological differences. As Arthur puts it, the debate about the sub-optimality or otherwise of the QWERTY keyboard design (widely cited as the paradigmatic case of path-dependence in action) is 'very obviously not about keyboards. It is about an ideology, in this case the libertarian one that markets steer us to the correct outcome (Arthur 2013, p.1187).

Importantly, although much literature has focused on negative outcomes resulting from lock-in, and how it can be avoided, it is also the case that a degree of lock-in is, in many cases unavoidable, and need not always carry negative connotations. As Walker points out:

> 'in complex fields of technology, commitments can become — and have to become — multifarious, extensive and entangling. Otherwise, nothing can happen. This gives rise to an unavoidable predicament: the very act of 'digging in' commitments makes societies and their institutions vulnerable to entrapment. Not only does 'lock-in' exist, it is an essential but dangerous facet of complex infrastructural innovation' (Walker 2000, p.834).

Given the necessity of some degree of lock-in, Shackley et al have argued for a differentiation of the concept from deep to shallow lock-in. As they put it

> 'lock-in per se is not the problem; it is rather the depth of lock-in which creates problems because deeper lock-in reduces flexibility and increases the 'error cost' (i.e. the cost of a decision which turns out to be based on incorrect understanding) and should be avoided' (Shackley & Thompson 2011, p.101).

Similarly Stirling refers to a 'milder, more routine' form of lock or 'momentum' consisting of 'complex networks of technical, operational, financial, regulatory, educational, cultural, and behavioural factors' and points out that this is generally seen as an essential element in the successful development of new technologies (Stirling 2008). Indeed, the idea of 'strategic niche management' (Kemp et al. 1998) aimed at helping to induce a socio-technical transition towards sustainability, can be thought of as the process of achieving a desired end by attempting to *facilitate* a degree of lock-in around a desired novel technology through the protection of a niche in which it can develop. In other words, by 'creating a little bit of irreversibility in the right direction' (Rip & Kemp 1998, p.391).

Despite the permanence implied by the metaphor of lock-in, various debates have highlighted that the term 'lock-in' should not be taken too literally, and cannot be understood as a permanent condition (Melosi 2005). For example Some authors have highlighted that one's view on whether a technology is 'locked in' depends substantially on the timescale over which one examines the process (e.g. Vergne and Durand suggest that arguably 'history did not matter' in the oft cited battle between VHS and Betamax because in the long run both became obsolete, giving way to the use of DVDs)(Vergne & Durand 2010, p.748). A conceptualisation that usefully serves to emphasize processes (rather than the static state suggested by the term 'lock-in') is that of 'emerging irreversibilities' (Rip & Kemp 1998; Robinson & Propp 2008). These can be thought of as socio-technical entanglements which over time enable and constrain alignments and activities of persons institutions and artefacts.

Debate also surrounds the role of contingency versus the agency of actors in path-dependent processes or lock-in (Garud, Kumaraswamy, & Karnøe, 2010; Vergne & Durand, 2010). For example, Garud et al., argue against what they see as fatalistic notions of agency implicit in the commonly applied versions of path-dependence in which 'actors become 'locked-in' by self-reinforcing mechanisms into paths whose evolution is determined by contingencies (chance events). Once locked in, actors cannot break out unless exogenous shocks occur' (Garud et al., 2010, p. 760). However, they also argue that the 'heroic' notion of agency found in more entrepreneurial models in which 'actors are driven by 'a logic of control' to effectuate through complex processes' is also inappropriate. This has lead these authors to coin the term 'path creation' (rather than path-dependence), in which agency is theorised as 'being distributed and emergent through the interactions of actors and artefacts that constitute action nets' (p.761). Likewise, Ebbinghaus (2005) has suggested the need to move beyond what he considers to be overly 'deterministic and inflexible' understandings of path dependence, in favour of a more developmental understanding of path dependence as structuring of choices that provides a basis for theorising not just stabilisation and inertia, but also the potential for what he calls 'path departure' and institutional change.

Simplistic notions of a linear progression from early to late development of a technology as it passes through defined stages of path-dependence through to lock-in, have also been questioned. For example, Liebert & Schmidt (Liebert & Schmidt 2010), argue that 'there is no linear time ordering as presupposed by the dilemma [formulated by Collingridge] and its classic linear innovation theory'. They go on to suggest then that although 'the temporal dimension of Collingridge's dilemma might actually exist …the processes are significantly more multi-faceted, non-linear, complex and interactive than the dilemma presupposes.' (p 67). Others have critiqued the notion of the existence of a 'right time' to influence technological development. As Nordmann puts it, '[t]o consider this as a dilemma is tantamount to viewing the present as an obstacle that can and needs to be overcome' (Nordmann 2010, p.10). Likewise, Garud et al have highlighted that 'starting points' for analysis of path-dependent processes are not self-evident because 'the past, present and the future are intertwined, with actors playing an active role in determining what portions of the past they would like to mobilize in support of their imagined futures'(Garud, Kumaraswamy, & Karnøe, 2010, p. 763).

Assessment: generic methodological challenges

Although in an important sense, all technological assessment shares a concern for possible *future* impacts of socio-technical development, the unpredictability of the future led to Collingridge himself denouncing what he called the 'predictionist approach' (the idea that what is needed to avoid damaging lock-in is simply better forecasting tools), saying that this was a misconception of the problem, since 'harmful effects of a technology can be identified only after it has been developed and has diffused' and 'a whole bundle of unknown factors' will remain (Collingridge 1980, p17). Likewise, Guston and Sarewitz refer to what they call a 'central truth' about the development and proliferation of technology in society, namely 'that this process is largely unpredictable, and thus not subject to anticipatory governance' (Guston & Sarewitz, 2002, p. 96). They go on to argue that although predicting the social consequences of a technology might be desirable, this goal:

> 'will never be fully attained, because consequences emerge not from the static attributes of a fully formed technology, but from the complex co-production that simultaneously and continually moulds both technology and social context' (Guston & Sarewitz 2002, p.98).

Methodological challenges are not limited to analysis of possible future lock-in. The gathering of empirical data about past technological developments to support the theory of path-dependence is equally challenging. While attempts at prediction of path-dependence and potential future lock-in, come up against the ontological limit that future states are open to change and in many cases unknowable (Liebert & Schmidt 2010), carrying out empirical analysis of purportedly path-dependent processes in the past faces the problem of not being able to prove the counter-factual (Cowan & Foray 2002), i.e. the impossibility of gathering empirical material to draw a comparison 'between the current state of the world and what the world would now be like had a different path been followed' (Cowan & Gunby 1996). Indeed it has been argued that '[i]n most case study research, path dependence theory is simply unfalsifiable' (Vergne 2013, p.1192). Given these temporal challenges, there are a number of methodologies that focus analysis on the present moment. One such approach is the use of indicators of flexibility to assess the likelihood or otherwise of a given technology becoming 'locked-in.' For example, Shackley and Thompson (2011) argue that:

> '[t]echnological (in)flexibility can … be used as a proxy measure of low (high) lock-in. The crucial idea here is that, although lock-in is unavoidable (and necessary), we can do something about the depth of that lock-in; the more flexible are the constituent technologies, the shallower is the lock-in' (Shackley & Thompson, 2011, p. 112).

Collingridge's original set of indicators of flexibility (1980, 1992) included: high capital intensity; long lead-time from conception to realisation; large scale of the production unit relative to the sector; major infrastructure requirements; exaggerated claims about performance; and hubris. He argued that the more of these indicators that are present with regard to a specific technology, the more cautious society should be in committing to adoption of that technology. Others have amended or added to this list, for example, Shackley and Thompson also add a number of what they refer to as 'organisation indicators', including closure to criticism and 'single mission outfits'. Similarly the Royal Commission on Environmental Pollution's report on nanotechnology (RCEP, 2008) makes use of Collingridge's indicators, and adds an additional indicator of irreversibility in the form of whether or not a technology involves the uncontrolled release of substances into the environment.

While the use of indicators has been usefully applied, one critique of this approach is that – aside from the implicit normative desirability of corrigibility or flexibility in socio-technical development - there is little room for a consideration of what might be considered socially desirable directions for change. This is a generic challenge to the assessment of processes of path-dependence and lock-in, namely, that while this kind of technology assessment is usually understood as being an explicitly normative project (Collingridge, 1980), in that it represents an attempt to 'anticipate and ameliorate the down-side impacts of human interventions' (Guston & Sarewitz, 2002, p. 95), work in this area soon encounters the issue that values are not always shared. It is not always the case that 'an unambiguous set of societal goals can be enunciated. In reality, societies incorporate and express many different (sometimes contradictory) goals, the importance of which may change over time and will differ among people' (Rip & Kemp 1998, p.372). Indeed technological developments may even change the societal norms by which their impacts are to be judged, they can 'transform our very conception of human beings, human flourishing, and of the proper relationship between human beings and nature' (Barry 2010, p.170). Given that multiple values and different visions of desired futures exist, there are multiple possible directions for what constitutes desirable technological 'progress.' For example, as Brown (2003) puts it:

> 'The future – and its associated meta-concept of 'progress' – emerge through an unstable field of language, practice and materiality in which different groups compete for the right to represent near and far term developments. And like any other contested field, actors engage in such struggles with unequal access to the resources with which futures are manufactured.' (Brown 2003, p.13)

These issues raise fundamental questions about the role of assessment. Traditionally, much technology assessment has focused primarily on the notion of risk, utilising expert-led analytical methods such as cost-benefit analysis, and risk assessment. However the inadequacy of these approaches to determining the desirability of a given direction of development, or for operating in situations of uncertainty, ignorance or ambiguity has been the subject of sustained academic critique. For example Stirling argues:

> 'Where there exist divergent socio- political interests and values, it is a fundamental finding in axiomatic rational choice theory that there cannot exist – even in principle – any purely analytical means definitively to reconcile the resulting contrasting preference orderings (Arrow 1963; Kelly 1978). This refutes the value of the aggregated quantitative results routinely produced in social appraisal by methods like cost benefit analysis, risk assessment and decision theory' (Stirling 2009, p.25).

An overly narrow conceptualisation of technology as separate from society has also been the subject of critique which has drawn attention to the hybrid characteristics of technology, incorporating social and discursive elements, and of the importance of social deliberation around the form and direction that technologies take, rather than simply making efforts to minimise impacts. As MacNaghten and colleagues point out, often:

> 'the academic literature has framed technology as 'black-boxed' and well-defined, with an independent asocial logic that results in 'impacts' or 'effects'. Social questions are often narrowly framed as 'impacts' or 'risk' issues, placing the site of social science inquiry firmly 'downstream' of innovation processes' (Macnaghten et al. 2005, p.268)

As a result of this awareness of the social character of technology, the plurality of potential directions of 'progress' and the profound implications for society and democracy of the choosing of particular development paths over others, there has been a turn to greater transparency and reflexivity in processes of technological assessment as evidenced by the development of approaches such as 'real time TA' (Guston & Sarewitz 2002), 'constructive TA' (Rip et al. 1995) and participatory TA (Joss 2002). An important component of these approaches is the need for assessment to be engaged at an 'upstream' moment (Nordmann 2010; Macnaghten et al. 2005) rather than simply considering downstream 'impacts', and to examine the different kinds of visions of the future embedded in particular ideas about emerging technologies, an endeavour sometimes referred to as vision or expectation assessment (Grunwald 2007; Lucivero et al. 2011) , or the 'forensics of wishing' (Nordmann 2010).

Assessment: geoengineering-specific challenges

A number of large multi-partner, multi-disciplinary projects are currently underway with the remit of assessing geoengineering proposals, including the Integrated Assessment of Geoengineering Proposals (IAGP) and the European Transdisciplinary Assessment of Climate Engineering (EUTrace), and a growing body of work relevant to the assessment of socio-technical entanglements and geoengineering exists, including efforts to trace the historical emergence of the field (Fleming 2006), and to map out the current extent of work in this area (Belter & Seidel 2013), or to explore possible future scenarios in which geoengineering technologies feature (Banerjee et al. 2013). In addition to the generic challenges of technology assessment and the study of processes of socio-technical entanglement outlined above, there are a number of characteristics that make assessment of geoengineering particularly challenging, including the difficulties posed by the inherent ambiguity of the term geoengineering; the diversity of technologies that are currently discussed using this terminology and the different ways in which various actors have attempted to categorise these; and the variety of extant framings of geoengineering.

For example, while many authors refer to the Royal Society definition of geoengineering as the 'deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming' (Shepherd et al. 2009, p.ix), the term is still contested, with some authors suggesting that the term needs disaggregating (Heyward 2013), that it is too ambiguous (Edenhofer et al. 2011), or that other terms such as 'climate remediation' (Long et al. 2011; D. Sarewitz 2011) or 'climate management' (Michaelson 2013) might be more appropriate. The diversity of approaches subsumed within the umbrella term 'geoengineering' likewise raises significant issues for assessment, and has led to calls for the different approaches to be analysed individually (Hulme 2012), or to attempts to group approaches into particular types - such as the much-used Solar Radiation Management (SRM)/ Carbon dioxide Removal (CDR) distinction (Shepherd et al. 2009) – and carry out analysis with regard to these categories. Rayner has suggested that the CDR/SRM taxonomy could be improved by distinguishing techniques involving so-called 'ecosystems enhancement' from those described as 'blackbox engineering.' The former refers to technologies that 'stimulate or enhance natural processes' (Rayner 2011, p.4) such as ocean iron fertilization or stratospheric aerosol injection, while the latter refers to techniques such as direct air capture or space mirrors. Another classificatory system draws an ethical distinction between approaches which attempt to remediate or clean up damages, such as direct air capture (labelled as 'geo-remediation'), and those which aim at 'steering around or repairing anticipated damages', such as stratospheric aerosol injection, labelled as 'geo-steering' (Hale 2013, p.201).

The variety of different classificatory systems indicates that no one typology can be considered final or absolute. These struggles around the naming and typologizing of a field are about more than just semantics, and much work in the social and political sciences has emphasized the fact that the act of naming is an important way in which power operates (Escobar 1998; Bourdieu 1991). With regard to the naming of an academic discipline or field, work examining the emergence of distinctive fields of 'nanotechnology' (Robinson 2010), and 'synthetic biology' (Molyneux-Hodgson & Meyer 2009) has shown that the act of naming is crucial to the coming together of a 'community of practice' (Wenger 1998) in a particular domain. This delimitation of a named field has important material and political consequences, in that it 'renders more visible, more powerful, and increases the potential to attract funding for, certain forms of work' (Molyneux-Hodgson & Meyer 2009, p.136). Existing, previously unconnected research trajectories may then engage with the new label in different ways – either actively seeking to be incorporated or asserting distinctiveness. In the case of geoengineering, existing research in diverse areas such as climate modelling, cloud physics, aerosols, forestry or soil science might, from particular vantage points be considered 'geoengineering research', but the cohesiveness of a singular 'field' cannot be assumed. This serves to highlight the need for assessment or consideration of socio-technical entanglements to engage critically with the term itself, to decentre the analysis (c.f. Carolan 2010).

An important part of this process of engaging critically with the label of geoengineering is discourse analytical work examining the framings of geoengineering. A number of such studies have been carried out, highlighting the important ways in which framings are emerging (or being used strategically) and impacting on the development of geoengineering as a distinctive 'field' (Nerlich & Jaspal 2010; Sikka 2012; Luokkanen, Huttunen & Hildén 2013; Porter & Hulme 2013; Scholte et al. 2013; Luokkanen, Huttunen, Hildén, et al. 2013; Buck 2010). Bellamy et al (2012) in particular have illustrated the ways in which the framing of assessment and appraisal themselves are powerful ways in which particular processes of 'cognitive lock in' might occur, and draw attention to the way in which many assessments of geoengineering to date have created an artificial choice between technologies by focusing on these approaches in contextual isolation, rather than in the context of the wider portfolio of options for tackling climate change.

The existence of diverse framings of geoengineering is related to the existence of diverse societal values in this domain. As mentioned, all technology assessment faces the challenge of incorporating and responding to diverse societal goals and values, and this issue is particularly relevant to the appraisal of geoengineering technologies, and ties into broader debates about the role of technological assessment and appraisal itself – i.e. that it needs to be participatory, deliberative, reflexive, embedded etc., in order to be able to reflect these pluralities and indeed to avoid reinforcing particular path dependent processes. The elicitation and incorporation of public views and perceptions of geoengineering into governance arrangements is clearly crucially important for any assessment process (Adam Corner et al. 2012; Pidgeon et al. 2012; Poumadère et al. 2011; Macnaghten & Szerszynski 2013), and yet the very act of engaging publics with the topic of geoengineering is, itself fraught with potential for feeding into path dependent processes.

Another framing with which assessment needs to engage critically, is that of geoengineering technologies as being 'novel' or at an early stage. For example, historical work on weather and climate modification has illustrated that the supposed novelty of these ideas doesn't always stand up to scrutiny (Fleming 2010; Fleming 2006), but are the latest manifestation in a long history of attempts to control the climate. With regard to the study of potential lock-in, the idea that humanity is currently at the frontier of technological development or at an 'upstream' stage, and even the idea of assessing potential lock-in in the future might reinforce this idea of novelty, or act to obscure certain lessons from history. It is also the case that although many of the schemes being discussed have not been attempted to date, history is replete with example of socio-technical developments in other areas that might be relevant to understanding possible patterns of development in geoengineering. The use of historical analogues to examine possible social patterns of responses to technological innovation has been carried out with regard to a number of technologies (J. Watson, Kern, and Nils Markusson 2013). Clearly the choice of analogue in any given case is crucial: as Walker points out, generalisation from particular historical cases of technological development should be approached 'with caution as the histories of all technologies are sui generis in considerable degree where there is great complexity' (Walker 2000, 845). With regard to geoengineering, a number of analogues have been suggested, including weather modification (Travis n.d.), nanotechnology, molecular biology, and nuclear science (Bracmort & Lattanzio 2013), ecological analogies such as the use of biological control (Matthews & Turner 2009), or human interventions in other natural cycles such as the nitrogen cycle (Morton 2013). While some work in this field has been carried out, the use of analogues to better understand the likely social processes at work in different kinds of geoengineering interventions is likely to be helpful.

Section 4. Workshop aims

Given the scale and the far reaching implications of many of the interventions being discussed in terms of geoengineering, and the growing academic and policy interest in this area, discussion of issues around emerging irreversibilities of various types is timely and crucial. Despite the many generic and more specific challenges facing assessment of path-dependent processes and forms of potential lock-in in the field of geoengineering, the theoretical frameworks of path-dependence and lock-in, and empirical material drawn from experiences with other socio-technical developments are likely to have much to offer. This workshop, being run by the Climate Geoengineering Governance project, aimed to bring together leading academics and others:

- To examine the insights gained by, and limitations to applying frameworks of path-dependence and lock-in to the study of emerging geoengineering technologies.
- To bring together scholars from diverse disciplinary backgrounds (including those not currently engaged with geoengineering research) to re-examine the concepts of path-dependence and lock-in through the lens of geoengineering.
- To generate discussion on potential methods for appraising likelihood of lock-in of various types of geoengineering technologies
- To highlight fruitful areas for further research

About us: The Climate Geoengineering Governance project (http://geoengineering-governance-research.org) is a collaborative research project being carried out by the Universities of Sussex, Oxford and UCL, which aims to provide a timely basis for the governance of geoengineering through robust research on the ethical, legal, social and political implications of a range of geoengineering approaches. It is funded by the Economic and Social Research Council (ESRC) and the Arts and Humanities Research Council (AHRC), and will run between July 2012 and September 2014.

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