

EGU25-7461, updated on 13 Apr 2026

<https://doi.org/10.5194/egusphere-egu25-7461>

EGU General Assembly 2025

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Quantifying climate implications of a future hydrogen economy using a two-box model

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Hydrogen (H₂) provides an alternative to fossil fuel use during the transition to net zero emissions. However, the climate impacts of a H₂ economy are dependent on its production method and leakage rates during production, transport, and storage. H₂ acts as an indirect greenhouse gas through its impacts on methane (CH₄), tropospheric ozone, and stratospheric water vapor. H₂ reacts with hydroxyl radicals (OH), the primary sink of CH₄, thereby causing the CH₄ lifetime to increase. The climate impacts of H₂ are not well constrained, largely due to uncertainties in the H₂ soil sink, which accounts for ~75% of atmospheric H₂ loss.

Here, we develop a two-box model of the CH₄-CO-OH-H₂ scheme based on the work of Prather (1994). We improve the conventional four-equation system and incorporate data from UK Earth System Model (UKESM1) simulations to generate time-varying OH production and parameterize impacts of nitrogen oxides (NO_x) on the system. We evaluate the CH₄ lifetime under various H₂ leakage rates and SSP scenarios to quantify impacts of changes in carbon monoxide (CO), CH₄, volatile organic compounds, and NO_x. As the H₂ soil sink dominates uncertainty in the H₂ budget, we perform a Monte Carlo analysis of uncertainties in H₂ soil deposition and quantify impacts on the CH₄ lifetime. We estimate the indirect global warming potential of H₂ under each scenario relative to both CH₄ and CO₂ and propose H₂ leakage rates required for climate benefits under various SSP scenarios.