Reconsidering the lower end of long-term climate scenarios

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1. Introduction

With the Sixth Assessment Report (AR6) cycle of the Intergovernmental Panel on Climate Change (IPCC) now completed, climate research communities involved in all three AR6 working groups must consider future directions. Many important decisions will be made regarding future scenarios, especially those related to selecting socioeconomic and emissions scenarios to be included in climate-related simulations [1]. The previous process, Coupled Model Intercomparison Project Phase 6 (CMIP6) [2], was carried out within the framework of the Shared Socioeconomic Pathways–Representative Concentration Pathways (SSP-RCP) scenario, in which climate conditions at the end of the 21st century included an increase in temperature between +1.5 and +5°C (here and throughout, relative to the preindustrial level). Despite the scientific advancement represented by CMIP6, scenarios that use SSP-RCPs and the relevant literature reviewed in AR6, whether the scenario framework used by those processes includes a sufficiently broad range of future climate outcomes is unclear. For high-end emissions scenarios, which are known as RCP8.5 or SSP5-8.5, there are some debates [3]. However, there is little discussion that questions the lower boundary. Given this background, this article aims to bring up some arguments on the low-end emissions scenarios and to initiate a discussion as to whether the lower boundary of the current SSP-RCP scenarios should be maintained at existing levels or not.

2. Reasons to reconsider the lower end of emissions scenarios

There are multiple possible reasons to extend the lower boundary of climate outcomes (Fig 1). First, there are the climate change impacts we are already observing, including extreme events (e.g., frequent fires, heat waves, pervasive flooding) and their consequences in many parts of the world even under the currently observed +1°C increase [4]. An increase of +1.5 or +2°C predicted for the end of this century may be disastrous for both humans and ecosystems [5–7]. Moreover, the irreversibility of certain climate change impacts is another important consideration. Even at +1.5°C, the sea level rise by 2150 would be 0.57 (0.37–0.86) m [8] and will not stop for a hundred years5, which may force consideration of measures aimed at cooling the planet at some point.

Secondly, because the range of scenarios in CMIP6 was narrower than that compiled in the AR6 database, whether the SSP-RCP scenarios represent plausible ranges is open to question...
One study published after the release of the AR6 database examined a potential lower emissions pathway [10]. Such lower emissions scenarios revolve around the potential availability and feasibility of Carbon Dioxide Removal (CDR) technologies. The technological capabilities of technologies such as Direct Air Carbon Capture and Storage (DACCs) have changed over the past several years [11], which could improve the feasibility of large-scale CDR implementation.

Thirdly, the need to explore deeper emissions reduction scenarios has been put forwards in the past by the international climate policy community. The Integrated Assessment Models...
(IAMs) provided emissions pathways equivalent to 1.5˚C climate stabilization shortly after the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement. The 1.5˚C-equivalent scenarios were almost entirely non-existent before the Paris Agreement partly because large-scale CDR was thought to be infeasible, but have become more common after the Paris Agreement—not necessarily because they have become more feasible, but because analysis of such scenarios has been requested by the climate policy community. To demonstrate the independence of science in policy-support research, it is essential that the scientific community takes the lead in presenting scenarios in advance of policy requests. Thus the examination of a wide range of scenarios is desirable, and should not necessarily be limited to those deemed plausible on the basis of current assumptions [12].

3. Illustrative examples of lower climate scenarios

Given the above background, to stimulate further discussion we present a pair of possible quantitative climate mitigation scenarios associated with more stringent emissions reductions than specified by the currently existing scenarios bounded by 1.5˚C using an Integrated Assessment Model (AIM) [13] (https://doi.org/10.5281/zenodo.7471205). More specifically, the climate of these scenarios is reverted to that of the 1990s and to the preindustrial climate, equivalent to global temperature increases of +0.7 and +0˚C respectively, and with radiative forcing of 1.0 W/m² and −1.0 W/m² respectively by the end of this century. These climate return scenarios are hereafter referred to as CurClimate and PreInd respectively. The climate of the 1990s can be interpreted as immediately preceding severe, visible climate change impacts, when most social infrastructure and residential areas were adapted to the past climate.

The increase in temperature in both climate return scenarios peaks at 1.5˚C during the 2030s and then declines (Fig 1A). Emissions reductions begin in 2023, and the respective measures are more aggressive than in existing scenarios. Net emissions sharply decrease until the 2050s, then reach the lower boundary constraints of our scenario assumptions, thus remaining at −30 and −50 GtCO₂ respectively (Fig 1B). By contrast, in the scenario targeting 1.5˚C (1p5C), net-zero emissions are reached in the 2050s, with roughly −10 GtCO₂ as the lower boundary of annual emissions occurring in the second half of this century. Interestingly, while the CO₂ emissions trajectory until 2050 substantially differs between the two climate return scenarios and the 1p5C scenario, the temperature difference in 2050 is only around 0.2–0.3˚C, which implies inevitable climate change even under the extremely high level of negative emissions assumed by our scenarios, due to the delayed response of the climate and the lifetime of CO₂ in the atmosphere. Only the PreInd scenario achieves a warming level of +1.5˚C in the 2050s. Although there are some minor differences in sectoral CO₂ emissions other than DACCS among the three mitigation scenarios, the overall differences in emissions reduction are mainly determined by DACCS. This is also evidenced by the large differences in carbon sequestration among the scenarios, such that a dramatic scale-up in the absorption of CO₂ from the atmosphere is assumed (Fig 1D). The total primary energy supply in 2100 is 1170 (PreInd) and 989 (CurClimate) EJ/year in the climate return scenarios and 801 EJ/year in the 1p5C scenario. Unlike the enormous emissions differences among the scenarios, the energy outcomes in the climate return scenarios are less dramatic and within the range of those in existing scenarios (Fig 1C).

4. Discussions on the numerical scenarios

Here we leave some discussion points regarding the feasibility or plausibility concerns which could be considered by multiple aspects such as technological, geophysical, and social/political
aspects. Regarding technological aspects of large-scale CDR, there is much debate over emerging trends (https://carbonengineering.com/, https://globalthermostat.com/, https://www.climeworks.com/), and it is very challenging to determine the feasibility of scaling. Regarding the geological potential of the CCS, we confirmed that cumulative storage until 2100 is still within the global total geological potential. However, deploying tens of giga-tonnes of CCS capacity globally will involve numerous challenges. The earlier literature discussed how there could be a potential decline in the injection rate under long-term use, as well as difficulties associated with local contexts [14]. Meanwhile, frameworks for assessing social and political feasibility of large-scale CDR deployment in the far future are poorly developed [15].

5. Final remarks

We have argued for a reconsideration of lower-end climate change scenarios by the climate research community, and presented two possible scenarios that consider temperature climate conditions lower than those of existing scenarios. We finally describe the possible research agenda for each working group (WG) of the IPCC (see also Fig 1).

1. Within the Earth system modelling community in IPCC WGI, there could be many interesting discussions and investigations on the representation of the carbon cycle, the validity of reduced forms of climate models, and ocean or sea level responses under a cooling climate. Although climate responses under idealized carbon removal or overshoot (>2°C) scenarios have been investigated within CDRMIP, further studies are needed.

2. Regarding climate change impact research considered by IPCC WGII, given the current status of infrastructure developed concerning past climate, the optimal adaptation would also be needed to be investigated. Our scenarios will also interest the biodiversity research community, given the negative consequences of all existing climate scenarios, including those based on an increase of 1.5°C.

3. In the field of climate change mitigation research of relevance to IPCC WGIII, the large-scale implementation of DACCS is controversial. Further research into the widespread implementation of CO₂ removal technologies is sorely needed, including comprehensive assessments of the socioeconomic and environmental impacts and the physical constraints (e.g., large-scale factories, use and impacts of chemical substances). Moreover, implementing multiple IAMs will lead to more robust insights into the effectiveness of various mitigation scenarios.

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References


