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# Mid- and long-term climate projections for fragmented and delayed-action scenarios

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ABSTRACT

This paper explores the climate consequences of "*delayed near-term action*" and "*staged accession*" scenarios for limiting warming below 2 °C. The stabilization of greenhouse gas concentrations at low levels requires a large-scale transformation of the energy system. Depending on policy choices, there are alternative pathways to reach this objective. An "*optimal*" path, as emerging from energy-economic modeling, implies immediate action with stringent emission reductions, while the currently proposed international policies translate into reduction delays and higher near-term emissions. In our *delayed action* scenarios, low stabilization levels need thus to be reached from comparatively high 2030 emission levels. Negative consequences are higher economic cost as explored in accompanying papers and significantly higher mid-term warming, as indicated by a rate of warming 50% higher by the 2040s. By contrast, both mid- and long-term warming are significantly higher in another class of scenarios of *staged accession* that lets some regions embark on emission reductions, while others follow later, with conservation of carbon-price pathways comparable to the *optimal* scenarios. Not only is mid-term warming higher in *staged accession* cases, but the probability to exceed 2 °C in the 21st century increases by a factor of 1.5.



## 1. Introduction

Greenhouse-gas emission scenarios are an important tool to provide coherent storylines exploring the options and costs of realizing mid- to long-term climate-change mitigation goals. A prominent method for developing such scenarios is the use of integrated assessment models (IAMs). These models show a large diversity in approaches that lead to differences in coverage of geographical regions, sectors, greenhouse gases and pollutants, as well as structural differences that relate to economic feedback mechanisms.

Many of these models also include simple representations of the physical climate system, to be able to optimize emission pathways for achieving long-term climate goals. This special issue presents the results from the AMPERE project, involving a large number of IAMs aimed at limiting total greenhouse-gas emissions to achieve a set of standardized $CO_2$ emission budgets. Different models achieve these budgets by means of different time-dependent emission pathways. Given (a) the wide range of approaches for estimating first-order climate-system response

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in IAMs and lack of these in others (e.g. [1]), and (b) the differences in the time-dependent emission pathways produced by the IAMs, the consequences of mitigation policy cases and technological options for long-term climate goals are not immediately clear and comparable across IAMs.

Therefore, in this paper the emission scenarios developed by IAM groups within the AMPERE project are assessed in a common climate-modeling framework. This allows us to provide a context of mid- to long-term projections of greenhouse-gas concentrations and warming for evaluation of the mitigation scenarios.

The AMPERE project has some unique features compared to previous IAM intercomparisons that make it particularly interesting for an in-depth analysis of the climate response to anthropogenic emissions. AMPERE focused on scenario variants that deviate from the idealized assumption of immediate full cooperative action on meeting a stabilization target. First, it explored a *delayed action* situation where moderate levels of mitigation stringency are aimed for in the short term (2030) and the long term target is only adopted thereafter [2]. Secondly, it studied *staged accession* to a global climate regime, where some regions join the global climate mitigation effort at later times than others [3]. The two scenario sets allow to explore strong peak and decline emission scenarios, as well as the loss of mitigation stringency due to *staged accession* of key emitting countries. These types of scenarios are highly policy relevant and at the same time sufficiently different from the standard set of representative concentration pathways (RCPs — see [2]) that have been investigated by a suite of climate models [4,5]. For example, the AMPERE scenarios with moderate near-term mitigation policies lead to a pronounced "emissions gap" over the next two decades compared to immediate and optimal climate policy scenarios, which have been the focus of the vast majority of scenarios in the past. As shown by single-model studies [6–8] and with a large suite of models by Riahi et al. [9] in this special issue, many IAM models suggest that low long-term targets compatible with 2 °C temperature change can still be reached from relatively higher near-term emissions. The transient temperature consequences of this near-term emissions gap have, however, only been explored to a limited degree [6,7]. This is thus a key issue that will be addressed in this paper.

As a further original contribution to the literature, the paper draws on two different approaches to explore the climate outcome of the IAM emission scenarios. One approach uses the simple coupled carbon-cycle/climate model MAGICC6 that generates probabilistic information [10] about the climate response. The second approach uses a step function emulation of CMIP5 [5] general circulation models to deduce the temperature response to the forcing projections generated by MAGICC6. The comparison of the two approaches delivers two insights that are new to the literature. It shows how the climate outcomes from an approximation of the latest round of climate model ensemble runs relate to the temperature estimates from MAGICC6, and to this end the IAMs which often rely on this type of simple climate models to explore climate consequences of mitigation pathways.

The AMPERE project adopted cumulative $CO_2$ emission budgets as long-term targets (including $CO_2$ equivalent pricing of non-$CO_2$ emissions) while earlier studies mostly focused on a variety of greenhouse gas stabilization targets. This leads to a better harmonization of cumulative greenhouse-gas emissions across model scenarios and allows to explore the range of climate outcomes that can emerge from emission budgets.

Drawing from the AMPERE scenario exercises, we will analyze four key variants of "default" mitigation scenarios to explore how sensitive mid- to long-term projections are to:

- An extrapolation of the current level of mitigation ambition over the 21st century, without new policies required, for example, for achieving presently proposed Copenhagen Pledges and emission targets under the Cancun Agreement [3,9].
- Concerted immediate action to meet the long term $CO_2$ budget in an economically efficient way [3,9]. This and the first scenario serve as benchmark cases.
- Concerted, but weak action broadly consistent with presently proposed Copenhagen Pledges and the Cancun Agreement, leading to relatively high emission levels by 2030 [9].
- Fragmented participation of country groups, including cases of Europe and China taking early mitigation action, followed later by other regions, or not at all [3].

Additional scenario variants [9] represen technology sensitivity cases that assume limited potential for biomass (maximum of 100 EJ/yr), exploring strategies that would avoid large-scale expansion of bioenergy and thus avoid potential competition over land for food and fiber. These sensitivity cases (LimBio) are very relevant also for the emission pathways, since they limit the potential for negative emissions from Bio-CCS that can possibly compensate in the long term for overshoots of near-term emission targets or budgets, thus inhibiting such near-term overshoots.

## 2. Methods

### 2.1. Multi-gas scenarios

Five of the 12 Integrated Assessment Models included in the AMPERE comparison were able to directly provide all the greenhouse gases and air pollutants (see Table 1) required as input for the coupled carbon-cycle/climate model MAGICC6 (see Section 2.3). For other IAMs, a protocol was developed to supplement scenarios with "missing" emission species or categories, to enable climate projections and intercomparison across all models and scenarios:

- If $CO_2$ from land use was not reported, the mean across the RCP scenarios [2,11] for each time step was added
- If SOx was not reported, emissions were derived using an average relation between $CO_2$ emissions from the fossil-fuels & industry sectors and SOx emissions across the "full-gas" models (see Supplementary information)
- For other unreported species and given the weaker correlation with $CO_2$ emissions compared to SOx, the time series was inserted from the same scenario produced by MESSAGE, for no reason other than the completeness of coverage of AMPERE scenarios by that model
- For any other gas or sector that was not reported, for each time step emissions were derived by interpolation between the lowest and highest RCP emission scenarios RCP3PD and RCP8.5, using $CO_2$ emissions from energy and industry as interpolation key.

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