



Contents lists available at ScienceDirect

## Global Environmental Change

journal homepage: [www.elsevier.com/locate/gloenvcha](http://www.elsevier.com/locate/gloenvcha)



# Policy responses to rapid climate change: An epistemological critique of dominant approaches

Mark Charlesworth<sup>a,\*</sup>, Chukwumerije Okereke<sup>b,1</sup>

<sup>a</sup> Research Institute of Law Politics and Justice, Keele University, Keele, Staffordshire ST5 5BG, UK

<sup>b</sup> Smith School of Enterprise and the Environment, University of Oxford, Hayes House, 75 George Street, OX1 2BQ, UK

### ARTICLE INFO

#### Article history:

Received 7 January 2008

Received in revised form 22 August 2009

Accepted 14 September 2009

#### Keywords:

Rapid climate change policy

Prediction

Epistemology

Ethics

### ABSTRACT

This paper reviews existing policy responses to rapid climate change and examines possible assumptions that underpin those responses. The analysis demonstrates that current policy responses to rapid climate change make unwarranted epistemological and ethical assumptions. Specifically, we argue that the assumptions about the possibility of predicting the climate system including tipping points linked to utilitarian ethical assumptions in the form of cost–benefit analysis are open to contestation and should be subject to global public debate. The paper considers alternative normative approaches and briefly proposes complementary policy responses.

© 2009 Elsevier Ltd. All rights reserved.

## 1. Introduction

Evidence is starting to accumulate for the possible beginnings of rapid climate change or at least more rapid change of systems that may affect the climate, than had been assumed (NSIDC, 2005; NASA, 2006; Walter et al., 2006; ESA, 2008, 2009; cf. Pearce, 2006). It can reasonably be argued that the climate and climate related systems are already rapidly changing. Schellnhuber et al. (2006) does not robustly dispel this possibility. This is not evidence of runaway climate change, but might be seen as an indication that a rapid cascade of climate change may become evident more quickly than has previously been ‘assumed’ (cf. IPCCWG2, 2001, p. 129).

In this situation crucial questions are (1) how should society and policy respond to current indications of rapid climate change? (2) What should human responses be if the evidence becomes clearer? These questions are already being addressed in the seminal scholarship and highly influential policy documents (Hulme, 2003, 2008; Stern Report, 2006). However, extant approaches appear to embody critical assumptions that might lead to the development of grossly inadequate policies; or at a minimum should be subject to global public debate.

These assumptions relate firstly, to the idea that humans can or will soon be able to predict the climate system including tipping points for its period of inertia—perhaps thousands of years. And,

secondly that utilitarian economic assumptions can capture the range of human preferences over these periods. This article explores the origin of the predictive paradigm and questions the validity of this and closely related ideas as a basis for national and global climate policy-making. To end, we draw from theories of discursive democracy and virtue ethics to offer brief suggestions for complimentary or alternative approaches. Given the wide acknowledgement that climate change might be the most important challenge ever faced by humanity, we share with Achterberg (2001, p. 183) that the ethical basis for climate policy and indeed the governance of global environmental change be urgently held up for scrutiny.

## 2. Existing policy responses to rapid climate change

The possibility of ‘rapid’ or ‘abrupt’ climate change had been mooted at least as long ago as 1992 (Mintzer, 1992, pp. 55–64; cf. Mercer, 1978, pp. 321–325). However, significant discussions of policy implications have only recently begun to emerge in the literature and policy circles (Rahmstorf, 1994, 1995; Schellnhuber, 1998, 2001; Schneider et al., 2002; Hulme, 2003, 2006, 2007, 2008; Schneider, 2003; POST, 2005; US Congressional Budget Office, 2005; Stern Report, 2006; Lowe, 2006). Existing policy or policy theory responses to rapid climate change tend to make the following key epistemological and ethical assumptions (cf. IPCCWG2, 2001, p. 124; Lenton et al., 2008; Pielke et al., 2000, pp. 385–386; Smith, 2003, pp. 29–51; Stern Review, 2006). The assumptions about knowledge of the Earth System appear to be (1) we need more knowledge so that we can know just how far we can push the climate (earth) system. (2) Humans can know what level

\* Corresponding author. Tel.: +44 01977 780116; fax: +44 01782 733592.

E-mail addresses: [m.e.charlesworth@keele.ac.uk](mailto:m.e.charlesworth@keele.ac.uk) (M. Charlesworth), [Chuks.okereke@smithschool.ox.ac.uk](mailto:Chuks.okereke@smithschool.ox.ac.uk) (C. Okereke).

<sup>1</sup> Tel.: +44 01865 614916; fax: +44 01865 614960.

of stress we can cause to the Earth System before the climate (earth) system changes state. (3) 'Experts' can tell us this. (4) All tipping points will be imagined and identified. (5) Levels of stress before tipping points are reached can be identified and 'measured' robustly enough and soon enough to allow avoidance of tipping points in the Earth System despite significant inertia.

The dominant implicit ethical assumptions appear to be (1) humans could and should get as much material benefit from the Earth System as possible within legal and Earth System limits. (2) Economic cost–benefit analysis captures the range of human values and preferences within and between cultures. The above two groups of assumptions can be gathered together under two key terms: prediction and economic utilitarianism. Both are equally important in understanding the underlying philosophy and prevailing direction of climate policy-making in the Western democracies. However in this article we shall focus on the issue of epistemology.

### 2.1. Climate prediction and policy for rapid climate change

Climate prediction and projections have become without a doubt the bedrock of climate policy at least in the developed world. To a more or less degree, all the targets and policy responses for climate change both at national and continental levels derive from projections made available by climate scientists. Indeed, accordingly to Alan Thorpe, former director of UK Hadley centre in the met Office and a leading scientists in climate science in the UK, the ability of scientists to predict climate for seasons and years into the future is precisely what makes science "crucial in determining government and international policy" (Thorpe, 2005, p. 3). To be sure, predictions of future climate change based on numerical global models and probabilistic analysis are certainly important outputs of climate science. There is also the need to be clear that climate monitoring and projections, including the estimation of possible impacts on society and the environment "have been crucial in the emergence of climate change as a global problem for public policy and decision making" (Dessai et al., 2009a).

What is intriguing however is that while many of those adopting a predictive approach to climate policy admit the possibility of abrupt climate change, they have consistently failed to consider what the policy options should be if rapid climate might or should start to happen. For example, in one of the seminal papers on the topic entitled "Abrupt climate change: can the society cope?", Hulme (2003) clearly notes rapid change in climate is a distinctive possibility but then he suggests "it is premature to argue that abrupt climate change ... constitutes a dangerous change in climate that should therefore be avoided at all reasonable cost" (p. 16). Later Hulme (2003, p. 16) goes on to imply that more probabilistic estimates of abrupt climate change are needed before significant decisions can be made—a conclusion that appears to assume that the climate system will not change abruptly until humans have done some (robustly predictive) studies. Hulme does call for the assumptions of these estimates to be transparent. Whether he means purely scientific assumptions or epistemological, ethical, political, faith in the robustness of the Earth System, etc. is not clear.

Similar tensions exist in a report by the Committee on Abrupt Climate Change (CACC), a study of the science and potential impacts of abrupt climate change. The report, on the one hand, recognises the possibility of rapid climate change saying that "recent scientific evidence shows that major and widespread climate changes have occurred with startling speed..." (CACC, 2003, p. 1). On the other hand, however, the report provides little insight into policy-making in a context of a possible rapid climate change other than a call for better science and a discussion of potential impacts of abrupt climate change. Again, this is perhaps

because of an assumption that the prediction of abrupt climate change (e.g. CACC, 2003, pp. 4–5), or even prediction of the financial costs of abrupt climate change (e.g. CACC, 2003, pp. 152, 157–159) is needed before policy can be made.

Another, equally telling example can be found in POST (2005), which is a UK Parliament report that addresses rapid climate change. Like the CACC document before it, the POST makes clear that, in spite of significant uncertainties, abrupt climate change remains an important question that policy-making needs to consider. However, the most concrete policy responses it offers is to "... instigate coordinated research; install monitoring systems; implement win-win strategies to reduce vulnerabilities; and ultimately stabilise atmospheric GHG concentrations at a level that would lower the risk of rapid changes in the future" (POST, 2005, p. 4).

Other significant sources which demonstrate similar lacunae are the UK Stern Report on the Economics of Climate Change and a report by the US Congressional Budget Office (2005). Both documents explicitly consider abrupt or non-linear climate but offer no detailed discussion on possible ways of responding to the unprecedented levels of uncertainty in climate science (cf. Hof et al., 2008). All of the above examples illustrate the difficulties of predict-and-control<sup>2</sup> approaches to policy where levels of stress to the Earth System before tipping points are reached cannot be robustly identified. These measures are largely based on the assumptions that humans can predict the level of stress to the Earth System before significant harm to human societies is inevitable (cf. Pilkey and Pilkey-Jarvis, 2007).

But given the uncertainties surrounding climate science, and our knowledge of the Earth System in general, there may be considerable risk attached to policy processes that simply assume uncertainties can be removed. Schneider et al. (2002, pp. 53–87) offer a useful discussion of 'decision making under uncertainty' with regard to the Earth System which effectively highlights the problems with these approaches. They state clearly that 'unwarranted complacency may result from the inability to foresee non-linear events' (p. 65) and suggest that "... in view of the wide range of plausible climatic change scenarios available in the literature – including a growing number of rapid non-linear change projections – it is important for costing analyses to consider many such scenarios, including the implications of rapid changes in emissions triggering non-linear climatic changes with potentially significant implications for costing" (p. 79). Similarly, in a separate report to the OECD on the topic, (Schneider, 2003, p. 16) repeats the message that approaches "which neglects surprises ... of the earth system ... is indeed questionable, and should carry a clear warning to users of the fundamental assumptions implicit in it." The main point here is quite simply that given the dependence of human societies on the Earth System, the element of surprise which is well recognised in Earth System science, should be emphasised in both scholarship and decision-making circles and with clear considerations of implications and policy options. Indeed, one option, as suggested by Rial et al. (2004, p. 31) is "not to rely on prediction as the primary policy approach to assess the potential impact of future regional and global climate change."

#### 2.1.1. Predictability of the Earth System?

Given the emphasis on prediction in the climate policy literature it is important to ask whether the uncertainties around predicting future climate can be removed. A brief exploration of

<sup>2</sup> See the later discussion of Bacon for an indication of the relationship of prediction and control in the dominant Baconian policy paradigm. The relationship between prediction and control is typically not made explicit; however, an implicit aim of prediction is commonly control. This article is more concerned with prediction to avoid rapid climate change than prediction to 'control' the climate—i.e. geo-engineering.

the literature on climate science and Earth System science will provide useful insight. In 2001, the IPCC explicitly recognised that non-linear climate change was a possibility with which policy-makers ought to be concerned. The body stated that "... with a rapidly changing external forcing, the non-linear climate system may experience as yet *unenvisionable, unexpected, rapid change*" (IPCCWG1, 2001, p. 96, emphasis added). By their fourth assessment IPCCWG1 (2007, pp. 123–124) felt the need to address 'Frequently Asked Question 10.2: How Likely are Major or Abrupt Climate Changes, such as Loss of Ice Sheets or Changes in Global Ocean Circulation?' Their answer can be summarised as—not very likely, we cannot dismiss the possibility, but we do not really know. Given the difficulties in prediction highlighted in this paper and indicated in the detail of their reasoning, the tension between 'not very likely' and 'we do not really know' is significant. While it was useful to summarise the research that has been complete since 2001 it would perhaps have been more helpful for policy-makers for the IPCC to emphasise 'we cannot dismiss the possibility but we do not really know' more. As stated, the IPCC admits to deep epistemological issues with climate science:

The evaluation of uncertainty and the necessary precaution is plagued with complex pitfalls. These include the global scale, long time lags between forcing and response, the impossibility to test experimentally before the facts arise, and the low frequency variability with the periods involved being longer than the length of most records. (IPCCWG3, 2001, 656)

Furthermore, it says:

Finally, a series of potential large-scale geophysical transformations ... have been identified and examined more closely in recent years. These imply thresholds that humanity might decide not to cross because the potential impacts ... are considered to be unacceptably high. *Little is know about these thresholds today* (IPCCWG3, 2001, 673, emphasis added)

However despite making these telling statements about abiding uncertainty and ignorance, the IPCC still manages to find enough confidence to make assurances that abrupt climate change is an unlikely event. Meanwhile, it is important to be aware, as the IPCC itself well recognises that the inertia implied in 'long time lags' may be hundreds of years (IPCCWG1, 558) for some components of the Earth System and conceivably thousands of years (IPCCSR, 2001, pp. 16–21). This suggests that predictive efforts will need to be robust for these lengths of time for predictive management of the climate (and earth) systems to be effective.<sup>3</sup> The IPCC's evaluation of limitation in human theories of knowledge is very instructive:

Some of these uncertainty aspects may be *irreducible in principle*, and hence decision makers will have to continue to take action under significant uncertainty, so the problem of climate change evolves as a subject of risk management in which strategies are formulated as new knowledge arises. (IPCCWG3, 2001, 656, emphasis added)

These quotations taken together are important because they indicate the tensions but equally the stakes that may be involved in the choice of how to respond to climate change. It is at least apparent that, in assuming management as the correct response to uncertainty (as opposed to for example precaution), the IPCC makes a normative assumption with which a large section of the global

population might not necessarily agree (cf. Jamieson, 1992; Padilla, 2004; Smith, 2003, pp. 29–51; Palmer and Finlay, 2003). It is significant that the IPCC themselves have still not made it clear to the general public what these 'large-scale geophysical transformations' might be so that 'humanity might decided [to try] not to cross' them. IPCCWG3 (2001, p. 677) appears to suggest these are events such as the shutdown of the North Atlantic Thermohaline Conveyor or the collapse of the West Antarctic Ice Sheet, which would almost certainly have very detrimental effects to human societies.

IPCCWG2 (2001, p. 129) assumes that the assessment of the 'low probability [of] ... the occurrence of extreme climate outcomes such as a "runaway greenhouse effect"' is known in an objective sense from 'subjective probabilities' from 'experts'. Of course, this may well be the best process humanity has for making this type of assessment, but it is hardly 'objective science'<sup>4</sup> and appears to take no assessment of various factors that may affect the judgement of these experts. Some of these factors could include (1) commitment to: particular ontological assumptions, scientific paradigms; scientific methods, ethical frameworks, economic and political arrangements; (2) supra-rational beliefs about the robustness or otherwise of the Earth System and the basis of those beliefs and (3) level of expertise in the philosophy of science, in particular any current limitations of science.<sup>5</sup>

A recent synthesis and assessment report on abrupt climate change produced by the US Climate Change Science Program (2008) supports the possibility of abrupt change. But like the IPCC, the report, on the one hand, considers abrupt change unlikely in the next few years, but on the other hand emphasises profound ignorance and current limitations of predictive approaches. Again like the IPCC and other high profile reports before it, makes no obvious attempt to address the profound philosophical questions about persistent limitations of prediction that is acknowledged. Indeed, the report takes a strongly reductive approach in the sense that it considers individual examples of abrupt change, but makes little effort to consider if one form of abrupt change should happen then whether this could trigger further abrupt changes. One example could be the rapid melting of the Greenland ice sheet that then triggers a rapid reduction in the Gulf Stream (e.g. AMOC). This limitation, in our view, underlines the difficulties of a predictive approach more than a lack of effort on behalf of the authors (cf. Allen and Frame, 2007; Stainforth et al., 2005).

The persistence of predictive approaches led Shackley and Wynne (1995) to suggest that a conclusion of low probability of extreme events might be as much conditioned by the answers policy-makers would like as by what science on its own can justify. The ingrained dislike of unpredictable events may largely stem from the realisation that policy-makers standard tools, particularly economic cost–benefit analysis, find it difficult to respond to this possibility.<sup>6</sup> A number of different authors have also argued that maintenance of a 1.5–4.5 °C climate sensitivity is as much a result of its social convenience as of the science itself (Shackley and Wynne, 1995; Morgan and Keith, 1995; Demeritt, 2006).

Similarly, Van der Sluijs et al. (1998, p. 318 emphasis added) insist that abrupt climate change are not taken very seriously in

<sup>4</sup> Compare this approach to the motto of the Royal Society 'On the words of no one' (<http://royalsociety.org/page.asp?id=6186> and <http://www.royalsoc.ac.uk/page.asp?id=1020>).

<sup>5</sup> Scientists may or may not need expertise in philosophy of science to operate as scientists; however, to offer rational evaluation of the limits or otherwise of science as it is applied to policy questions an understanding of philosophy of science seems one essential skill.

<sup>6</sup> Schimmelpenninck (1996) presents a good analysis of many of the types of uncertainty in economic models of climate-change impacts and a range of responses; however, this just serves to emphasise the difficulties of using predictive, numeric and utilitarian approaches to climate change impacts as well as the democratic opaqueness of any results and questionable nature of such results.

<sup>3</sup> The 2001 IPCC third assessment reports put more effort into discussing inertia in economic systems than they do into discussing inertia in the climate or Earth System. This arguably implies a normative assumption in favour of economic utilitarian ethics by the 2001 IPCC reports.

policy debate because such a course "... would upset the existing commitment by most ... policy actors and institutions to the idea of smooth and *manageable* forms of anthropogenic climate change, corresponding with the idea of its intellectual amenability to the modern epistemic culture of prediction and control". This verdict might be subjective, but what is incontrovertible is that previous inaccurate predictions of climate change and existing evidence of rapid change already strongly suggest the limitations of predictive approaches. Moreover, inertia in the climate systems means that a domino effect of imagined and unimagined climate feedbacks producing barely imaginable temperature change cannot be ruled out on the basis of science alone, though this is not yet clearly evident.

Furthermore, the problem with the limitations of climate prediction is exacerbated when one notes that scholarship on broader Earth System science make clear that changes in the earth environment happen in ways that "are difficult to understand and often impossible to predict" (Steffen and Tyson, 2001, Foreword). Steffen and Tyson (2001) go on to indicate more specifically that the Earth's dynamics are characterised by the possibility of abrupt changes with catastrophic consequences which can be triggered by human activities. They claim that "the nature of changes now occurring *simultaneously* in the Earth System, their *magnitudes* and *rates of change* are unprecedented" (p. 3). If then, as it seems, we cannot confidently rule of abrupt change, one would think it makes sense to have serious discussion about what the response option should be.

### 2.1.2. Thresholds and the epistemology of the Earth System<sup>7</sup>

Are there ideas that indicate that humans will be able to predict-and-control (manage) the Earth System and what do theories of knowledge tell us about this important question? There are many areas of debate but the key argument centres on the existence or otherwise of critical thresholds and possibility of identifying and measuring these. Thus, Schellnhuber (1998, p. 21, *emphasis in original*) captures the scene well when he said that "One of the most burning questions of modern environmental research is... whether there is a possibility that *critical thresholds* ... exist in the ... complex Earth System for certain global conditions."

Majority of the leading scholars in the field tend to think that critical thresholds exists but that these can be imagined and identified (Schellnhuber and Held, 2002; Schellnhuber, 1998, 2001; Schellnhuber et al., 2004; Steffen and Tyson, 2001; Steffen et al., 2004). In answer to the question posed in his seminal contribution, Schellnhuber (1998) suggests that while there are epistemological difficulties relating to "*irreducible cognitive and voluntative uncertainties*" (p. 181; our emphasis), thresholds can for practical purposes be established and measured. Furthering his thoughts on this topic later, Schellnhuber (2001, pp. 50–51) suggests that the control and management of the Earth System through the identification and measurement of critical thresholds is both possible and desirable. Schellnhuber et al. (2004, pp. 8–10, 17), recognise once again the inherent incompleteness and consequent limitation of prediction but nonetheless proceed to assert that developing a "comprehensive list" of critical thresholds in the Earth System will help to "support global stewardship" and avert run away climate change. Continuing, they express the confidence that "The S&T [Science & Technology] community could

therefore significantly improve the prospects for humanity consciously managing a transition toward sustainability by developing an understanding of the vulnerability and resilience of the Earth's life-support systems to "dangerous" disruption" (Schellnhuber et al., 2004, p. 18). They did not make clear the basis of this assertion of the possibility of a comprehensive analysis given especially the earlier admission of the limitations of prediction. Similarly Steffen and Tyson (2001, p. 25) say:

There are now methods developed in biophysics that try to anticipate when critical systems thresholds will be crossed by detecting warning signs of the imminent phase transition. The latter approach is particularly relevant to Earth System analysis that attempts to identify the switch and choke points in the planetary machinery that might be inadvertently activated by human activities. In fact, science can even benefit from the existence of strong nonlinearities in the Earth System by devising an inverse sustainability strategy that calculates the critical anthropogenic perturbations to be avoided at all costs.

However, like Schellnhuber et al. (2004), they do not provide details or references to how calculations of levels of these critical perturbations may be achieved. One possible approach to critical threshold measurement has been considered by Kleinen et al. (2003). These authors suggest that this can be done by the means of a 'simple two-box model of the hemispheric thermohaline circulation' (Kleinen et al., 2003, p. 53). However, at the current level of development the approach does not mean that robust process can be assumed.

Authors such as von Bertalanffy (1971), Laszlo (1972) and Jantsch (1980) discuss systems theory and systems science. Specifically, Jantsch (1980) discusses systems that change state at a specific or 'critical' level of disturbance, noting everyday occurrences of this phenomenon. He does describe ways of finding critical thresholds where switches in state will take place, but the indication appear to be that this is possible only with laboratory systems where repeatable experiments can be done. This difficulty in identifying such 'tipping points' without the use of repetitive experimental processes possible only with laboratory systems continues to weigh heavily on Earth System science to this day despite at least one journal devoted to 'Nonlinear Processes in Geophysics' (Schellnhuber, 1998, 1999; Schellnhuber and Held, 2002; Steffen et al., 2004; Schellnhuber et al., 2004; Rial et al., 2004; QUEST, 2005).

An example of critical thresholds in relatively simple systems is metal fatigue, where a crack propagates for months or years from a small imperfection, until the material is sufficiently weakened for it break in fractions of a second (Mann, 1967, p. 11). This can 'take place even though the peak stress is well below the ultimate tensile stress' (Cox and Tait, 1991, p. 42). It is also important to note that many materials, once stressed to a certain level, cannot return to their original state and will break even if the stress on them is reduced (White, 1999, p. 288; Boyer, 1986). In fact metal fatigue was only widely recognised after numerous fatal 'real world experiments' and is still an issue that leads to fatalities in industries such as aviation. This does not provide the confidence to presume that human beings can spot all thresholds in the Earth System in time to prevent them from being crossed. Other well-known examples of rapid change at critical thresholds include avalanches, anaphylactic shock, heart attacks, multiple organ failure, volcanoes, domino effects, economic crashes and political revolutions.

The above considerations would appear to lead to the conclusion that at present, there is no robust way of finding all critical thresholds in global and more local ecological systems without taking the risk of blowing up the 'laboratory' along with

<sup>7</sup> Cohen et al. (1998) is a useful comparison of climate change and sustainable development research noting the problems created by the separation of the two. They also emphasise the significance of ethical assumptions plus difficulties and significance of assumptions that prediction of the Earth System is required. On p365, they suggest that policy-making tools 'become less truth machines and more heuristic tools that engage users'—implying the democratisation of policy, even if there is no explicit call to directly engage citizens.

the experimenters. Faber et al. (1998, pp. 205–229) have argued very strongly on the epistemological limitations of Earth System science. In their detailed philosophical analysis of Earth System knowledge theories, they argue among other things that imperfect communication, inability to check all assumptions and the emergence of novel ‘natural systems’ and technology constitute nearly insuperable challenges for threshold predictions. One popular example that throws some light to some of the difficulty associated with new technologies is the case of chlorofluorocarbons (CFCs) the devastating effect of which was not known until it was almost too late. Indeed Crutzen (1996) suggests that if bromine had originally been used rather than chlorine, ozone depletion from fluorocarbons would have been much worse than it has been. Thus, it is not clear what basis the authors who believe in the robust prediction and management of critical thresholds have for assuming that all side effects of new technology can be anticipated and ‘managed’. Although Steffen et al. (2004) appear to embrace predict-to-control approaches, they also reflect on the near insurmountable epistemological difficulties implicated in this endeavour. They were prepared to admit that:

Systems theory suggests that complex systems can never be managed; they can only be perturbed and the outcomes observed. Furthermore many of these outcomes will be likely unpredictable ... This property of complex systems is manifest in the Earth System ... Humans ... cannot be in a position to manage the Earth System ... (Steffen et al., 2004, 286 see also 295, 297–8)

In addition, further difficulties are raised by questions around climate and Earth System models such as limitations of datasets, difficulties providing robust predictions at a small enough scale to be useful for local policy decisions, difficulties reconciling models with paleoclimate data, and difficulties collecting adequate paleoclimate data for comparisons at local levels. Beyond this, there is the even more fundamental philosophical issue of the ‘problem of induction’ (Hume, 1748/1975; Popper, 1972, pp. 27–30; Caws, 1965, pp. 256–265; Worrall, 1989; Bostrom, 1996; Howson, 2000; Norgaard, 1989, p. 44; Lemons, 1996, pp. 18–19) as illustrated by Popper’s example of the discovery of black swans when all swans had been assumed to be white (cf. Taleb, 2007). Indeed, Popper (1966, 1989, pp. 336–346) argues that the same problems that characterise the ‘natural’ component of the earth equally inhere in the human social component of the Earth System. He argues that assumptions of predictability of the development of societies lead to historicist totalitarianism implicated in some of the most unpleasant regimes of the twentieth century. Like Popper, many other notable authors on the philosophy of science such as Kuhn (1970), Lakatos (1970) and Feyerabend (1970, 1975) also suggest serious difficulties in the prediction of complex systems such as the Earth System.

## 2.2. The quest to dominate nature

The preceding sections indicate that while prediction-and-control of the physical world is the dominant approach to national and international climate policy, the method is nonetheless fraught with grave ethical and epistemological difficulties. Before considering possible alternative approaches, let us briefly shed light on the intellectual precursor of the predictive paradigm. The origins of the assumption of predictive approaches are undoubtedly complex; however, one key articulation of prediction-and-control assumptions (or even ideology) that is paradigmatic for most contemporary climate change policy comes from Francis Bacon and can be captured in the phrase ‘knowledge is power’

(Bacon, *Meditationes Sacrae*, 1597).<sup>8</sup> This knowledge and power come from systematic observation and systematic repeatable experiment organised by underlying reasonable theory (Milton, 1998, vol. 1, pp. 627–628). Milton goes on to write of Bacon: “... it was the ability of a theory to endow its holders with *power over nature* that provided the best, and indeed the only genuinely satisfactory, evidence for its truth.” (Milton, 1998, vol. 1, p. 628, emphasis added). Or in Bacon’s own words, “Human knowledge and human power meet in one, for where the cause is not known the effect cannot be produced. Nature to be commanded must be obeyed; and that which in contemplation is as the cause is in operation as the rule” (Bacon, *Novum Organum*, 1620, i 3; Quoted in Milton, 1998, vol. 1, 628).

Bacon applied his perspective on ‘science’ to politics primarily in a ‘utopian’ literary work<sup>9</sup> *New Atlantis* (Bruce, 1999, xxviii). According to Bruce (1999), the essence of this project, for Bacon, was to envision an ideal society that has managed to bring nature to subjection through breakthroughs in science and technology. Given of course, Bacon’s epoch, it is unsurprising that no consideration was given to ecological issues. Interestingly, Bacon’s *Atlantean* society has an equivalent of today’s Royal Society the purpose of which is to help enlarge “the bounds of human empire, to the effecting of all things possible” (Bruce, 1999, p. 177). It is not clear just how the above Baconian types of idea affect ‘modernity’ but commentators such as Jung (1993), Norgaard (1989, pp. 38, 53), Davidson (2000) and Simpson (2005) suggest they are important. Milton (1998, vol. 1, p. 626) argues that *New Atlantis* had a ‘profound influence ... on the founders and early practice of the Royal Society’ and Norgaard (1989, pp. 42–43) argues that they provide key inspiration for current attitudes to international environmental decision policy-making. Williams (1992, p. 132) equally highlights the significance of Bacon and also connects this significance to current dominant approaches to climate policy-making.

It is instructive, to the extent that these suggestions are valid, that one of the intellectual precursors of the predictive approaches to Earth System management is based on a project the explicit intention of which is to dominate and control nature. This is important not only because of the well-rehearsed problems with unrestrained anthropocentrism but also because there are deep epistemological problems as the discussions in previous sections have shown. Many ecological discussion of Bacon have highlighted the deep implications for ecological questions of Bacon’s ethical assumptions especially as it relates to the domination of nature (and women) (Attfeld, 1994, pp. 29–31, 48; Hay, 2002, pp. 75–76, 123; Merchant, 1983; Rodman, 1975). However, with the exception of Jamieson (1996) the equally problematic epistemological assumptions have hardly been seriously discussed. That is, they tend to be critical of an ethical assumption in favour of exploiting ‘nature’ rather than questioning human ability to sustain societies on the basis of controlling nature. More bluntly, they ask whether we should control nature rather than whether we can ultimately control nature or know the limits of our control.

Emerging discussion on geo-engineering illustrates this point. So far, with attention focusing on the important issue of ethics—

<sup>8</sup> cf. Attfeld (1994, 17, pp. 29–31). Also ‘For knowledge, too, is itself a power’, (Bacon: *Treatise De Hoeresiis*) ‘Knowledge and human power are synonymous, since the ignorance of the cause frustrates the effect’ (Bacon: *Aphorism III*). It is worth noting that Bacon may have put the above into the ethical context of ‘The desire of power in excess caused the angels to fall; the desire of knowledge in excess caused man to fall; but in charity there is no excess, neither can angel or man come in danger by it’ (Bacon: *Essay—On goodness*); as well as ‘Knowledge bloweth up, but charity buildeth up’ (Bacon, *Rendering of I Corinthians 8:1*, <http://www.worldof-quotes.com/author/Francis-Bacon/2/index.html>).

<sup>9</sup> Bruce (1999, xxxi) notes that in the preface (Bruce, 1999, p. 151) to the first publication of *New Atlantis*, it was described as a fable.

rightness or wrongness of this project and less attention devoted to philosophical arguments on why engineering the climate cannot be done robustly. One possible result of this oversight is that Baconian attitudes and epistemological assumptions continue to figure more or less prominently in national and globally influential institutions such as the UK's Royal Society, the US's National Science Board, IPCC and World Commission on Environment and Development (WCED, 1987). This paper suggests that it is currently a large leap of faith to assume that humans can successfully control, manage or know the 'tensile strength' of the Earth System as these institutions and their scientific intelligentsia would seem to believe.

### 3. Prediction and inaction on climate change

While climate prediction has played an important role in popularizing climate change as an issue, there is also evidence to suggest that it also has given room for inaction. Cast broadly this is at the heart of the 'sound science' debates that have particularly characterised US climate politics (e.g. Edwards, 1999; Schellnhuber et al., 2004, p. 18). More specifically, Demeritt (2006, p. 496) has argued that the fact that policymakers want prediction has had very significant implications on delaying urgent policy action. He notes that the obsession with prediction has led to a situation where all focus is on reducing the uncertainty of scientific predictions about the scale and impacts of future climate change with only a tiny fraction spent on the development of renewable energy technologies needed to mitigate further climate changes and even less on adaptation to cope with them.

Similarly, Brunner (1996) offers one highly relevant discussion of how policymakers have required prediction for climate policy and argues that this has led to inaction to reduce reasonable causes of climate change (Brunner, 1996, pp. 121–127, 140–141). The Economist (1994, 85), for example, warned that "A global change science that prefers fiddling with ever more complex number-crunching models to the fuzzier assessments of human risks and impacts will eventually forget about saving the planet and lose its political support." (cited in Brunner, 1996, p. 124).

More recently Steve Rayner<sup>10</sup> has compared the approach used by governments to deal with the global economic crisis and the one with which they deal with climate change. He noted that no lengthy debilitating cost–benefits analysis was done before the nationalization of the Northern Rock (UK) and Fannie Mea and Freddie Mac (US). However when it comes to climate change, policy-makers appear bent on the search for accurate predictions and pristine cost–benefit analysis which serve as excuses for inaction. Perhaps, however part of the reason for the lack of progress on less prediction-focused models of policy is perhaps that most of the authors critiquing predictive approaches have not clearly articulated alternative epistemological and ethical frameworks for policy-making.

### 4. Alternative policy responses to rapid climate change

If predictive approaches, despite their role in popularizing climate change have severe limitations as a basis for effective policy response, what are the possible complementary approaches or alternatives? We briefly highlight the promise and limits of five approaches.

The first is the "modest" incremental adaptive model as outlined by Brunner (1996). Brunner's key idea is that policy-makers should move away from long-term comprehensive-type prediction of Earth System to a more piecemeal approach. Similarly

<sup>10</sup> Professor Rayner made this comment in a public lecture on climate change at the University of Oxford in April 2009.

Lempert et al. (2004) and Dessai et al. (2009b) suggest a decision-making process that is based on plausible alternative future climate states for which exact prediction is not attempted but adaptation decisions are assessed to suggest their 'robustness' in these various states. This is a useful approach; however, it still relies to some extent on prediction, even if less exacting than typically desired by climate policy processes. From the evidence offered it is not clear that the detail of these processes are robust to the possibility of unknown, unimagined tipping points that might bring about local or global climate catastrophe. In addition, given hundreds of years of inertia and tipping points in the Earth System the detail of the proposals may be too reformist to bring about radical reductions in stress to the Earth System that this paper suggests may well be needed.

Second is to adopt technical solutions that are believed, on the basis of a lifecycle assessment (ISO 14040) or similar, to reduce stress to the Earth System. In comparison to system-wide predictive approaches, this is arguably less ambitiously predictive than cost–benefit analysis (cf. Pacala and Socolow, 2004).<sup>11</sup> Examples could range from organic agriculture to carbon capture techniques (e.g. Read, 2008; Shackley et al., 2008) and even geo-engineering (e.g. Crutzen, 2006). However, controversy around environmental lifecycle assessment for technologies as well understood as steel or aluminium for car production (ENDS Report, 1994, No 233, 24) demonstrates the difficulties of this approach. The previous analysis suggests that emphasis on Baconian technical solutions may be prompted by ethical and epistemological assumptions of 'modernity' rather than evidence of the effectiveness of this approach; see Binswanger (2001) for an illustration of the difficulties in predicting the environmental effects of technology when mediated by society. Permaculture (Mollison, 1988) as a technical system may be less affected by these difficulties than more industrial approaches because it is, in effect, a system where individuals (and communities) apply a virtue of prudence (even wisdom) in order to minimise stress on the earth, but maximise material welfare or even happiness through a broader virtue scheme including moderation. That permaculture is not industrial, and that it would be difficult for industry (rather than small businesses) to make profits by promoting it, is arguably one key reason for the lack of adoption and awareness of permaculture.

The third is the precautionary principle. The precautionary principle (PP) could readily suggest action to address climate change including reduced consumption without the need for perfect knowledge; however, the lack of an agreed philosophical basis for the PP and a lack of agreement about what the precautionary principle does in practice limit the effectiveness of the PP in a policy context where cost–benefit analysis is dominant. Ahteensuu (2007) and Dupuy and Grinbaum (2004) provide useful discussions of the PP as a possible basis for alternative approaches and highlight some ethical implications that arise. Essentially, they suggest the democratisation of policy aims as one possible response to difficulties of prediction, but their discussions do not do adequate justice to all the virtue schemes they might have considered.

The fourth idea is virtue ethics and epistemology with emphasis on moderation, prudence (wisdom) and hope. Jamieson (1992, pp. 139–146) (cf. Berkhout et al., 2003, pp. 22–33; Risbey, 2006), argues for virtue ethics where there are difficulties in prediction. Sandler and Cafaro (2005) indicate practical implications of broad conceptions of ecological virtue perhaps particularly usefully the virtue of moderation—consuming enough but not too much. From a less theoretical perspective, Palmer and Finlay (2003) illustrate that a range of cultures from across the globe respond to ecological

<sup>11</sup> Moderation in the use of private cars is discussed in this report.

and development questions with similar virtue ideas to those described in Sandler and Cafaro (2005). Moderation is also implicit in the 'steady-state economics' literature that includes Daly (1977) and Jackson (2009).

Prudence as an intellectual virtue is broader and more clearly theorised<sup>12</sup> than the typical utilitarian notion of prudence, which is closer to the shrewdness that is a component of some virtue notions of prudence. Something of how a virtue of prudence might be applied is illustrated by Brunner (1996). In this there is no discussion of (economic) optimality; rather, the model is similar to the intellectual virtue of prudence of Aquinas where balance of evidence is weighed up, appropriate caution applied and where all this is then combined with a virtue ethic judgement about what the right approach is—considering the consequences but not attempting to predict utility or welfare.<sup>13</sup> As classic virtue theories suggest, hope may be a key idea if humans are to avoid despair when they realise that humanity cannot control nature. Hope can be defined as 'the object of hope is a future good, difficult but possible to obtain' (Aquinas, *Summa Theologia*), this may be a valuable orientation in the face of unpredictable abrupt climate.

The last is discursive democracy. A key response to difficulties in prediction by a number of authors already mentioned (Dupuy and Grinbaum, 2004; Risbey, 2006; Demeritt, 2006; Cohen et al., 1998) and others (Dryzek, 1987, 1990, 2000; Funtowicz and Ravetz, 1991; Jasanoff, 2003; Wynne, 1996; Torgerson, 1999; Swyngedouw, 2007) is democratising policy rather than leaving it principally to economists and other experts who might not share the same normative position as large groups even the majority of citizens. This appears largely based not only on a (deontological) notion of a right to involvement in decisions that may affect individuals, but also on an implicit awareness of the argument of Popper's *Open Society* (1966): when experts cannot predict, then a process of decision-making that is as open as possible to knowledge and ideas from all sectors of society is most effective. Something of this logic is already enshrined in international 'soft law' such as Agenda 21 (cf. UNECE, 1998). Moves in the direction of greater democratic participation in policy are justified for these reasons. However, they may not aid actual decision-making in the face of unpredictable abrupt change; in this situation, a virtue notion of prudence as illustrated by Brunner (1996) may be more helpful. Democratisation of policy could mean that decisions take more time, although lack of action to address climate change over the last 20 years suggests that economic methods are little better at achieving action. Nonetheless, there is perhaps a need to focus participation in climate policy on specific questions; Jamieson (1992), Palmer and Finlay (2003) plus Sandler and Cafaro (2005) suggest that the utilitarian assumptions on which dominant notions of economics and current climate policy are based should be a key focus for democratic scrutiny for analytical and democratic reasons.

## 5. Conclusions

Natural science is and will remain absolutely essential to inform policy about rapid climate and Earth System change. If rapid changes in the Earth System become increasingly apparent, society will almost certainly demand more natural science research to better inform policy. However, it is not clear that natural science will ever be able to tell policy-makers what the limits of stress to the Earth System are before rapid changes take place or are inevitable because of inertia in the Earth System.

<sup>12</sup> At least by Aquinas, although contested.

<sup>13</sup> Later discussions of science policy (Brunner, 1996, p. 140) also have strong flavour of Aquinas.

It is typically assumed by policy-makers that science can tell us what level of stress to the Earth System consumerism can 'get away with'. This appears connected to a desire by policy-makers to use economic cost–benefit analysis. The huge or even 'infinite' possible ranges of economic costs from rapid climate and Earth System change, which current Earth System science suggests are plausible, means that economic cost–benefit analysis can be methodologically questioned. It can also be criticised for normatively favouring a particular notion of utilitarian ethics that appears widely contested or even globally undemocratic (cf. Palmer and Finlay, 2003). There are alternative rational epistemological and ethical assumptions. These should be considered and debated by makers of global policy and citizens worldwide. Natural scientists have a responsibility as citizens and human beings with significant 'authority' to promote and facilitate these debates (Tickner, 2003, 16, pp. 377–380), in particular by repeatedly making clear the current limits of scientific prediction. Some may wish to become involved in such debates.<sup>14</sup>

## Acknowledgements

The authors wish to thank Professor A. Dobson, C. Melo-Escrihuela, Dr. H. Stephan, Dr. E.A. Page and P. Burton-Cartledge and especially three anonymous referees for commenting on earlier versions of the paper. We accept full responsibility for all faults that remain.

## References

- Achterberg, W., 2001. Environmental justice and global democracy. In: Gleeson, B., Low, N. (Eds.), *Governing for the Environment: Global Problems, Ethics and Democracy*. Palgrave, Basingstoke.
- Allen, M.R., Frame, D.J., 2007. Call off the quest. *Science* 318, 582–583.
- Ahteensuu, M., 2007. Rationale for taking precautions: normative choices and commitments in the implementation of the precautionary principle. In: *Risk & Rationalities* (Conference Proceedings), Queens' College, Cambridge, UK <http://www.kent.ac.uk/scarr/events/ahteensuu.pdf>.
- Attfield, R., 1994. *Environmental Philosophy: Principles and Prospects*. Ashgate, Aldershot.
- Berkhout, F., Leach, M., Scoones, I. (Eds.), 2003. *Negotiating Environmental Change: New Perspectives from Social Sciences*. Edward Elgar, Cheltenham.
- Binswanger, M., 2001. Technological progress and sustainable development: what about the rebound effect? *Ecological Economics* 36 (1), 119–132.
- Boyer, H., 1986. *Atlas of Stress–Strain Curves*. ASM International, Metals Park.
- Bostrom, N., 1996. What We Should Say to the Skeptic. <http://www.nickbostrom.com/old/skepticism.html>.
- Bruce, S. (Ed.), 1999. *Three Early Modern Utopias*. Oxford University Press, Oxford.
- Brunner, R.D., 1996. Policy and global change research. *Climatic Change* 32 (2), 121–147.
- Caws, P., 1965. *The Philosophy of Science—A Systematic Account*. Van Nostrand, London.
- Cohen, S., Demeritt, D., Robinson, J., Rothman, D., 1998. Climate change and sustainable development: Toward dialogue. *Global Environmental Change* 8 (4), 341–371.
- Committee on Abrupt Climate Change, 2003. *Abrupt Climate Change: Inevitable Surprises*. National Academy Press, Washington, DC.
- Cox, S., Tait, N., 1991. *Reliability, Safety and Risk Assessment*. Butterworth–Heinemann, Oxford.
- Crutzen, P., 1996. My life with O<sub>3</sub><sup>-</sup>, NO<sub>x</sub>, and other YZO(x) compounds (Nobel Lecture). *Angewandte Chemie-International Edition* 35 (16), 1758–1777.
- Crutzen, P., 2006. Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma? *Climatic Change* 77 (3–4), 211–220.
- Daly, H.E., 1977. *Steady-state Economics: The Economics of Biophysical Equilibrium and Moral Growth*. Freeman, San Francisco.

<sup>14</sup> In a spirit of openness about the limitations of open participatory approaches, it may be that some form of expert less–predictive or non–predictive policy process for rapid climate change and other complex environmental issues may be developed. If this is clearly better than democratic policy processes, even discursive processes, then these conclusions would be out of date. Indeed, with a complete revolution in the philosophy of science, robust and near perfect prediction of the Earth System for the thousands of years required may become possible. However, it is not clear that such developments exist even in concept and are currently beyond the imagination of the authors; so until then, where robust prediction is not possible, we need to consider policy processes that are analytically more robust and democratic than economic cost–benefit analysis.

- Davidson, J., 2000. Sustainable development: business as usual or a new way of living? *Environmental Ethics* 22 (1), 25–42.
- Demeritt, D., 2006. Science studies, climate change and the prospects for constructivist critique. *Economy and Society* 35 (3), 453–479.
- Dessai, S., Hulme, M., Lempert, R., Pielke jr, R., 2009a. Climate prediction: a limit to adaptation? In: Adger, W.N., Lorenzoni, L., O'Brian, K. (Eds.), *Adapting to Climate Change: Thresholds, Values, Governance*. Cambridge University Press, Cambridge, pp. 513, pp. 64–78.
- Dessai, S., Hulme, M., Lempert, R., Pielke jr, R., 2009b. Do we need better predictions in order to adapt to a changing climate? *EOS* 90 (13), 111–112.
- Dryzek, J., 1987. *Rational Ecology Environment and Political Economy*. Blackwell, Oxford.
- Dryzek, J., 1990. *Discursive Democracy—Politics, Policy, and Political Science*. Cambridge University Press, Cambridge.
- Dryzek, J., 2000. *Deliberative Democracy and Beyond—Liberals, Critics, Contestations*. Oxford University Press, Oxford.
- Dupuy, J.-P., Grinbaum, A., 2004. Living with uncertainty: toward the ongoing normative assessment of nanotechnology. *Techné: Research in Philosophy and Technology* 8 (2), 4–25.
- Edwards, P.N., 1999. Global climate science, uncertainty and politics: data-laden models, model-filtered data. *Science as Culture* 8 (4), 437–472.
- ESA, 2008, 28 August. Arctic Ice on the Verge of Another All Time Low. European Space Agency [http://www.esa.int/esaCP/SEMCKX0SAKF\\_Protecting\\_0.html](http://www.esa.int/esaCP/SEMCKX0SAKF_Protecting_0.html).
- ESA, 2009, 28 April. Satellite Imagery Shows Fragile Wilkins Ice Shelf Destabilised. [http://www.esa.int/esaCP/SEMRAVANJTF\\_index\\_0.html](http://www.esa.int/esaCP/SEMRAVANJTF_index_0.html).
- Faber, M., Proops, J., Manstetten, R., 1998. *Ecological Economics; Concepts and Methods*. Edward Elgar, Cheltenham.
- Feyerabend, P., 1970. Consolations for the specialist. In: Lakatos, I., Musgrave, A. (Eds.), *Criticism and the Growth of Knowledge*. Cambridge University Press, London.
- Feyerabend, P., 1975. *Against Method: Outline of an Anarchistic Theory of Knowledge*. NLB, London.
- Funtowicz, S.O., Ravetz, J.R., 1991. A new scientific methodology for global environmental issues. In: Costanza, R. (Ed.), *Ecological Economics: The Science and Management of Sustainability*. Columbia University Press, New York.
- Hay, P., 2002. *Main Currents in Western Environmental Thought*. Indiana University Press, Bloomington.
- Hof, A.F., den Elzen, M.G.J., van Vuuren, D.P., 2008. Analysing the costs and benefits of climate policy: value judgements and scientific uncertainties. *Global Environmental Change* 18, 412–424.
- Howson, C., 2000. *Hume's Problem: Induction and the Justification of Belief*. Oxford University Press, Oxford.
- Hulme, M., 2003. Abrupt climate change: can society cope? *Philosophy and Transactions of the Royal Society London (A)* 361, 2001–2021.
- Hulme, M., 2006. Chaotic World of Climate Truth. BBC News, 2006/11/04 08:06:56 GMT. <http://news.bbc.co.uk/1/hi/sci/tech/6115644.stm>.
- Hulme, M., 2007. Newspaper scare headlines can be counter-productive. *Nature* 445, 818.
- Hulme, M., 2008. The conquering of climate: discourses of fear and their dissolution. *The Geographical Journal* 174 (1), 5–16.
- Hume, D., 1748/1975. *Enquiries Concerning Human Understanding and Concerning the Principles of Morals*. Clarendon Press, Oxford.
- IPCCSR, 2001. *Climate Change 2001: Synthesis Report*. Cambridge University Press, Cambridge.
- IPCCWG1, 2001. *Climate Change 2001: The Scientific Basis*. Cambridge University Press, Cambridge.
- IPCCWG1, 2007. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, Cambridge.
- IPCCWG2, 2001. *Climate Change 2001: Impacts*. In: *Adaptation and Vulnerability*, Cambridge University Press, Cambridge.
- IPCCWG3, 2001. *Climate Change 2001: Mitigation*. Cambridge University Press, Cambridge.
- Jackson, T., 2009. *Prosperity Without Growth?—The Transition to a Sustainable Economy*. Sustainable Development Commission [http://www.sd-commission.org.uk/publications/downloads/prosperity\\_without\\_growth\\_report.pdf](http://www.sd-commission.org.uk/publications/downloads/prosperity_without_growth_report.pdf).
- Jamieson, D., 1992. Ethics, Public Policy, and Global Warming. *Science, Technology and Human Values* 17, No 2, 139–53. (Also in Light, A. and Rolston III, H. (2003) *Environmental Ethics: An Anthology*. Blackwell, London.
- Jamieson, D., 1996. Ethics and intentional climate change. *Climatic Change* 33 (3), 323–336.
- Jantsch, E., 1980. *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution*. Pergamon, Oxford.
- Jasanoff, S., 2003. Technologies of humility: citizen participation in governing science. *Minerva* 41 (3), 223–244.
- Jung, H., 1993. Francis Bacon's philosophy of nature: a postmodern critique. *Trumpeter*. <http://trumpeter.athabascau.ca/content/v10.3/jung.html>.
- Kleinen, T., Held, H., Petschel-Held, G., 2003. The potential role of spectral properties in detecting thresholds in the Earth System: application to the thermohaline circulation. *Ocean Dynamics* 53, 53–63.
- Kuhn, T., 1970. The structure of scientific revolutions. In: Neurath, O., Carnap, R., Morris, C. (Eds.), *Foundations of the Unity of Science*, 2nd ed., 2. University of Chicago Press, Chicago.
- Lakatos, I., 1970. Falsification and the methodology of scientific research programmes. In: Lakatos, I., Musgrave, A. (Eds.), *Criticism and the Growth of Knowledge*. Cambridge University Press, London, pp. 91–195.
- Laszlo, E., 1972. *Introduction to Systems Philosophy Toward a New Paradigm of Contemporary Thought*. Gordon and Breach, New York.
- Lemons, J. (Ed.), 1996. *Scientific Uncertainty and Environmental Problem Solving*. Blackwell, Cambridge, Massachusetts.
- Lempert, R., Nakicenovic, N., Sarewitz, D., Schlesinger, M., 2004. Characterizing climate-change uncertainties for decision-makers. *Climatic Change* 65 (1–2), 1–9.
- Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S., Schellnhuber, H.-J., 2008. "Tipping elements in the Earth's climate system". *Proceedings of the National Academy of Sciences* 105, No. 6, 1786–93. doi:10.1073/pnas.0705414105. PMID 18258748. PMC: 2538841. <http://www.pnas.org/cgi/pmidlookup?view=long&pmid=18258748>.
- Lowe, T., 2006. Tyndall Briefing Note No. 16. Tyndall, Norwich. [http://www.tyndall.ac.uk/publications/briefing\\_notes/bn16.pdf](http://www.tyndall.ac.uk/publications/briefing_notes/bn16.pdf).
- Mann, J., 1967. *Fatigue of Materials—An Introductory Text*. Melbourne University Press, Victoria.
- Mercer, J.H., 1978. West antarctic ice sheet and CO<sub>2</sub> greenhouse effect: a threat of disaster. *Nature* 271, 321–325.
- Merchant, C., 1983. *The Death of Nature—Women, Ecology, and the Scientific Revolution*. Harper and Row, San Francisco.
- Milton, J., 1998. Bacon, Francis. In: Craig, E. (Ed.), *Routledge Encyclopedia of Philosophy*. Routledge, London, OR <http://www.rep.routledge.com/>
- Mintzer, M., 1992. *Confronting Climate Change: Risks, Implications and Responses*. Cambridge University Press, Cambridge.
- Mollison, B., 1988. *Permaculture: A Designers Manual*. Tagari Publications, Tyalgum, NSW.
- Morgan, M.G., Keith, D.W., 1995. Subjective judgments by climate experts. *Environmental Science and Technology* 29 (10), 468A–476A.
- NASA, 2006. Arctic Ice Meltdown Continues With Significantly Reduced Winter Ice Cover. [http://www.nasa.gov/centers/goddard/news/topstory/2006/seaiice\\_meltdown.html](http://www.nasa.gov/centers/goddard/news/topstory/2006/seaiice_meltdown.html).
- Norgaard, R., 1989. The case for methodological pluralism. *Ecological Economics* 1, 37–57.
- NSIDC, 2005. Sea Ice Decline Intensifies. [http://nsidc.org/news/press/20050928\\_trendscontinue.html](http://nsidc.org/news/press/20050928_trendscontinue.html).
- Pacala, S., Socolow, R., 2004. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* 305 (5686), 968–972.
- Padilla, E., 2004. Climate change, economic analysis and sustainable development. *Environmental Values* 13 (4), 523–544.
- Palmer, M., Finlay, V., 2003. *Faith in Conservation: New Approaches to Religions and the Environment*. The World Bank, Washington, DC. [http://publications.worldbank.org/ecommerce/catalog/product?item\\_id=1703018](http://publications.worldbank.org/ecommerce/catalog/product?item_id=1703018) or <http://www.arcworld.org/books.asp?sectionID=1>.
- Pearce, F., 2006. One degree and were done for. *New Scientist* 191 (2571), 30 September 2006, 8–9. <http://www.newscientist.com/article/mg19125713.300-one-degree-and-were-done-for.html>.
- Pielke Jr., R., Sarewitz, D., Byerly Jr., R., 2000. *Prediction: Science Decision Making and the Future of Nature*. Island press, Washington.
- Pilkey, O., Pilkey-Jarvis, L., 2007. *Useless Arithmetic: Why Environmental Scientists Can't Predict the Future*. Columbia University Press, New York.
- Popper, K., 1966. *The Open Society and its Enemies*, 5th ed. Routledge and Kegan Paul, London.
- Popper, K., 1972. *The Logic of Scientific Discovery*, 3rd ed. Hutchinson, London.
- Popper, K., 1989. *Conjectures and Refutations: The Growth of Scientific Knowledge*, 5th ed. Routledge, London.
- POST, 2005. *Rapid Climate Change*. Parliamentary Office for Science and Technology, London <http://www.parliament.uk/documents/upload/POSTpn245.pdf>.
- QUEST, British Embassy Berlin, PIK, 2005. *Climate Change Workshop, Tipping Points in the Earth System* [http://www.britischebotschaft.de/en/embassy/environment/climate\\_change/tipping\\_summary.pdf](http://www.britischebotschaft.de/en/embassy/environment/climate_change/tipping_summary.pdf).
- Rahmstorf, S., 1994. Rapid climate transitions in a coupled ocean-atmosphere model. *Nature* 372, 82–86.
- Rahmstorf, S., 1995. Bifurcation of the of the Atlantic thermohaline circulation in response to changes in the hydrological cycle. *Nature* 378, 145–150.
- Read, P., 2008. Biosphere carbon stock management: addressing the threat of abrupt climate change in the next few decades: an editorial essay. *Climatic Change* 87 (3–4), 305–320.
- Rial, J., Pielke Sr., R.A., Beniston, M., Claussen, M., Canadell, J., Cox, P., Held, H., de Noblet-Ducoudre, N., Prinn, R., Reynolds, J., Salas, J.D., 2004. Nonlinearities, feedbacks and critical thresholds within the earth's climate system. *Climatic Change* 65, 11–38.
- Risbey, J.S., 2006. Some dangers of 'dangerous' climate change. *Climate Policy* 6 (5), 527–536.
- Rodman, J., 1975. On the human question: being the report of the erewhonian high commission to evaluate technological society. *Inquiry* 18 (2), 127–166.
- Sandler, R., Cafaro, P. (Eds.), 2005. *Environmental Virtue Ethics*. Rowman and Littlefield, Lanham, MD.
- Schellnhuber, H.-J., 1998. Earth system analysis—the concept. In: Schellnhuber, H.-J., Wenzel, V. (Eds.), *Earth System Analysis—Integrating Science for Sustainability*. Springer-Verlag, Berlin.
- Schellnhuber, H.-J., 1999. 'Earth system' analysis and the second Copernican revolution. *Nature* 402 (6761), C19–C23 Supplement.
- Schellnhuber, H.-J., 2001. Earth system analysis and management. In: Ehlers, E., Krafft, T. (Eds.), *Understanding the Earth System: Compartments, Processes and Interactions*. Springer-Verlag, Berlin.

- Schellnhuber, H.-J., Held, H., 2002. How fragile is the Earth System. In: Briden, J., Downing, T. (Eds.), *Managing the Earth: The Linacre Lectures 2001*. Oxford University Press, Oxford.
- Schellnhuber, H.-J., Crutzen, P., Clark, W., Claussen, M., Held, H. (Eds.), 2004. *Earth System Analysis for Sustainability*. MIT Press, Boston.
- Schellnhuber, H.-J., Cramer, W., Nakicenovic, N., Wigley, T., Yohe, G. (Eds.), 2006. *Avoiding Dangerous Climate Change*. Cambridge University Press, Cambridge.
- Schimmelpfennig, D., 1996. Uncertainty in economic models of climate-change impacts. *Climatic Change* 33 (2), 213–234.
- Schneider, S., Rosencranz, A., Niles, J. (Eds.), 2002. *Climate Change Policy: A Survey*. Island Press, Washington, DC.
- Schneider, S., 2003. Abrupt Non-Linear Climate Change, Irreversibility and Surprise. Working Party On Global And Structural Policies—OECD Workshop On The Benefits Of Climate Policy: Improving Information For Policy Makers—ENV/EPOC/GSP(2003)13/FINAL, OECD, <http://www.oecd.org/dataoecd/9/59/2482280.pdf>.
- Shackley, S., Wynne, B., 1995. Global climate change: the mutual construction of an emergent science-policy domain. *Science and Public Policy* 22 (4), 218–230.
- Shackley, S., Sohi, S., Haszeldine, S., 2008. Biochar, reducing and removing CO<sub>2</sub> whilst improving soils: a significant and sustainable response to climate change? <http://www.geos.ed.ac.uk/scs/biochar/documents/Biochar1page.pdf>.
- Simpson, D., 2005. 'Francis Bacon', Internet Encyclopaedia of Philosophy. <http://www.iep.utm.edu/>
- Smith, G., 2003. *Deliberative Democracy and the Environment*. Routledge, London.
- Stainforth, D., Aina, T., Christensen, C., Collins, M., Faull, N., Frame, D., Kettleborough, J., Knight, S., Martin, A., Murphy, J., Piani, C., Sexton, D., Smith, L., Spicer, R., Thorpe, A., Allen, M., 2005. Uncertainty in predictions of the climate response to rising levels of greenhouse gases. *Nature* 433, 403–406.
- Steffen, W., Tyson, P. (Eds.), 2001. *Global Change and the Earth System: A Planet Under Pressure*, International Geosphere-Biosphere Programme, Stockholm, 2001 <http://www.igbp.kva.se/documents/resources/science-4.pdf>.
- Steffen, W., Sanderson, A., Tyson, P., Jäger, J., Matson, P., Moore III, B., Oldfield, F., Richardson, K., Schellnhuber, H.-J., Turner, B.L., Wasson, R., 2004. *Global Change and the Earth System: A Planet Under Pressure*. Springer-Verlag, Berlin Executive Summary: [http://www.igbp.net/documents/IGBP\\_ExecSummary.pdf](http://www.igbp.net/documents/IGBP_ExecSummary.pdf).
- Stern Report, 2006. *Stern Review on the Economics of Climate Change*. [http://www.hm-treasury.gov.uk/independent\\_reviews/stern\\_review\\_economics\\_climate\\_change/stern\\_review\\_report.cfm](http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm).
- Stern Review, 2006. *What is the Economics of Climate Change?—Discussion Paper—31 January 2006*. [http://www.hm-treasury.gov.uk/media/213/42/What\\_is\\_the\\_Economics\\_of\\_Climate\\_Change.pdf](http://www.hm-treasury.gov.uk/media/213/42/What_is_the_Economics_of_Climate_Change.pdf).
- Swyngedouw, E., 2007. Impossible sustainability and the post-political condition. In: Krueger, R., Gibbs, D. (Eds.), *The Sustainable Development Paradox: Urban Political Economy in the United States and Europe*. The Guilford Press, London, pp. 13–40.
- Taleb, N., 2007. *The Black Swan: The Impact of the Highly Improbable*. Allen Lane, London.
- Thorpe, A., 2005. *Climate Change Prediction: A Challenging Scientific Problem*. Institute of Physics, 1–16. [http://www.iop.org/activity/policy/Publications/file\\_4147.pdf](http://www.iop.org/activity/policy/Publications/file_4147.pdf).
- Tickner, J. (Ed.), 2003. *Precaution, Environmental Science and Preventative Public Policy*. Island Press, Washington.
- Torgerson, D., 1999. *The Promise of Green Politics Environmentalism and the Public Sphere*. Duke University Press, Durham.
- UNECE, 1998. *Convention On Access To Information, Public Participation In Decision-Making And Access To Justice In Environmental Matters—done at Aarhus, Denmark, on 25 June 1998*. United Nations Economic Commission for Europe <http://www.unece.org/env/pp/treatytext.htm>.
- US Climate Change Science Program, 2008. *Abrupt Climate Change*. U.S. Geological Survey, Reston, VA <http://www.climatechange.gov/Library/sap/sap3-4/final-report/>
- US Congressional Budget Office, 2005. *Uncertainty in Analyzing Climate Change: Policy Implications*. The Congress of the United States. Congressional Budget Office <http://www.cbo.gov/ftpdocs/60xx/doc6061/01-24-ClimateChange.pdf>.
- Van der Sluijs, V., van Eijndhoven, J., Shackley, S., Wynne, B., 1998. Anchoring devices in science for policy: the case of consensus around climate sensitivity. *Social Studies of Science* 28 (2), 291–323.
- von Bertalanffy, L., 1971. *General Systems Theory: Foundations Development Applications*. Penguin, London.
- Walter, K., Zimov, S., Chanton, J., Verbyla, D., Chapin III, F., 2006. Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. *Nature* 443, 71–75.
- WCED, 1987. *Our Common Future*. Oxford University Press, Oxford.
- White, M., 1999. *Properties of Materials*. Oxford University Press, New York.
- Williams, R., 1992. Transformation of scientific data into policy relevant information. In: Lykke, E. (Ed.), *Achieving Environmental Goals: The Concept and Practice of Environmental Performance Review*. Belhaven, London.
- Worrall, J., 1989. Why both Popper and Watkins fail to solve the problem of induction. In: D'Agostino, F., Jarvie, I. (Eds.), *Freedom and Rationality: Essays in Honor of John Watkins*. Kluwer, London.
- Wynne, B., 1996. 'May the sheep safely graze? A reflexive view of the expert-lay knowledge divide'. In: Szerszynski, B., Lash, S., Wynne, B. (Eds.), *Risk, Environment and Modernity: Towards a New Ecology*. Sage, London.