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Probabilistic temperature change projections and energy system implications of greenhouse gas emission scenarios

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Abstract

This paper explores the implications for global average temperature change of a set of reference and mitigation scenarios in a probabilistic framework. First, we use published probability density functions for climate sensitivity to investigate the likelihood of achieving targets expressed as levels or rates of global average temperature change. We find, for example, that limiting warming to 3 C above pre-industrial levels with at least a medium likelihood requires cumulative emissions reductions on the order of 30-60% below one unmitigated reference scenario by 2100, while a more favorable baseline scenario requires no reductions at all to achieve this outcome with the same likelihood. We further conclude that the rate of temperature change may prove to be more difficult to control, especially if most of the mitigation effort is postponed until later in the century. Rate of change targets of 0.1–0.2 °C/decade are unlikely to be achieved by a target for the long-term level of climate change alone. Second, we quantify relationships between mitigation costs and the likelihood of achieving various targets and show how this depends strongly on the reference scenario. Third, we explore relationships between medium-term achievements and long-term climate change outcomes. Our results suggest that atmospheric concentrations and the share of zero-carbon energy in the middle of the 21st century are key indicators of the likelihood of meeting long-term climate change goals cost-effectively. They also suggest that interim targets could be an effective means of keeping long-term target options open. Our analysis shows that least-cost mitigation strategies for reaching low climate change targets include a wide portfolio of reduction measures. In particular, fundamental long-term structural changes in the energy system in these scenarios are a

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necessary but not sufficient condition to achieve high likelihoods for low temperature targets. The cost-effective portfolio of emissions reductions must also address demand-side measures and include mitigation options in the industry, agriculture, and the forest sector.

Keywords: Climate change; Energy modeling; Climate sensitivity; Uncertainty analysis

1. Introduction

The IIASA mitigation scenarios [1] were designed to meet various targets set in terms of radiative forcing in 2100. Radiative forcing lies near the center of a causal chain that runs from human activities to changes in emissions, concentrations, forcing, and climate, and ultimately to impacts. There is uncertainty in each link of this chain. Scenarios that meet the same radiative forcing goal but assume different development pathways, such as the mitigation scenarios in [1], explore uncertainties near the start of this chain. Here we explore uncertainties toward the end of the chain, specifically the range of possible global average temperature change outcomes implied by individual radiative forcing pathways.

Evaluating the global average temperature changes that result from mitigation scenarios is important for assessing the potential benefits of climate change mitigation policies, in terms of avoided damages. While it is the spatial pattern of various aspects of climate change (temperature, precipitation, extreme events, seasonality, etc.) that determine the impacts, the rates and levels of global average temperature change can serve as a reasonable first-order proxy. These global metrics are also useful in discussions of global climate policy, in particular regarding strategies to avoid dangerous interference with the climate system, as called for by the United Nations Framework Convention on Climate Change (UNFCCC). A growing body of literature has begun to associate particular levels and rates of change with impacts that may be considered dangerous ([2–8]), and policy proposals, such as the European Union (EU) target to limit warming to 2 °C above the pre-industrial level, have been advanced on these grounds.

To account for uncertainty in climate change projections is important, since currently it is not possible to predict with precision what rate and level of warming will result from a given radiative forcing path. The most important climate system characteristic that links radiative forcing pathways to climate outcomes is climate sensitivity. This is conventionally defined as the equilibrium global mean temperature change that results from a doubling of the pre-industrial CO_2 concentration. Not only is the value of this parameter unknown, but there is disagreement on the quantification of its uncertainty as well. A number of different probability density functions (PDFs) for climate sensitivity have been estimated [9–13]. Thus, achieving a given concentration target will only achieve a given temperature outcome with a certain degree of likelihood, and that likelihood itself is uncertain. While this state of affairs means we cannot say precisely how much climate change will be reduced by a given mitigation scenario, we *can* begin to estimate how much a given mitigation scenario will increase our confidence in meeting a certain temperature change target.

Our aim is to explore the probabilistic implications of a *limited* set of illustrative emissions scenarios that cover the range of baseline and stabilization uncertainties in the literature. In this study we model the probabilistic temperature change consequences of 11 scenarios: the revised A2r