# Supplementary material: Sensitivity of climate effects of hydrogen to leakage size, location, and chemical background

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**Supplementary figures**
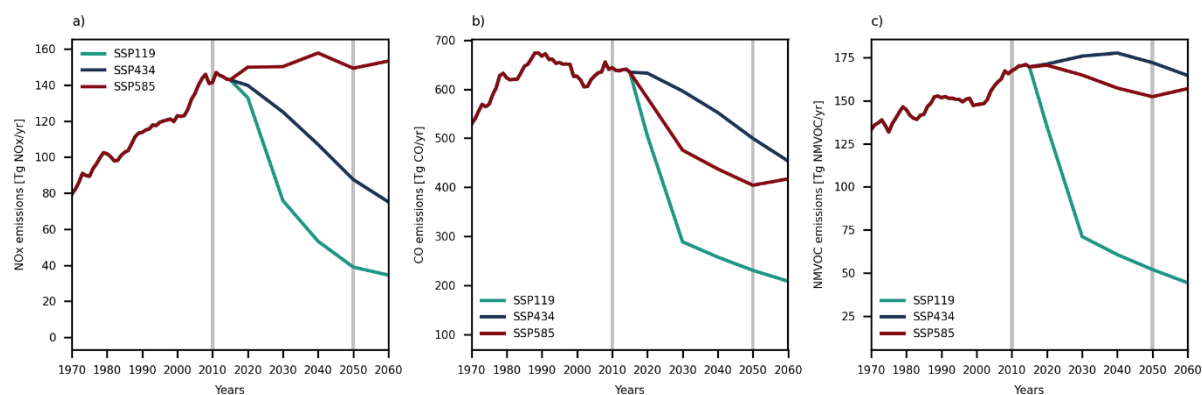
**Figure S1: Historical (Hoesly et al., 2018) and future (Gidden et al., 2019) anthropogenic emissions of a) NOx, b) CO and c) NMVOCs for the three SSPs used in this study. In this study the emissions for the years 2010 and 2050 are used in the model simulations (vertical gray line).**
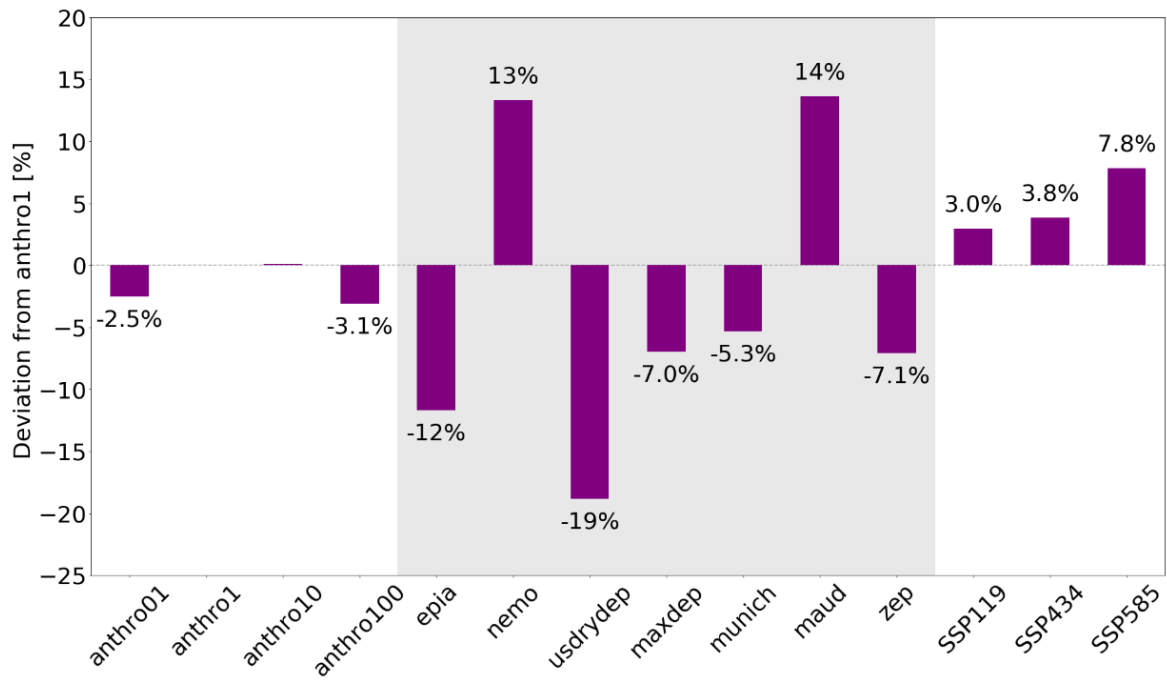
**Figure S2: For each sensitivity test, the deviation of H$_2$ GWP100 relative to anthro1 given as percentages.**

20    **Supplementary tables**

**Table S1: H$_2$ GWP100 values presented in Fig. 3.**

|          | CH4dir | CH4indir | O3   | O3 CH4ind | strat H2O | strat H2O CH4ind | Total |
|----------|--------|----------|------|-----------|-----------|------------------|-------|
| anthro01 | 3.26   | 1.52     | 2.13 | 2.79      | 1.87      | 0.65             | 12.2  |
| anthro1  | 3.29   | 1.53     | 2.38 | 2.81      | 1.87      | 0.66             | 12.5  |
| anthro10 | 3.28   | 1.52     | 2.42 | 2.80      | 1.88      | 0.66             | 12.6  |
| anthro100| 3.11   | 1.45     | 2.41 | 2.66      | 1.90      | 0.62             | 12.2  |
| epia     | 2.95   | 1.37     | 2.06 | 2.53      | 1.57      | 0.59             | 11.1  |
| nemo     | 3.80   | 1.76     | 2.59 | 3.25      | 2.05      | 0.76             | 14.2  |
| usdrydep | 2.71   | 1.26     | 1.89 | 2.32      | 1.45      | 0.54             | 10.2  |
| maxdep   | 3.02   | 1.40     | 2.27 | 2.58      | 1.80      | 0.60             | 11.7  |
| munich   | 3.16   | 1.47     | 2.22 | 2.70      | 1.69      | 0.63             | 11.9  |
| maud     | 3.80   | 1.77     | 2.62 | 3.25      | 2.05      | 0.76             | 14.2  |
| zep      | 3.12   | 1.45     | 2.14 | 2.67      | 1.65      | 0.62             | 11.7  |
| SSP119   | 3.18   | 1.64     | 2.48 | 2.94      | 1.95      | 0.73             | 12.9  |
| SSP434   | 3.18   | 2.26     | 2.05 | 2.79      | 1.96      | 0.79             | 13.0  |
| SSP585   | 3.43   | 2.31     | 2.01 | 3.03      | 1.92      | 0.83             | 13.5  |

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**Table S2: Changes in atmospheric composition and effective radiative forcing due to a flux of hydrogen (1 Tg yr⁻¹). In the first column, the hydrogen flux (in Tg yr⁻¹) in each perturbation simulation is shown. The rest of the columns show hydrogen surface concentrations (in ppb), methane surface concentrations (in ppb), methane flux (Tg yr⁻¹), ERF (in Wm-2) from methane, ozone, stratospheric water vapor due to a flux of 1 Tg yr⁻¹ hydrogen.**

|  | Flux H2 [Tg/yr] | Surf. conc. H2 per flux [ppb yr/Tg] | Surf. conc. CH4 per flux [ppb yr/Tg] | Flux CH4/Flux H2 [Tg CH4/Tg H2] | CH4 RF per flux [mW m-2 yr/ Tg] | ozone RF per flux [mW m-2 yr/ Tg] | Strat. H2O RF per flux [mW m-2 yr/ Tg] |
|---|---|---|---|---|---|---|---|
| anthro01 | 0.10 | 6.27 | 1.11 | 0.30 | 0.43 | 0.19 | 0.17 |
| anthro1 | 0.99 | 6.27 | 1.12 | 0.31 | 0.43 | 0.21 | 0.17 |
| anthro10 | 9.90 | 6.28 | 1.12 | 0.31 | 0.43 | 0.22 | 0.17 |
| anthro100 | 99.07 | 6.35 | 1.06 | 0.29 | 0.41 | 0.22 | 0.17 |
| epia | 0.99 | 6.05 | 1.01 | 0.28 | 0.39 | 0.18 | 0.14 |
| nemo | 0.99 | 7.92 | 1.29 | 0.35 | 0.50 | 0.23 | 0.18 |
| usdrydep | 0.99 | 5.20 | 0.92 | 0.25 | 0.36 | 0.17 | 0.13 |
| maxdep | 0.99 | 5.48 | 1.03 | 0.28 | 0.40 | 0.20 | 0.16 |
| munich | 0.99 | 6.32 | 1.08 | 0.29 | 0.41 | 0.20 | 0.15 |
| maud | 0.99 | 9.24 | 1.29 | 0.35 | 0.50 | 0.23 | 0.18 |
| zep | 0.99 | 6.69 | 1.06 | 0.29 | 0.41 | 0.19 | 0.15 |
| SSP119 | 9.90 | 6.36 | 1.12 | 0.30 | 0.43 | 0.22 | 0.17 |
| SSP434 | 9.90 | 6.53 | 1.26 | 0.30 | 0.49 | 0.18 | 0.18 |
| SSP585 | 9.89 | 6.42 | 1.33 | 0.32 | 0.51 | 0.18 | 0.17 |

**Table S3: Changes in atmospheric composition and effective radiative forcing due to a flux of methane (1 Tg yr⁻¹). In the first column the methane flux in the perturbations. The rest of the columns show change in methane surface concentration (in ppb), ERF (in mW m⁻²) for ozone and stratospheric water vapor due to a methane flux of 1 Tg yr⁻¹.**

|  | Flux CH4 [Tg/yr] | Surf. conc. CH4 per flux [ppb yr/Tg] | ozone RF per flux [mW m-2 yr/ Tg] | Strat H2O RF per flux [mW m-2 yr/ Tg] |
|---|---|---|---|---|
| anthro01 | 49.7 | 3.65 | 0.82 | 0.19 |
| anthro1 | 49.7 | 3.65 | 0.82 | 0.19 |
| anthro10 | 49.7 | 3.65 | 0.82 | 0.19 |
| anthro100 | 49.7 | 3.65 | 0.82 | 0.19 |
| epia | 49.7 | 3.65 | 0.82 | 0.19 |
| nemo | 49.7 | 3.65 | 0.82 | 0.19 |
| usdrydep | 49.7 | 3.65 | 0.82 | 0.19 |
| maxdep | 49.7 | 3.65 | 0.82 | 0.19 |
| munich | 49.7 | 3.65 | 0.82 | 0.19 |
| maud | 49.7 | 3.65 | 0.82 | 0.19 |
| zep | 49.7 | 3.65 | 0.82 | 0.19 |
| SSP119 | 37.8 | 3.78 | 0.89 | 0.22 |
| SSP434 | 52.1 | 4.27 | 0.84 | 0.24 |
| SSP585 | 58.6 | 4.17 | 0.85 | 0.23 |

**Table S4: Similar to Table S2, but for total changes that include the methane induced changes. The numbers include the changes directly due to the hydrogen perturbation (Table S2) and the changes due to methane changes (Table S3) mapped by the methane flux per hydrogen flux (column 4 in Table S2).**

| | Flux H2 [Tg/yr] | Surf. conc. H2 per flux [ppb yr/Tg] | Surf. conc. CH4 per flux [ppb yr/Tg] | Flux CH4/Flux H2 [Tg CH4/Tg H2] | CH4 RF per flux [mW m-2 yr/ Tg] | ozone RF per flux [mW m-2 yr/ Tg] | Strat. H2O RF per flux [mW m-2 yr/ Tg] |
|---|---|---|---|---|---|---|---|
| antro01 | 0.10 | 6.27 | 1.11 | 0.30 | 0.43 | 0.44 | 0.23 |
| antro1 | 0.99 | 6.27 | 1.12 | 0.31 | 0.43 | 0.47 | 0.23 |
| antro10 | 9.90 | 6.28 | 1.12 | 0.31 | 0.43 | 0.47 | 0.23 |
| antro100 | 99.07 | 6.35 | 1.06 | 0.29 | 0.41 | 0.45 | 0.23 |
| epia | 0.99 | 6.05 | 1.01 | 0.28 | 0.39 | 0.41 | 0.19 |
| nemo | 0.99 | 7.92 | 1.29 | 0.35 | 0.50 | 0.52 | 0.25 |
| usdrydep | 0.99 | 5.20 | 0.92 | 0.25 | 0.36 | 0.38 | 0.18 |
| maxdep | 0.99 | 5.48 | 1.03 | 0.28 | 0.40 | 0.43 | 0.21 |
| munich | 0.99 | 6.32 | 1.08 | 0.29 | 0.41 | 0.44 | 0.21 |
| maud | 0.99 | 9.24 | 1.29 | 0.35 | 0.50 | 0.53 | 0.25 |
| zep | 0.99 | 6.69 | 1.06 | 0.29 | 0.41 | 0.43 | 0.20 |
| SSP119 | 9.90 | 6.36 | 1.12 | 0.30 | 0.43 | 0.48 | 0.24 |
| SSP434 | 9.90 | 6.53 | 1.26 | 0.30 | 0.49 | 0.43 | 0.25 |
| SSP585 | 9.89 | 6.42 | 1.33 | 0.32 | 0.51 | 0.45 | 0.25 |

**Table S5: The methane induced contribution to the $H_2$ GWP100 given as percentages [%].**

| | O3 CH4ind [%] | CH4 ind [%] | Strat H2O CH4ind [%] |
|---|---|---|---|
| anthro01 | 56.7 | 31.7 | 25.8 |
| anthro1 | 54.1 | 31.7 | 26.0 |
| anthro10 | 53.7 | 31.7 | 25.9 |
| anthro100 | 52.4 | 31.7 | 24.7 |
| epia | 55.1 | 31.7 | 27.3 |
| nemo | 55.6 | 31.7 | 27.0 |
| usdrydep | 55.1 | 31.7 | 27.2 |
| maxdep | 53.2 | 31.7 | 25.1 |
| munich | 54.9 | 31.7 | 27.2 |
| maud | 55.3 | 31.7 | 27.0 |
| zep | 55.5 | 31.7 | 27.5 |
| SSP119 | 54.2 | 34.0 | 27.2 |
| SSP434 | 57.7 | 41.6 | 28.7 |
| SSP585 | 60.2 | 40.3 | 30.2 |

**Table S6: Percent contribution to $H_2$ GWP100. The methane induced and direct effects of the GWP100 are combined.**

|          | O3   | CH4  | strat H2O |
|----------|------|------|-----------|
| anthro01 | 40.2 | 39.1 | 20.6      |
| anthro1  | 41.4 | 38.4 | 20.2      |
| anthro10 | 41.6 | 38.2 | 20.2      |
| anthro100| 41.8 | 37.5 | 20.7      |
| epia     | 41.4 | 39.1 | 19.5      |
| nemo     | 41.1 | 39.1 | 19.8      |
| usdrydep | 41.4 | 39.0 | 19.6      |
| maxdep   | 41.6 | 37.9 | 20.6      |
| munich   | 41.4 | 39.0 | 19.5      |
| maud     | 41.2 | 39.1 | 19.7      |
| zep      | 41.3 | 39.2 | 19.5      |
| SSP119   | 42.0 | 37.3 | 20.8      |
| SSP434   | 37.1 | 41.8 | 21.1      |
| SSP585   | 37.3 | 42.5 | 20.3      |

45 **Table S7: Methane GWP100 presented in Fig. 5.**

|          | present-day | SSP119 | SSP434 | SSP585 |
|----------|-------------|--------|--------|--------|
| O3       | 9.2         | 9.9    | 9.4    | 9.5    |
| CH4      | 15.7        | 16.3   | 18.4   | 18.0   |
| strat H2O| 2.1         | 2.5    | 2.7    | 2.6    |
| Total    | 27.0        | 28.6   | 30.5   | 30.0   |