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The myriad challenges of the Paris Agreement

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Introduction

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The much awaited and intensely negotiated Paris Agreement was adopted on 12 December 2015 by the Parties to the United Nations Framework Convention on Climate Change. The agreement set out a more ambitious long-term temperature goal than many had anticipated, implying more stringent emissions reductions that have been under-explored by the research community. By its very nature a multidisciplinary challenge, filling the knowledge gap requires not only climate scientists, but the whole Earth system science community, as well as economists, engineers, lawyers, philosophers, politicians, emergency planners and others to step up. To kick start cross-disciplinary discussions, the University of Oxford's Environmental Change Institute focused its 25th anniversary conference upon meeting the challenges of the Paris Agreement for science and society. This theme issue consists of review papers, opinion pieces and original research from some of the presentations within that meeting, covering a wide range of issues underpinning the Paris Agreement.

This article is part of the theme issue 'The Paris Agreement: understanding the physical and social challenges for a warming world of 1.5°C above pre-industrial levels'.

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1. What are the Paris Agreement goals?

Article 2 of the Paris Agreement [1] identifies its purpose as:

1. Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.
2. Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production.
3. Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

In their contribution to this theme issue, Rajamani & Werksman [2] analysed the legal character of the long-term temperature goal contained in Article 2 in the context of the overall framework of the Paris Agreement. They argue that although this goal has an operational role in infusing global and national discourse on climate policy with greater ambition and urgency, it does not have specific legal force in relation to the actions of individual Parties. Parties may have chosen to circumscribe the legal force of the long-term temperature goal, in part, over concerns about its feasibility.

2. How feasible are the Paris Agreement goals?

Fossil fuels provide energy for many of our most fundamental technologies. Millar & Friedlingstein [3] suggest that due to the substantial uncertainty in net radiative anthropogenic forcing on the climate system, uncertainty in observational constraints on the transient climate response to cumulative emissions (the prime uncertainty in remaining carbon budgets) remains large. They provide a best estimate of 920 $GtCO_2$ (250 GtC) for the remaining carbon budget to give a 50% probability of temperatures remaining below 1.5°C based on historical constraints, but highlight a number of reasons for caution in extrapolating carbon budgets from historical data alone. Using potential future scenarios, Lowe & Bernie [4] found that current estimates of the remaining carbon budget may well be too large, and the remaining budget might be less than estimated. Their analysis is based on an assessment of including additional Earth system processes that are thought to be important for the carbon budget analyses, which range from the release of methane from wetlands, to the more uncertain contribution of fire to the carbon budget.

The analysis from Kriegler *et al.* [5] suggests that it may only be possible to limit our global temperature increases to below 1.5°C without a global mean temperature overshoot, if the remaining carbon budget is of the order of 800 $GtCO_2$, and only if emission reductions begin immediately. A simple consequence of the cumulative impact of CO_2 emissions on global temperature is that, for every year of delay, as emissions continue at a constant rate, the time available for the transition to net zero emissions to limit warming to any given level shortens by two years. Millar & Friedlingstein [3] suggest that 800 $GtCO_2$ is well within the range consistent with the historical record, but even limiting future cumulative emissions to this amount gives at best approximately even odds of limiting warming to 1.5°C, highlighting the need for robust or precautionary response strategies to hedge against the possibility of a higher climate response. If the remaining budget is smaller, an overshoot is inevitable, even when assuming very strong energy demand and fossil fuel emission reduction initiatives. Either way, a crucial step in stabilizing climate at any level is to balance the anthropogenic sources and sinks, thereby reducing net carbon dioxide emissions to zero. Fuglestvedt *et al.* [6] point out that this 'balance', as formulated in the text of the Paris Agreement, is not well defined, and that the interpretation can influence how global temperature evolves over time. They study possible interpretations and their implications and discuss how clarifications are needed to make the concept of 'balance' operational for climate policies.

In our fossil fuel-dependent society, the task of emission reduction can seem somewhat abstract, and Eyre *et al.* [7] argue that transition to a system that can fully replace fossil fuels will require social and technical change, and thus both parts of this problem should be addressed in conjunction. Furthermore, Gomez-Echeverri [8] argues that intertwining the sustainable development goals (SDGs) with the Paris agenda is the most natural and efficient method to reduce carbon emissions, but that governance and institutions will pose major challenges for policy and decision makers. Ethiopia is offered as an exemplar as it addresses both climate and development challenges, with changes to agricultural practices, replanting forests and introducing low-carbon technologies for its infrastructure. The Paris Agreement takes a hybrid approach—combining bottom up nationally determined contributions from countries with a top down oversight system that seeks to ensure that countries follow through on the contributions that they voluntarily assume. The emphasis on self-selected national contributions enables countries like Ethiopia to put forward initiatives and innovations tailored to national circumstances that assist it in advancing both climate and development goals.

One way to further reduce net carbon emissions is through so-called negative emissions technologies, and carbon capture and storage. Some of these techniques have already been prototyped. Haszeldine [9] notes the emergence of relatively low-cost technologies, few of which are commercially viable at the moment: although in the absence of an active market for CO_2 removal, it is difficult to assess what commercial viability means. Haszeldine argues that to make these viable there needs to be political commitment to a carbon price that is sufficiently high to provide the incentive to deploy negative emissions technologies at scale.

Geoengineering offers a more controversial instrument for achieving the goals of the Paris Agreement. MacMartin *et al.* [10], among others, argue that direct injection of sulfate aerosol into the stratosphere is considered the most plausible geoengineering method, employing physical science and technological arguments. They show that a 1.5°C climate that employs some form of geoengineering would not be the same as a 1.5°C climate that was stabilized through emissions reductions and negative emission technologies alone. However, these two climates would be substantially closer to each other than either is to a 3°C world untouched by geoengineering. Nonetheless, geoengineering is fraught with environmental and geopolitical risks. Frumhoff & Stephens [11] argue that early and continuous engagement regarding the underpinning science of geoengineering, especially in terms of the Earth system response to it, should be initiated with politicians, and even more so with the wider society. They argue that this should take priority over field research on geoengineering, so that any such technologies are not deployed before they gain public legitimacy.

3. What are the tradeoffs for stabilizing climate at 1.5°C and 2°C?

Small island states were among the principal proponents of 1.5°C temperature goal in the Paris Agreement, recognizing the importance of curtailing global warming to limit sea level rising and engulfing large portions of their islands. Unfortunately, Nicholls *et al.* [12] show that sea-level rise will inevitably continue after stabilization of global mean temperatures, and it will only be slowed by stabilizing climate at 1.5°C. They show that sea-level rise in 2300 under the Paris Agreement goals will exceed unmitigated sea-level rise in 2100. Crucially, however, the 1.5°C stabilization leaves time for small island states and coastal cities to adapt. They also show that under the Paris Agreement goals, ocean pH and temperature will stabilize within the century, benefiting vulnerable ecosystems such as coral reefs.

Other authors have considered further Earth system impacts. For instance, Seneviratne *et al.* [13] show a substantial change in regional temperature and water cycle extremes over densely populated regions of the world when climate is stabilized at 1.5°C compared with 2°C, with much of this change coming from land use forcing, and soil moisture feedbacks. The temperature extremes, in particular, were amplified in dry-to-wet transition regions. Betts [14] find similar results for temperature extremes, and further added that stabilization at 2°C would lead to higher flood risk, and lower river flows during droughts, compared to stabilization at 1.5°C, highlighting the importance of changes in both tails of the river flow distribution. These changes have clear knock on effects for biodiversity in regions all over the globe, and Smith *et al.* [15] show that stabilizing climate at a level of 1.5°C would avoid 50% of species losing 50% of their climatic range relative to stabilization at 2°C. They emphasize that when referring to the 1.5°C temperature level, the United Nations Framework Convention on Climate Change states that '[this] level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change', and therefore, like [8], argue for careful integration with the SDGs to achieve this.

It is critical to understand impacts avoided on Earth system components as well the impact sectors they feed through to. Rosenzweig *et al.* [16] demonstrate that the global agricultural picture is complex in this regard, but that some breadbaskets would see a decline in productivity, more so for the 2°C scenario than the 1.5°C scenario, with clear onward price implications for agricultural commodities.

Performing a broader sweep of global economics (i.e. beyond agricultural finances) using empirical estimates, Pretis *et al.* [17] find economic growth in general would be similar between the present day and a 1.5°C warmer world, but would be significantly lower for a large set of countries in a 2°C world compared with present day. Although they emphasize high uncertainties around both economic and climate projections, they show that economic inequality across countries is likely increased under 2°C when compared with present day. Sonja & Harald [18] also note that inequality will likely be higher than present day under the Paris climate goals, and they note that more needs to be done to include inequality arguments into integrated assessment models, as only then can a thorough evaluation of inequality and climate change occur. It is through this understanding of inequality that loss and damage play a critical role. Verchick [19] argues that even the half a degree difference between the Paris temperature goals should be enough to require adequate future plans to be put in place to help the most vulnerable.

4. What we have learned

Evidence suggests that while reductions in greenhouse gas emissions play an essential role in stabilization of climate at 1.5°C, it is looking ever more unlikely that emission reductions alone will be sufficient, so they will likely need to be supplemented by large-scale carbon dioxide removal if a commitment to permanent albedo geo-engineering, with all its concomitant governance challenges and geopolitical hazards, is to be avoided. While the necessary 'negative emission technologies' already exist, their implementation globally will be enormously challenging, requiring policy incentives and industrial mobilization on a far greater scale than is currently evident. Shue [20] notes that in many regions of the world use of fossil fuels is reducing. Increasingly, low, zero and negative carbon technological developments are gaining momentum. But Shue stresses that strong policy measures are still essential to share the burden of inequality. Very significant changes are already underway following the Paris Agreement. The papers in this issue demonstrate that, on the balance of probability, limiting warming to 1.5°C, in the context of sustainable and equitable development, is still possible. It remains to be seen whether the evidence provided on the impacts of climate change avoided by stabilizing at 1.5°C over higher temperature thresholds will be sufficient to motivate action on the scale and pace needed to achieve the 1.5°C goal.

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