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Risking the earth Part 1: Reassessing dangerous anthropogenic interference and climate risk in IPCC processes

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A B S T R A C T

This two-part paper details the arguments and evidence that have been marshalled by both climate scientists and social scientists to critique the current procedures and methodologies deployed by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC) to represent the risks of anthropogenic forcing and a continuation of business-as-usual. In the first part, the rationale for moving from an atmospheric stabilisation target to an average surface temperature target is explained. This is followed by a discussion of the IPCC's representations of nonlinear behaviour in relation to climate forcing, and the problems associated with using a single temperature target in assessing climate risk. An outline is then provided of efforts to define what can or should constitute physical, biological and socio-economic indicators of dangerous anthropogenic interference (DAI). The paper reviews the IPCC's representations of sea-level rise to illustrate the argument that it continues to take insufficient account of the paleoclimate record and improved methods of modelling. Part 1 concludes by arguing that the IPCC continues to under-represent the risks associated with DAI. In the second part, the rationale and methodologies for reconfiguring international climate governance are discussed in more detail. Part 2 argues that the currently dominant model of international policy-making is primarily an outcome of compromises made by governments under pressure from powerful polluting industries and their business allies. It is argued that the political economy of international climate governance has produced systematic biases in the kinds of expertise and evidence that national governments deem appropriate for consideration via the IPCC and UNFCCC frameworks, along with the relative importance that is ascribed to them. Drawing on the research of climate scientists and social scientists, some suggestions for how to restructure and refocus the activities of the IPCC, UNFCCC and climate governance more generally are canvassed, including the necessity of creating far more interdisciplinary and democratically accountable structures of expertise for climate policy-making at the national and supra-national levels. Part 2 concludes with a discussion of the kinds of reforms which could be undertaken to reduce the ability of incumbent actors to shape climate policy and politics to their advantage.

1. Introduction

Since the early 1990s, the international community has been engaged in the complex and difficult process of negotiating how best to evaluate the risks associated with human interference in the Earth's climate, and how those evaluations should be incorporated into policy and action at the local, national and international levels. The Intergovernmental Panel on Climate Change (IPCC) is the official source of advice to governments on climate science-related matters, and was invested with that authority by the United Nations on behalf of member countries in 1988 (IPCC, 1990). The IPCC's primary function is to provide the world's governments with regularly updated scientific assessments of the current state of the earth's climate, together with policy recommendations based on the likely socio-economic and environmental outcomes of a range of future emission scenarios (IPCC 1990, 1990a). The IPCC's assessment reports are based on peer-reviewed literature synthesized by experts from the physical sciences and a handful of other disciplines. These consensus-based reports provide the basis for determining the 'common but differentiated responsibilities' of nation states to reduce emissions under the United Nations Framework Convention on Climate Change (UNFCCC), to which 197 countries are

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currently parties (Hoppe and Rödder 2019). They also provide the scientific data upon which most academics and non-government organizations gauge the effectiveness of the relevant policy commitments made by governments, business and industry (Shackley, 1997; Alfsen et al., 1998; Skodvin and Alfsen, 2010). The IPCC's reports are based on the advice of three functionally differentiated working groups whose participants are respectively focused on assessing the physical science basis (Working Group I), the vulnerability, consequences and adaptation options for socio-economic and natural systems (Working Group II), and the options for limiting greenhouse gas (GHG) emissions and climate change more generally (Working Group III). Participants in the working groups are nominated and chosen by the governments of member countries, which are encouraged to choose those individuals based on appropriate expertise (Leemans 2008).

The IPCC's technical reviews are intended to represent summaries of the latest research concerning anthropogenic influence on the world's climate, and to be apolitical in their evaluations and recommendations to inform UNFCCC deliberations. However, the IPCC has been criticised since its inception for being overtly political in its preferences for certain disciplines, findings and methodologies, and in the kinds of evidence it is prepared to consider, evaluate and represent. The most frequent and visible criticisms directed at the IPCC have been made by those involved in the climate change counter-movement (CCCM), which consists of major polluting industries supported by conservative advocacy groups, trade associations, media outlets, think tanks, scientists, political parties, and politicians. Participants in the CCCM claim that the IPCC routinely exaggerates the risks and is therefore unjustifiably 'alarmist' (e.g. Michaels, 2005; Holland, 2007; Carter, 2008, 2010; McKitrick, 2011). Less visible in the public policy debate have been procedural and methodological criticisms of the IPCC by climate scientists themselves. This is the focus of the first part of this paper. It attempts to summarize the concerns of climate scientists who have expressed ongoing dissatisfaction with how the IPCC is currently organized, and in particular, the ways in which it represents climate risks to policy-makers and the public (cf. Wasdell, 2007; IAC, 2010; Schiermeier, 2010; Adam and Goldenberg, 2010; Beck, 2012; Freedman, 2013; Anderson, 2015; Müller-Jung, 2015). Equally marginal within the public policy debate have been criticisms of the IPCC by interpretive social scientists and humanities scholars. These criticisms, which will be explored in detail in Part 2 of this paper, are that the IPCC is too narrow in its disciplinary base and therefore mischaracterizes and underplays climate risks. They argue, furthermore, that its ongoing commitment to an overtly technocratic and positivist approach is highly political because it conceals its political preferences for particular strategies and advocacy for particular values and goals behind the mantle of scientific objectivity (cf. Hoppe et al. 2013; Blue, 2015; Corbera et al., 2015; Einecker and Kirby, 2020). This two-part paper details the arguments and evidence that has prompted these criticisms. It argues that the gravity of the risks associated with a continuation of business-as-usual have not been given sufficient attention in successive assessment reports by the IPCC, and that the downplaying and omission of those risks are an outcome of the influence exercised by nations and corporations with heavy investments in, and dependence on, fossil fuels. Research demonstrating how polluting interests have orchestrated climate science denial and sought to delay and derail decarbonisation has consequently not been incorporated into IPCC assessments or UNFCCC deliberations.

Part 1 of this paper is focused on 'internal' considerations about the kinds of techniques and methodologies that have informed climate risk assessments since the inception of the IPCC. It details how a growing body of evidence indicates not only that dangerous anthropogenic interference is already happening across a range of biophysical parameters, but that current international commitments are inadequate to the task of preventing catastrophic changes to the earth's climate by the end of this century. Part 2 is focused on more 'external' considerations. It outlines the broader sociological and political basis for climate change denial and climate risk minimization, drawing attention to research that has exposed the strategies deployed by polluting interests to delay climate action and shape the deliberations of the IPCC and UNFCCC. It concludes by outlining the kinds of structural reforms to the IPCC and UNFCCC that could be made to reduce the influence of 'special interests' on international climate governance and generate momentum for deep decarbonisation.

2. The development of climate risk assessment in international climate governance

On 11 December 1997, the Kyoto Protocol to the UNFCCC was adopted, and entered into force on 16 February 2005. Based on the principal of common but differentiated responsibilities, it set binding obligations on developed countries to reduce their emissions of GHGs with the goal of achieving 'the stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (Article 2, UNFCCC). The meaning of 'dangerous anthropogenic interference' (DAI) and its implications for policymaking will be explored in greater detail below. To follow is a brief summary of how the UNFCCC has developed its parameters for climate risk assessment over the last few decades.

Under the UNFCCC, two key indicators of GHG emissions and their effects have been developed to formally establish the limits of acceptable risk and the range of targets for emission reduction. Those indicators are global annual mean surface temperatures measured in degrees Celsius (°C) relative to pre-industrial levels, and atmospheric parts per million by volume (ppmv) of carbon dioxide (CO2) and carbon dioxide equivalent (CO2e) (IPCC, 2007). Because atmospheric burdens of CO2 and CO2e provide an indication of the global annual mean surface temperature of the earth and the rates of increase and decrease of that temperature, physical science advocates of these indicators have long argued that the two measures used together serve as a proxy for a wide range of observable effects, as well as a good indication of the extent of atmospheric temperature variation during the earth's history. Together, the two indicators are intended to provide clear points of focus for policymaking and the coordination of mitigation and adaptation efforts by national and regional governments.

Prior and subsequent to the Kyoto Protocol coming into force in 2005, a number of efforts were made to quantify what level of international emission reductions would need to occur by 2050 and 2100 in order to minimize the possibility of DAI (Randalls 2010). A number of these efforts subsequently informed international negotiations. For example, the UK Royal Commission on Environmental

Pollution argued in 2000 that a 60% reduction in CO2 emissions below 1998 levels would need to occur by 2050 if atmospheric concentrations of 550 ppmv by 2050 were to be avoided, and as much as 80% reductions by 2100 (Royal Commission on Environmental Pollution, 2000; cf. Owens 2012). Based on data that was already several years old when the review was published, the UK Government's *Stern Review* argued that an 80% cut on 1990 GHG levels would need to occur by 2050 to similarly avoid 550 ppmv of atmospheric CO2 (Stern 2006). In the same year, climate scientist Malte Meinshausen conducted an analysis of eleven sensitivity probability functions which demonstrated that, at a stabilisation level of 550 ppmv, the chance of exceeding the 2 °C target by 2100 was between 63% and 99%, with a mean of 82% (Meinshausen 2006). In other words, Meinshausen's findings clearly indicated that a 550 ppmv stabilisation level by 2100 would virtually guarantee that the 2 °C threshold would be crossed.

In a clear repudiation of the 550 ppmv stabilisation target endorsed in the *Stern Review* (2006), the IPCC's fourth assessment report from 2007 (AR4) stated that in order to keep global average surface temperature increases at 2 °C to 2.4 °C above pre-industrial values by the end of this century, atmospheric emissions need to be stabilized at 445 to 490 parts per million (ppm) of CO2e (IPCC, 2007; cf. Matthews and Caldeira 2008). AR4 also stated that to ensure this atmospheric burden of GHGs is not exceeded, anthropogenic CO2 emissions needed to peak in 2015, while emissions across the board would need to be reduced by 50% to 85% on 2000 levels by 2050 (IPCC, 2007: 67). In order to stabilize atmospheric concentrations of CO2e at 450 ppm, Annex I countries would have to make emission reductions of 25–40% by 2020, and 80–95% by 2050. Even though the 450 ppm threshold of CO2e was exceeded in 2013/14 (European Environment Agency 2013, 2019), this analysis provided the basis for subsequent UNFCCC negotiations, and continues to inform the policies of most nation states.

Prior to the publication of AR4, the European Commission (EC) had issued a communication on 10 January 2007 which strongly implied that if nation states were prepared to endorse a 2 °C target, DAI with the Earth's climate could be largely averted (Weaver et al. 2007). At COP 2009, most of the advanced industrialized nations endorsed the EC's proxy target of 2 °C, and have subsequently agreed to reduce emissions in line with that goal. COP2009 also saw the parties to the convention endorse a corresponding 'carbon budget' with which they are informally obliged to comply (Meinshausen et al. 2009; cf. Zickfield et al., 2009; England et al., 2009; Anderson and Bows, 2013; Anderson, 2015). Consequently, the 2 °C target also became the de facto mitigation goal for the IPCC's three working groups. What has seldom been acknowledged publicly, however, in either the mainstream media or the broader political debate, is the fact that a number of well-respected climate scientists and scientific organizations almost immediately began questioning whether the international commitment to a temperature target of 2 °C will be adequate to the task of keeping planetary warming within safe limits (e.g. Ekman et al., 2008; Adam, 2009; Randerson, 2009).

3. The Paris climate Agreement: The IPCC and UNFCCC endorse stronger emission reduction targets but equivocate on costs and rates of decline

The Paris Climate Agreement in late 2015 belatedly acknowledged that it would be prudent to heed the advice of James Hansen that if we are genuine about our desire to minimise the impacts on all species and the poor, warming of the planet will need to be kept well below 1.5 °C compared to pre-industrial levels over the next century. According to Hansen and colleagues, in order to achieve that goal over the longer term, stabilisation of the earth's atmosphere at 300–325 ppm of CO2e will be required (Hansen, 2005; Hansen et al., 2008; cf. Hare, 2003; Adam, 2008). Clearly, this constitutes a significantly lower atmospheric concentration target than that contemplated by AR4, as recently recognised by the IPCC in its special report on *Global Warming of 1.5* °C (IPCC 2018). It will also require sustained removal of existing GHGs in the atmosphere, a topic that will be discussed in more detail in Part 2.

The commitments contained in the Paris Agreement have been mildly reassuring for those of us who have been following the international negotiations. However, atmospheric methane levels have been rising since 2007 and have been further accelerating over the last four years: if those increases continue it will be very difficult to achieve the Paris goals (Nisbet et al. 2019). Furthermore, the logic of the carbon budget (i.e. a cumulative emissions budget) implies that in order to have a 50% chance of maintaining the 2 °C goal, developed countries would have had to begin CO2e reductions in the order of 8% to 10% per year as of 2013, which they have not done (Anderson and Bows, 2013; Anderson, 2015). Writing in 2011, Hansen and colleagues argued that if these measures had begun in 2005, the required reduction rate would have been 3% per year, and in 2007, 6% per year, but if reductions are delayed until 2020, the required reductions will be 15% per year (Hansen et al. 2011). The current COVID pandemic appears to have resulted in emission reductions of 8.8% during the first half of 2020 (Liu et al. 2020), and may result in 7% reductions throughout 2020 'if some restrictions remain worldwide until the end of 2020′ (Le Quéré et al. 2020). It is instructive that it has taken a global pandemic to achieve these outcomes.

With respect to the economic costs of achieving the 2 °C goal, the current pandemic also provides valuable insights. To give some idea of just how optimistic have been previous estimates of these costs, as recently as 2006, the UK *Stern Review* estimated that the annual costs of stabilisation of atmospheric GHGs at 500–550 ppm would be 'around 1% of GDP by 2050′, which it described as 'a level that is significant but manageable' (Stern 2006: xi). This contrasts with more recent, but equally optimistic, estimates cited elsewhere, including 2.5% of GDP by 2050 ('reducing annual growth by at most 0.05%/year') by the European Union (EU Commission 2008), and 2.5% of GDP in annual average investment 'in the energy system' between 2016 and 2035 to limit global warming to 1.5 °C (IPCC 2018: 24). It should be noted that this last figure does not include the costs of adaptation or other forms of low carbon infrastructure investment. By way of contrast, earlier this decade, William Nordhaus argued that between 1% and 2% of world income would be required to achieve the 2 °C target, constituting between 5% and 9% of GDP (Nordhaus 2013). Oxford Economics has estimated the global economic downturn as a result of COVID to be in the order of 4.4% of global GDP (May 2020). If these and the earlier cited figures concerning COVID-related emission reductions prove accurate, it would appear that Nordhaus's estimates for the economic consequences of deep decarbonisation are the most plausible of those cited.

It is nevertheless cause for considerable concern that the upper range estimates of the levels of emission reduction and clean investment now required after thirty years of policy torpor have been consistently overlooked by both the IPCC and UNFCCC. Given that such reductions and expenditures are inimical to most national governments' conceptions of economic growth (Anderson 2015), as flawed as those conceptions may be (Pilling, 2018), this is perhaps unsurprising. Nevertheless, the longer emission reductions are postponed, the higher will be the climate risks and long-term costs (den Elzen, van Vuuren and van Vliet, 2010; Solomon et al., 2010: 18358). The consequences of continued inaction will be unfairly placed upon future generations, indigenous people and the poor (Gardiner, 2011; Ford, 2009; Ford et al., 2015). At present, only a handful of small island nations (including Costa Rica, Iceland and the Marshal Islands) have been prepared to make a commitment to full decarbonisation. A handful of other developed and developing countries have pledged to decarbonise, but are yet to implement policies and allocate funds to achieve that goal (e.g. Bhutan, Chile, Denmark, Finland, France, New Zealand, Norway, Portugal and the UK) (Darby 2019). While these developments are certainly encouraging, it is arguably irresponsible for IPCC economic modellers to rely on the use of negative emission technologies to achieve deep decarbonisation (Anderson and Bows, 2013; Anderson, 2015). This issue will be taken up in more detail in Part 2.

According to Climate Action Tracker, the only major countries that have implemented policies consistent with achieving the 1.5 °C Paris Agreement goal are Morocco and Gambia, while Bhutan, Costa Rica, Ethiopia, India and the Philippines are the only countries to have implemented policies consistent with achieving the 2 °C target (Climate Action Tracker, 2019). Clearly, if the IPCC is to perform its functions adequately and provide well-informed guidance to help countries achieve such ambitions, it needs to represent the full spectrum of risks and possibilities. For its part, the UNFCCC needs to be far more frank with the citizens of the world about those risks and the kinds of changes that will need to be made to avoid them.

4. The nonlinearity of the climate system and further criticisms of the 2 °C target

It is widely accepted by climate scientists that the earth's climate is a complex, nonlinear system which can dampen or amplify fluctuations in its behaviour depending on the rates of change of multiple variables. If the rate of change of one or more of the variables which constitute a nonlinear system is pushed beyond a certain threshold, the system enters a chaotic regime before settling into a new form of dynamic stability, the precise nature of which is impossible to predict (Schellnhuber, 2009; Barnosky, et al., 2012). At present, it is linear projections that inform the vast majority of governments' policies that are focused on achieving temperature targets.

Over the last decade or so, vastly improved climate modelling, combined with more detailed and extensive research on the paleoclimate record, has enabled climate scientists to see far more clearly how the nonlinearity of the climate system makes it sensitive to forcing. This research has revealed that there have been many times during the earth's history when the biospheric processes that normally dampen large-scale climatic fluctuations have been overwhelmed, pushing the earth's climate past a critical threshold or 'tipping point' which throws it into a period of violent extremes, after which it settles into a new dynamic regime that may be very different from that which prevailed previously (e.g. Alley et al., 2003; Hansen, 2005; Holland et al., 2006; Hansen et al., 2007; Lenton et al., 2008; Rockström et al., 2009; Schellnhuber, 2009; Tripati et al., 2009; Allison, et al.: 40-42, 2009; Barnosky et al., 2012; USGCRP, 2017). As one group of climate scientists have noted, 'once [such] a critical transition occurs, it is extremely difficult or even impossible for the system to return to its previous state' (Barnosky et al. 2012: 52).

Due to the complexity of the climate system and uncertainties about some of the critical parameters, current best estimates place the time-scale during which such a large-scale state transition may occur as early as the 2030s and as late as the 2090s. However, even though the 2 °C target has not yet been exceeded, smaller-scale, regional transitions driven by human alteration of existing ecosystems are already happening (Sanders, 2012). While there is general agreement that more research on this topic needs to be done, many have argued that the issue has not received the attention it deserves in successive IPCC reports, even though a number of prominent climate scientists did manage to put the issue on the public agenda between 2008 and 2010, during which time it received a reasonable level of media coverage. However, in the wake of the global financial crisis, it soon disappeared from media attention, only to re-emerge in 2012 as climate scientists published and publicized new research indicating that the earth's climate is fast approaching a large-scale state transition, if indeed it has not already crossed the critical threshold (Schaefer et al., 2012; Barnosky et al., 2012; Pearson et al., 2015; Le Quéré et al., 2018).

Although the IPCC has discussed nonlinear responses in successive assessment and special reports from its inception, the word 'nonlinear' does not appear in any of the summaries for policymakers (SPMs) from 1990 to 2020. It is mentioned regularly in

Table 1
Types of Real Critical Threshold (Lenton, 2011).

Ice Melting	Biome Shifts
Arctic Sea Ice	Amazon Rainforest
Greenland Ice Sheet (1.6 °C?)	Boreal Rainforest
West Antarctic Ice Sheet	Coral reefs
Yedoma Permafrost	Decomposition of carbon-rich soils
Marine methane hydrates	
Hindu Kush-Himalaya-Tibetan glaciers	
Changes in Circulation & Modes of Variability	**Hydrological & Regime Shifts**
Atlantic Thermo-Haline Current	West African Monsoon
El Nino Southern Oscillation	Indian Summer Monsoon
Atlantic Sub-Polar Gyre	Sahara/Sahel Monsoon

assessment reports by Working Group I (WGI) and Working Group II (WGII) from 1990 onwards, but only intermittently in reports by Working Group III (WGIII). However, given the importance of nonlinear behaviour for understanding the parameters of climate risk, there are only a handful of discussions of the concept which extend beyond a few sentences in any of the reports by WGI and WGII. The failure of IPCC authors to undertake such a discussion in any of the WG III assessment reports or SPMs is both questionable and problematic given the low levels of scientific literacy among policy- and decisionmakers.

Contrary to the rationales cited previously for moving from atmospheric burdens of GHGs to a temperature target, Timothy Lenton and other climate scientists have been arguing for the last decade that the 2 °C target is too abstract: it is not a good motivator for action and does not have a sound scientific basis (cf. Randalls 2010). Climatic 'tipping points' – more accurately described as 'real critical thresholds' (RCTs) – do not all occur at the same temperature threshold (Alley et al., 2003; Archer et al., 2009; Lenton, 2011; IPCC, 2014: 1015; USGCRP 2017). Lenton (2011) has classified these RCTs into four categories: ice melting, biome shifts, changes in circulation and modes of variability, and hydrological and regime shifts (Table 1).

As can be seen from Table 2, biome shifts occur at only fractions of a degree shifts in temperature, which has already been observed in many contemporary ecological niches, and through shifts in the ranges and habitats of many terrestrial and aquatic species. There is also a significant body of accumulating evidence that some RCTs have probably already been crossed, including the loss of Arctic sea ice, the world's glaciers and the Greenland Ice Sheet, as well as the melting of the northern permafrost (Holland et al., 2006; Schaefer et al., 2012; Schaefer et al., 2011; Pearson et al., 2015; Schaefer, 2014; cf. Pritchard and Vaughan, 2007; Pritchard et al., 2009; Notz, 2009; Stroeve et al., 2012; USGCRP, 2017). According to AR5, however, 'Greenland has no known large-scale instabilities that might generate an abrupt increase in sea level rise over the 21st century', although it concedes that such a threshold 'may exist' and that it 'might become irreversible over multi-centennial time scales' (IPCC, 2013: 1179). SR15 from 2018 states that 'There is *high confidence* that sea level rise will continue beyond 2100. Instabilities exist for both the Greenland and Antarctic ice sheets, which could result in multi-meter rises in sea level on time scales of century to millennia. There is *medium confidence* that these instabilities could be triggered at around 1.5 °C to 2 °C of global warming' (IPCC 2018: 178). However, as will be discussed in more detail below, the paleoclimate research upon which these assessments are based does not inspire a medium level of confidence in SR15′s conclusions (IPCC 2018: 208; cf. Hansen et al., 2007, 2016; Xu and Ramanathan, 2017; Sweet et al., 2017; Harrison et al., 2018; Moore, 2019; Glikson, 2019a).

Lenton has argued that a new climate policy regime is required which takes into consideration the nonlinearity of the climate system and which enables greater focus on avoiding more RCTs from being crossed over the coming decades (cf. IPCC 2018: 257-8). The preferable policy objective, therefore, is to limit the overall magnitude, rate of change and spatial gradients of anthropogenic radiative forcing (Lenton, 2011; cf. Randalls 2010). Short-lived pollutants contribute between one-quarter and one-third of current global warming (IPCC, 2007: 36; US Department of State 2012), and are currently masking that warming by around 0.9 °C (Xu and Ramanathan 2017). They therefore require much more attention than they have hitherto received. Lenton has suggested altering the wording of Article 2 of the UNFCCC to recognize the threats posed by heterogeneous radiative forcing agents (especially aerosols), so that limiting them becomes the primary goal, with GHG concentrations becoming a sub-objective. He points out that reframing policy efforts in this way would provide greater incentives to reduce 'short-lived positive radiative forcing agents, help limit near-term rates and gradients of climate change, and could counterbalance the inevitable delays in turning the current growth of CO2 emissions into a comparable decline' (Lenton 2011: 458).

Although Lenton's recommendations have not been adopted by the UNFCCC, a year after his paper on RCTs appeared, the United Nations Environment Programme (UNEP) launched a voluntary initiative called the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC). Over the last eight years it has overseen and completed a number of projects involving 69 state partners and 76 non-state partners, but does not include in its strategies any commitment to incorporate the reduction of short-lived climate pollutants in the articles of the UNFCCC, or to make the associated commitments compulsory (CCAC 2020).

5. 'Dangerous anthropogenic interference': Reasons for concern and reasons for alarm

The term 'dangerous anthropogenic interference' (DAI) is the focus of Article 2 of the UNFCCC. It commits signatory nations to stabilizing GHG emissions to the atmosphere at a level that will prevent DAI, 'within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that production is not threatened and to enable economic development to proceed in a sustainable manner' (UNFCCC 1992; cf. Schellnhuber 2008). The prevention of DAI therefore forms the very basis of international negotiations to reduce GHG emissions. However, most nation states have not conducted or financed research which might help their

Table 2
Linking international climate change policy to RCTs (Lenton, 2011).

Real critical threshold & temp. increase required for threshold to be crossed	Policy response
Ice Melting	Limit magnitude of sea level rise (including rate of rise)
greater than 1.1 °C – 3 °C above pre-industrial	
Changes in Circulation & Modes of Variability	Limit magnitude & rate of temp. rise.
greater than 3 °C – 5 °C incr. per century	Limit magnitude & rate of CO2 rise
Hydrological & Regime Shifts	Limit rate of temp. rise & atmospheric concentrations of black soot aerosols
(not necess. temp. related)	
Biome Shifts	Limit rate of temp. & sea level rise.
greater than 0.2 °C incr. per decade	Limit magnitude of temp. & sea level rise

citizens better understand what constitutes DAI within their own geographical and socio-economic contexts, or the associated risks and what should be done about them. Some social scientists may have been under the misapprehension that the UNFCCC has actually defined what DAI means (e.g. Ford 2009), but it is predominantly the research of earth scientists working outside the UNFCCC and IPCC frameworks that has contributed the most to our understanding of what constitutes DAI.

While it is certainly the case that definitions of what is meant by DAI cannot be represented solely in biological and physical terms, and that what constitutes 'risk' and 'danger' requires qualitative assessments based on irreducibly geographical and social considerations, it remains the case that the biophysical parameters of risk and danger have been deemed sufficiently clear to establish relevant criteria for making such an assessment. Furthermore, although definitions of risk and danger are social constructions informed by a range of scientific, political, economic and cultural considerations, there is an irreducibly biophysical, i.e. 'material', basis to both risk and danger. If there were not, dominant social mores and conventions could never be challenged and proven inadequate or wrong by physical, chemical, biological and environmental realities. Any cultural elite that chose to ignore those realities could blithely continue to do so without any adverse repercussions for the societies they led. The historical record demonstrates, however, that this is not the case. Those cultural elites which have ignored radical environmental change and failed to act to mitigate its effects have condemned their cultures to oblivion (Tainter, 2006; Correia, 2013; cf. Flannery, 1994; Diamond, 2005).

For its part, the IPCC stated in its 3rd Assessment Report from 2001 (TAR) that 'deciding what constitutes dangerous climate change is a value judgement beyond the remit of the IPCC, and perhaps, of science itself' (Dessai et al. 2003; cf. Hansen 2005; Dietz et al., 2007). Nevertheless, consistent with its self-described key function of helping decision-makers determine what constitutes DAI (IPCC, 2001a, 2001b: 84), TAR went some way to addressing the issue by outlining five 'reasons for concern' (RFCs) based on a number of mixed biophysical and socio-economic criteria which were represented in what has come to be known as the 'burning embers diagram' (IPCC, 2001a, 2001b: Fig. SPM-2). The five RFCs are: 'risks to unique and threatened species', 'risk of extreme weather events', 'distribution of impacts', 'aggregate impacts' and 'risks of large scale discontinuities' (cf. Mann 2009; Mahony and Hulme, 2012).

As Smith et al. (2008) pointed out in an article which attempted to revise and clarify the RFCs in the light of more recent evidence, AR3 did not make an assessment about whether any single RFC was any more important than any other, nor at what threshold of impacts or atmospheric concentrations DAI would be deemed to have occurred. Although Hansen and co-authors argued a few years later that the RFCs indicate major biophysical problems begin with atmospheric warming of 2 °C to 3 °C above preindustrial levels (Hansen et al. 2011), it is clear from Smith et al.'s analysis, and their 'updated' RFCs, that AR3 under-estimated some of the risks involved (cf. Mann 2009). They also indicated that, with respect to risks to unique and threatened species and of extreme weather events, DAI is already occurring (Smith et al. 2008: 4134). With a more explicit focus on the need to completely decarbonise the world's energy systems, Hansen and colleagues argued on the basis of the paleoclimate record that anything above 350 ppm of atmospheric CO2 will result in DAI (Hansen et al. 2011). Of course, this is the level at which atmospheric GHGs were in 1990, consistent with the emissions baseline for the Kyoto Protocol. Their analysis therefore suggests that the world had already entered the 'danger zone' when international climate negotiations began in the early 1990s.

The earliest papers which attempted to define DAI and/or discuss the issue in detail were written in the mid- to late 2000s (Dessai et al., 2003; Mastrandrea and Schneider, 2004; Hansen, 2005; Schneider and Mastrandrea, 2005; Schneider et al., 2005; Schneider, 2006; Harvey, 2007; Ramanathan and Feng, 2008; Smith et al., 2008; Mann, 2009; Zickfield et al., 2009). Two of the first attempts were made by Steven Schneider and Michael Mastrandrea from Stanford University in 2004 and 2005. In their probabilistic analysis from 2004, they drew on the IPCC's 'Reasons for Concern' (Mastrandrea and Schneider 2004: n. 20), while assuming a median threshold for dangerous climate change of 2.85 °C. They concluded that, 'in certain regions and for certain sectors, different groups might set thresholds for DAI at very different levels', although '[i]t is possible that some thresholds for dangerous anthropogenic interference … are already exceeded, and it is likely that more such thresholds are approaching' (Mastrandrea and Schneider 2004: 574). Following further revisions to the model in their 2005 paper, the authors repeated their previous caveats about the normativity and value-ladenness of judgements concerning DAI, but found with 90% confidence that biophysical indicators of DAI occur at a temperature threshold of around 1.4 °C or higher above 2000 temperatures (Schneider and Mastrandrea 2005). The high degree of confidence with which this statement was made suggests a significant probability of DAI at lower temperatures.

In an attempt to broaden the meaning of DAI, researchers from the universities of East Anglia and Cambridge argued in 2003 that progress in defining what DAI means requires recognition that there are both 'internal' and 'external' definitions of danger, wherein 'external' refers to definitions 'usually based on risk analysis of system characteristics of the physical or social world', whereas 'internal' refers to dangers that must be either experienced or perceived to generate 'an individual or collective experience or perceptions of insecurity or lack of safety' (Dessai et al. 2003). Avoiding the conventional association of 'internal' with 'subjective' and 'external' with 'objective' factors, they identified a number of 'external' definitions of DAI in the scientific literature based on thresholds of physical and social vulnerability. The physical vulnerabilities included: large-scale eradication of coral reef systems, disintegration of the West Antarctic Ice Sheet, breakdown of the thermohaline circulation, modification of other crucial climate-system patterns, and climate change exceeding the ability of biomes to successfully migrate. This list largely echoes (but is more specific than) the criteria later identified by Schneider in 2006 and Hansen and co-authors in 2011, which includes accelerating loss of the Greenland ice sheet, Arctic sea ice cover, and mountain glaciers globally, as well as a greater frequency of mega-heatwaves (Schneider, 2006; Hansen et al., 2011).

Like the later paper by Hansen et al., the UK researchers list a number of studies that seek to measure danger through thresholds of social vulnerability. These largely revolve around sea level rise, water and food shortages, increased disease risks, and the instability and conflict likely to ensue. The main point made by the UK researchers was that, because definitions of climate change are socially constructed, '[u]nderstanding the assumptions implicit in external definitions … and their implications for perceptions of danger is important for developing a holistic understanding of climate risk management'. They also argue that because 'internal' (or subjective) understandings of risk and danger are routinely integrated into discussions about famine, poverty and public health, these understandings need to be integrated into risk analysis for climate change policy (Dessai et al. 2003).

However, Dessai et al.'s injunction to include social and subjective factors in the evaluation of what constitutes DAI was not factored into the compilation of AR4 in 2007. The authors of WGII did acknowledge that there is 'new and stronger evidence of observed impacts of climate change on unique and vulnerable systems', and that it is likely that there was already an increased risk of some extreme weather events, as well as 'higher damages for larger magnitudes of global mean temperature increases than was estimated in the TAR' (IPCC 2007: 781). They nevertheless remained confident that the RFCs as originally conceived provide 'a viable framework for assessing key vulnerabilities' (IPCC 2007: 15, 73). The RFCs have subsequently been further developed, but continue to emphasise biophysical risks (e.g. IPCC 2014: 12-14; 61-3, 176, 183, 1013–1017, 1066–1083, 1109), although the temperature parameters have been adjusted downward (IPCC 2018: 12-13).

The most recent research on DAI with respect to biophysical systems has sought to distinguish between 'dangerous', 'catastrophic' and 'unknown' climate risks, whereby anything greater than 1.5 °C is dangerous, anything greater than 3 °C is catastrophic, and anything greater than 5 °C is unknown, 'implying beyond catastrophic, including existential threats' (Xu and Ramanathan 2017: 10315; cf. Lynas 2009). The term 'catastrophic' is used in this context to refer to a rapid, nonlinear transition in climatic conditions, which may be caused by the warming of Arctic seas by melting ice (cf. Vinas, 2014; Hansen et al., 2016; Polyakov et al., 2017), or the release of methane previously locked up in Arctic permafrost, resulting in the collapse of the 'conveyor belt' circulation in the North Atlantic Ocean, the disruption of monsoonal rains, and rapid deglaciation of polar ice sheets (for examples of 'slow' and 'fast' tipping points, see: Archer et al., 2009; Notz, 2009; Ruppel, 2011; Glikson, 2019). In terms of the potential catastrophic impacts on human populations, it has been estimated that a temperature increase of 3 °C above preindustrial will result in an additional one to four billion people facing water shortages, and 150 to 550 million additional people being at risk of hunger. A temperature increase of 4 °C above preindustrial will result in an estimated 7 million to 300 million being put at risk of coastal flooding due to sea level rise (Randerson, 2009).

While such outcomes appeared until recently to be of low probability, there is growing observational evidence that their probability is rapidly increasing due to the recent rise in methane emissions, the sources of which remain highly uncertain (Nisbet et al. 2019). Both climate modelling and the paleoclimate record indicate a high probability that exceeding a global average atmospheric temperature of greater than 3 °C above preindustrial levels will result in catastrophic outcomes. Using scenarios derived from IPCC reports, and taking into account a number of uncertainties, Xu and Ramanathan have explored several different emission scenarios and the probability that they will reach dangerous, catastrophic and unknown levels of risk. They conclude that a continuation of BAU has a higher than 50% chance of generating dangerous climatic changes within three decades, i.e. more than 1.5 °C above preindustrial levels. There is a 5% probability that warming along this pathway will become catastrophic by 2050 (Xu and Ramanathan, 2017).

Xu and Ramanathan outline a 'three-lever' strategy to limit the possibilities of both outcomes being realized in both the near term (post-2050) and the long term (2100). These are: '[1] the carbon neutral (CN) lever to achieve zero net emissions of CO2, [2] the super pollutant (SP) lever to mitigate short-lived climate pollutants, and [3] the carbon extraction and sequestration (CES) lever to thin the atmospheric CO2 blanket'. By pulling on the first two levers and reversing the emissions curve by 2020, they argue it will be possible to keep warming below dangerous levels with respect to the higher probability scenarios. But in order to prevent the lower probability scenarios from unfolding, the third lever will need to be pulled in order to 'extract as much as 1 trillion tons of CO2 before 2100′ (Xu and Ramanathan 2017: 10315). Consistent with the earlier cited arguments made by Lenton (2011) in relation to real critical thresholds, Xu and Ramanathan argue that there needs to be a change in the international goals from stabilizing warming at 1.5 °C or 2 °C by 2100, to an effort to reduce the rate of warming over time. They point to evidence from the Eemian period of 130,000 years ago, when the earth was going through an interglacial period similar to the present. It suggests that sustained warming of 1.5 °C or more over centuries can cause catastrophic sea level rise of between 6 and 9 m (Xu and Ramanathan 2017: 10318; cf. Hansen et al. 2007).

Scientist critics have argued that the first five IPCC assessment reports failed to capture the speed at which some climatic changes have actually taken place in recent years (Pearson et al. 2015), and failed to model some equally probable future scenarios (Gramelsberger and Feichter, 2011; New et al., 2011). They argued that the modelling included in those reports was not always the most informative or comprehensive guide for policymaking, and any policy prescriptions based on those scenarios were not necessarily an accurate guide to the potential risks (Rahmstorf et al., 2007; Matthews and Caldeira, 2008; Schellnhuber, 2008; Steenhuysen, 2009; Young and Pilkey, 2010; Betts et al., 2011; New et al., 2011; Anderson, 2015; Raftery et al., 2017). Andrew Glikson has argued that the speed at which GHG burdens have entered the atmosphere since industrialization has not occurred in earth history for at least 65 million years, during the Palaeocene/Eocene thermal maximum (Glikson 2012, 2019; cf. Sluijs et al., 2006; Sherwood and Huber, 2010; Wright and Schaller, 2013). Although there is an emerging consensus that average surface temperatures are not likely to increase by more than 4 °C by the end of this century (Sherwood et al., 2020), due to a continuation of high emissions with strong carbon feedbacks, the possibility of such scenarios unfolding cannot be excluded from consideration (IPCC, 2007; Sherwood and Huber, 2009; Betts et al., 2011).

6. The IPCC, sea-level rise and the paleoclimate record

Several recent studies have argued that current emission trajectories and melt rates of polar and glacial ice suggest that there is now a high probability of mean global temperatures rising by 1.5 °C above pre-industrial levels between the late 2020s (Henley and King 2017; cf. Johnston 2017) and the early 2050s (Mauritsen and Pincus, 2017; Gabbatiss, 2018), and 2 °C to 3 °C above pre-industrial levels by 2060 (cf. Stern, 2006: vi). The former finding was recently confirmed by the IPCC in its 2018 report with a high rate of confidence (IPCC 2018: 6). It neglected, however, to point to the high probability of catastrophic climate damages later in the century were such temperatures to be maintained, rather than decreased (Xu and Ramanathan 2017).

The historically unprecedented rate at which GHGs have been released into the atmosphere over the last 200 years heightens the uncertainties surrounding short- and medium-term climate simulations (Glikson 2019). Because the cumulative growth of CO2 will persist in its effects upon the climate for thousands to tens of thousands of years, not just for hundreds of years, there will be irreversible changes to the climate over the medium to long term unless CO2 emissions are radically reduced within the next few decades (Solomon et al., 2009; Eby et al., 2009). These feedbacks have profound implications for sea level rise and the increased intensity and severity of extreme weather events, because the timescales required to reverse atmospheric loads of GHGs and associated temperatures below potentially dangerous thresholds involve very long recovery pathways (Lowe et al. 2009).

A recurring criticism of IPCC modelling of sea-level rise going back well over a decade is that the modelling which it has endorsed and the paleoclimate record indicate very different rates of change and levels of uncertainty in relation to their respective risk profiles (Pittock, 2006; Torn and Harte, 2006; Hansen, 2007a, 2007b; Hansen et al., 2007, 2008, 2011; Kopp et al., 2009). For example, the last time in earth's history during which current atmospheric burdens of GHGs prevailed was in the mid-Pliocene, 3.0 to 3.3 million years ago, when CO2 concentrations were 350 to 450 ppm, the mean surface temperature was 2 °C to 4 °C warmer than present, and sea levels were 10 to 30 m higher than today (Dowsett et al., 1999; Haywood et al., 2007; Pagani et al., 2010; Martínez-Botí et al., 2015; Sherwood et al., 2020; cf. IPCC 2019: 323). It is possible that equivalent atmospheric GHG levels have not occurred since the Middle Miocene, 14 to 16 million years ago, when mean surface temperatures were around 3 °C to 6 °C warmer than present and sea levels were between 15 and 40 m higher than today (Allison et al.: 44, 2009; Tripati et al., 2009; Glikson, 2012; Xu and Ramanathan, 2017; cf. Pagani et al., 2010; IPCC, 2013: 394). The paleoclimate record indicates that warming of 2 °C has an extremely high probability of leading to a 15 to 25 m sea level rise over the next few centuries (Hansen et al. 2007: 1949; Allison et al, 2009: 45). Were current global emission trajectories to continue unabated, however, there is a high probability of a 3 °C warming by the end of the century and much higher levels of sea level rise over the subsequent centuries (Adam, 2009a; Xu and Ramanathan, 2017; Ramanathan et al., 2017).

Detailed examination of successive IPCC assessment reports reveals that they only began to incorporate paleoclimate data in any substantive fashion in 2001. However, the relevant discussions in TAR were largely restricted to consideration of the Mid Holocene and Last Glacial Maximum, i.e. no more than 21,000 years BP (e.g. IPCC 2001a: 8, 61, 139). This was also true of AR4 (IPCC, 2007), which stated that a mean annual temperature increase of 1.1 °C to 3.8 °C above today's global average temperature will result in sea level rises of anything between 4 and 12 m over the 'longer term', but failed to specify what that meant (IPCC 2007: 41, 64). AR4 did concede, however, that '[t] he long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries' (IPCC, 2007: 67).

The report published by the IPCC Workshop on Sea Level Rise and Ice Sheet Instabilities in 2010 questioned the adequacy of extant approaches to sea-level rise projections and recommended three approaches that could supplement them, i.e. 'semi-empirical' and 'kinematic' constraints on the upper bound for the near-term ice sheet distribution, and probabilistic representation of paleoclimate analogues for the rate and magnitude of long-term sea-level rise (IPCC 2010: 147). The IPCC's long-term sea level projections began to include substantive discussion of research utilizing these approaches in AR5.

The full report by AR5 WGI incorporated extensive discussion of paleoclimate research, with around 140 substantive references to the topic (e.g. IPCC 2013: 77–78, 383–464, 923–924, 1200–1205). However, it continued to rely on data from the Mid Holocene and Last Glacial Maximum to calibrate its projections (IPCC 2013: 122, 146, 403–414). It should also be noted that there is no discussion of the paleoclimate record in the AR5 SPMs for WGII or WGIII, and that 66% of the paleoclimate studies cited in AR5 WGI are from 2010 or earlier.

After briefly citing a number of studies predicting higher than one-metre sea level rise up to 2100, AR5 WGI's full report states that '[c]onsidering this inconsistent evidence, we conclude that the probability of specific levels above the likely range cannot be reliably evaluated' (IPCC 2013: 1186). It also reasserted its claims from AR1 to AR4 that no more than 1 m of sea level rise can be expected by the end of the century:

> The basis for higher projections of global mean sea level rise in the 21st century has been considered and it has been concluded that there is currently insufficient evidence to evaluate the probability of specific levels above the assessed likely range. Many semi-empirical model projections of global mean sea level rise are higher than process-based model projections (up to about twice as large), but there is no consensus in the scientific community about their reliability and there is thus low confidence in their projections (IPCC 2013: 26).

Much later in the same report, it states that 'paleoclimate reconstructions provide no clear evidence either way whether models are over- or underestimating internal variability on time scales relevant for attribution' (IPCC 2013: 874). Although AR4 does include extensive discussion of the mid-Pliocene, stating that there is high confidence that sea levels during that period did not exceed 20 m above present levels (IPCC 2013: 46, 50, 385, 394, 425, 1145–1146; cf. IPCC 2019: 323), these observations did not find their way into the SPMs for WGII or WGIII.

The IPCC's most recent special report from 2018/19 includes comparisons of the Mid-Pliocene Warm Period with that of the Last Interglacial and the Holocene Thermal Maximum, but argues that 'the long (multi-millenial) time scales of these past climate and sea level changes, and regional climate influences from changes in Earth's orbital configuration and climate system feedbacks, lead to *low confidence* in direct comparisons with near-term future changes' (IPCC 2019: 323). Perhaps unsurprisingly therefore, it continues to endorse sea level modelling that has been repeatedly criticized for omitting the consideration of positive feedbacks related to melting glaciers, sea ice and ice sheets: 'Model-based projections of global mean sea level rise (relative to 1986–2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5° C global warming, 0.1 m (0.04–0.16 m) less than for a global warming of 2 °C (*medium confidence*)' (IPCC 2018: 9). Despite the IPCC's assurances on this score, in early 2017, the National Oceanic and Atmospheric Administration released a revised worst-case scenario estimate of 2.5 m of sea-level rise by 2100, 5.5 m by 2150 and 9.7 m by 2200, stating that sea-level science has 'advanced significantly over the last few years, especially (for) land-based ice sheets in Greenland and Antarctica under global warming', which, it added, have been 'losing mass at an accelerated rate' (Sweet et al. 2017; cf. Moore 2019). This study is not referenced in the special report.

For almost thirty years, the IPCC has continued to maintain its largely static assessment of sea level rise. Numerous studies have argued that if current emission trajectories are not curtailed, a two-metre sea level rise may occur by the end of this century, and as much as one metre by 2050 (Pfeffer et al., 2008; Allison et al., 2009; Young and Pilkey, 2010; European Environment Agency, 2013; Hansen et al., 2016; Bakker et al., 2017; Wong et al., 2017; cf. Rahmstorf et al., 2007; Pearson et al., 2015; Wang and Hausfather, 2020). The IPCC's response has been to appeal to the contentious notion of 'scientific consensus' to discount the probability of such outcomes (Pearce et al., 2017, 2018; Hulme and Mahony, 2010; Mahony and Hulme, 2012).

7. Conclusion

This paper has reviewed the evidence in support of three key areas of concern expressed by a large number of climate scientists and scientific organizations over the last decade with respect to the aims and achievements of the current international climate policy regime. The first is that atmospheric concentrations of CO2 and CO2e have already reached levels consistent with overshoot of the 2 °C target. The second is that the nonlinearity of the climate system renders far more likely the probability of significantly higher and more dangerous risks to biophysical and socio-economic systems than is currently acknowledged in IPCC processes. The third is that DAI is already happening across a range of biophysical indicators. Many climate scientists argue that real critical thresholds have already been crossed in relation to biome shifts, the loss of Arctic permafrost and sea ice, and probably also the Greenland and Antarctic ice sheets. There is also compelling evidence that stabilizing GHG levels in the atmosphere at 1.5 °C or 2 °C will not be sufficient to avert the possibility of catastrophic climate change by the end of the century.

While scientific representations of risk in recent assessments by the IPCC have to some extent incorporated nonlinear behaviour in their modelling techniques, observational evidence to calibrate their modelling, and the paleoclimate record as a historical control, these efforts arguably remain inadequate. The most recent IPCC projections of sea level rise do not take sufficient account of relevant paleoclimatological research or recent improvements in sea-level science, as well as the potential for nonlinear sea-level rise. Even though it may turn out to be the case that the IPCC's conservative assessments are accurate, there is already evidence from extreme weather events over the last decade that the potential risks to low-lying and coastal communities are more profound than IPCC assessments currently reflect.

Commenting upon an earlier draft of this paper, a colleague wrote, 'If policymakers set targets, the scientific community can evaluate them. If policymakers cannot agree on what outcomes they want, then it's not clear science can help.' But this comment assumes a linear relationship between scientists and policymakers, and overlooks the iterative nature of their communications, as well as the need to incorporate other forms of expert knowledge in the policy process (Beck, 2011, 2012; Hoppe et al., 2013). As will be argued in detail in Part 2 of this paper, policymakers' conceptions of the potential risks of anthropogenic forcing have not only been shaped by the climate scientists who contribute to IPCC processes. They have also been shaped by the kinds of scientific and socio-economic evidence which the world's most powerful nation states have been prepared to admit into those processes. Since the inception of both the IPCC and UNFCCC, many social scientists have argued that the disciplinary constrictions imposed on the structure and functions of both organisations have ensured that many important insights arising from a wide range of expert and unaccredited sources are simply excluded from consideration. The inclusion of a range of academic disciplines, civil society organizations and concerned citizens as equal stakeholders in formal deliberations about international climate policy will arguably go a long way to shifting public opinion and building the political momentum required to implement reforms that are commensurate with the risks we face.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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