Combining temperature rate and level perspectives in emission metrics

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1 Impact on natural systems

Additional comments to that given in Sect. 1 about the velocity of climate change is given here. According to Settele et al. (2014) , many species will not be able to keep track with climate change in the 21st. Among the species with lowest displacement capacity are herbaceous plants, trees, rodents, and primates.

2 Pulse metrics

It is well known that emissions of SLCFs give a strong and quick temperature response that decays fast, while emissions of LLGHGs give a more gradual temperature response that lasts for decades and centuries (e.g., Myhre et al., 2013). Figure S1(A) shows the temporal global temperature response due to pulse emissions of CO_2, N_2O, CH_4, and BC. A schematic view compatible with Figs. 1 and 2 is presented in Fig. S1(B). For pulse emissions, this simple calculation indicates that the maximum temperature ΔT occurs at 1 year for BC and 10 years for CH_4. In comparison, the LLGHGs CO_2 and N_2O have the maximum temperature increase occurring after about 22 and 26 years, respectively, and the perturbations last much longer. The timing of this peaking of the temperature change includes some uncertainty, as the metric parameterizations contain uncertainty, such as uncertainty in the IRF (Joos et al., 2013; Olivié and Peters, 2013).

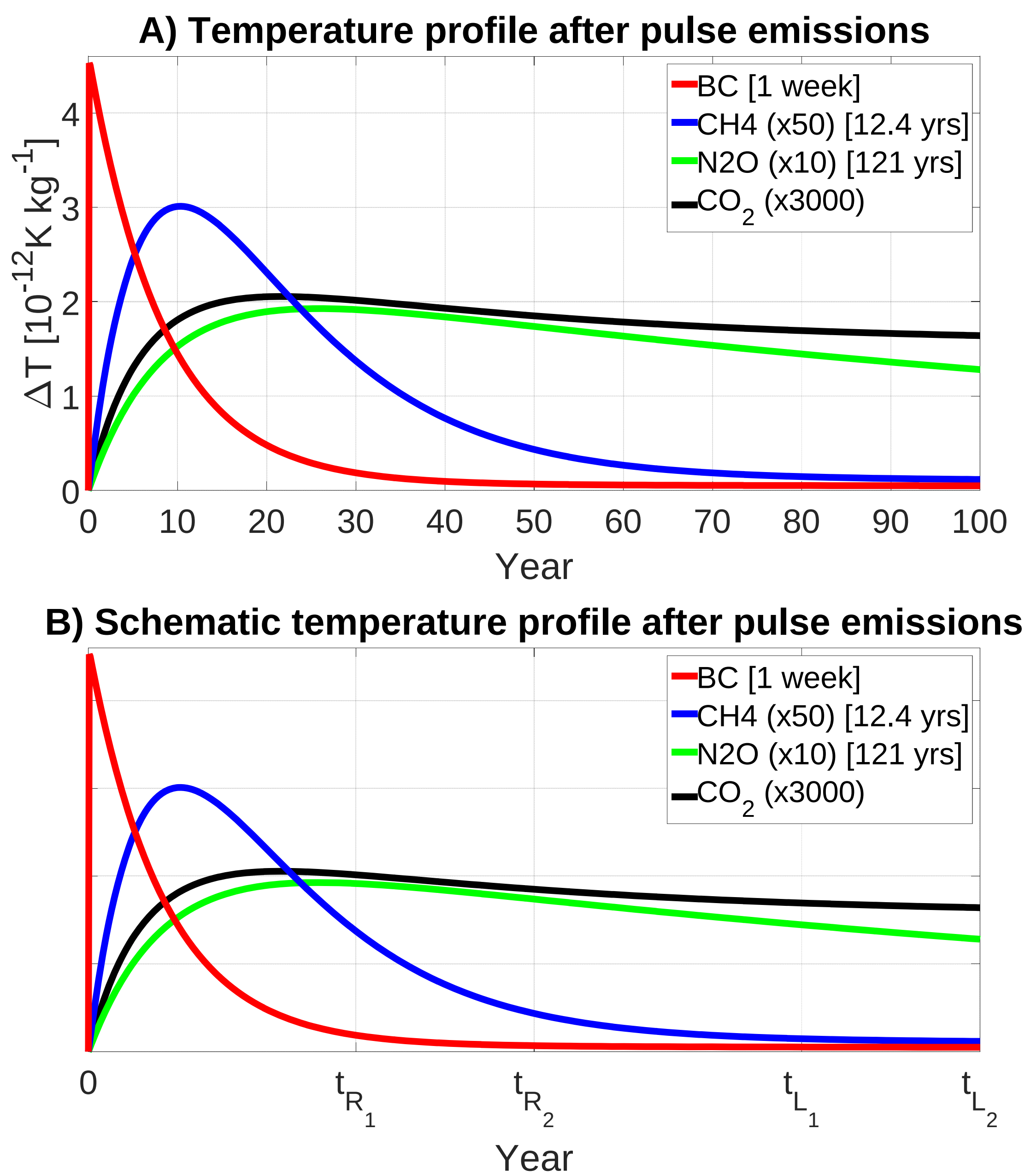

Figure S1: The global temperature perturbations due to pulse emissions for species (Myhre et al., 2013) representing atmospheric perturbation timescales from weeks to centuries are given in A. The emission pulse at year 0 is 1 kg for BC, 50 kg for CH_4, 10 kg for N_2O, and 3000 kg for CO_2. B gives a schematic view compatible with Figs. 1 and 2.

3 Global temperature change and RCPs

Historic and future temperature development according to the Representative Concentration Pathways (RCPs) (Collins et al., 2013) is shown in Figs. S2. Variability in the historic period shows that the decadal temperature change is not only governed by anthropogenic forcing, but also natural variability. Similarly, the future global and regional temperature trends will be determined by both anthropogenic emissions and natural variability in the climate system. The global temperature increase in the near future, the period 2016-2035 compared to 1986-2005, is by Kirtman et al. (2013) predicted to be in the 0.3-0.7 ^{0}C range, that is 0.1-0.23 ^{0}C/decade. Natural variability will sometimes increase and sometimes decrease the global temperature rate in the 21^{st} century. Regional variability may also give larger temperature rates locally than expected based on the global mean changes. In the near-term, the temperature increase in the mid-latitudes due to anthropogenic emissions will be similar to what is expected from natural variability, while in the tropics and subtropics, the anthropogenic emissions will quicker lead the climate system to a state outside of current natural variability (Kirtman et al., 2013). This natural variability add uncertainty to how adaptable ecosystems are (Diffenbaugh and Field, 2013).

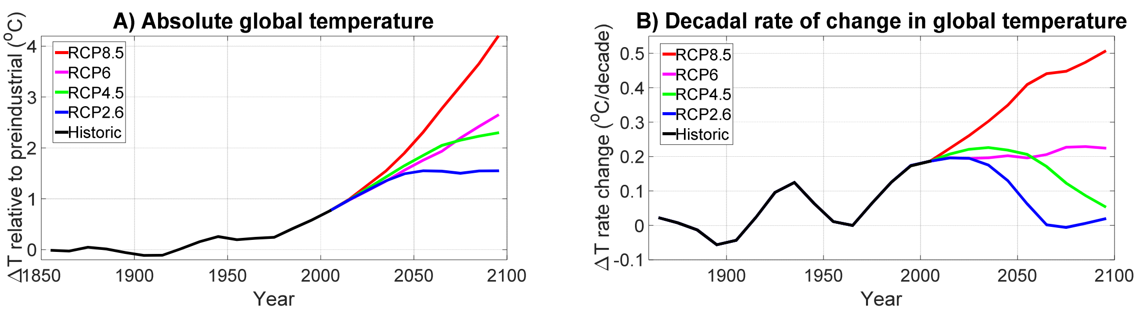

Figure S2: A: The historic and future global temperature change in the 21^{st} century according to the four RCPs (Collins et al., 2013). B: The smoothed decadal global temperature change for the same period and RCPs. Values are given for each decade, for instance the value in 2095 represents the difference in temperature between the period 2090-2099 and the period 2080-2089.

4 Overshooting

Level targets may be reached, although with a temporary temperature or radiative forcing peak above the long-term target, which is called overshooting. See Clarke et al. (2014) for an assessment of different emission pathways in the 21st century. Figure S3 presents the decadal global temperature change in scenario pathways that lead to CO_2 concentrations of 430-480 ppm and 530-580 ppm, for overshooting and non-overshooting, based on the AR5 WG3 Scenario database (Krey et al., 2014). The 430-480 ppm group equals to the RCP2.6. For the average of the 430-480 ppm group, overshooting leads to a maximum in the global temperature rate increase that is about 0.02 ^{0}C/decade larger than otherwise and a rate increase of more than 0.2 ^{0}C/decade lasting about a decade longer. The discrepancy is even larger in the 530-580 ppm case, with a maximum rate increase that is about 0.03 ^{0}C/decade larger and the period of temperature increase above 0.2 ^{0}C/decade lasting about 20 years longer.

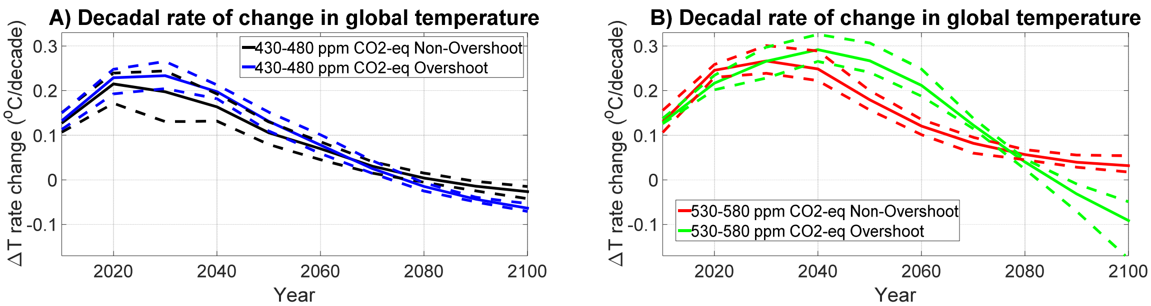

Figure S3: The rate in global temperature change in the 21st century according to pathways that approach either level targets directly or via a temporary overshoot. Solid lines give the average of the scenario pathways, while the dotted lines give the 25th to 75th percentile of scenario outcomes. The scenario pathways classified in the group 430-480 ppm equals to the RCP2.6 (A) and the group 530-580 ppm to a radiative forcing of 3.7 Wm^{-2} in 2100 (B). The figure is produced based on the AR5 WG3 Scenario database (Krey et al., 2014).

5 Different weighting of level and rate metrics

Figures 3(A), 3(C), and 3(E) present values for the rate metric, level metric, and a combined metric that weight the level and rate targets equally. In Fig. S4, other weighting factors (α) are also presented for CH_4, BC, and N_2O. The higher the α coefficient, the more is the combined metric value influenced by the rate metric.

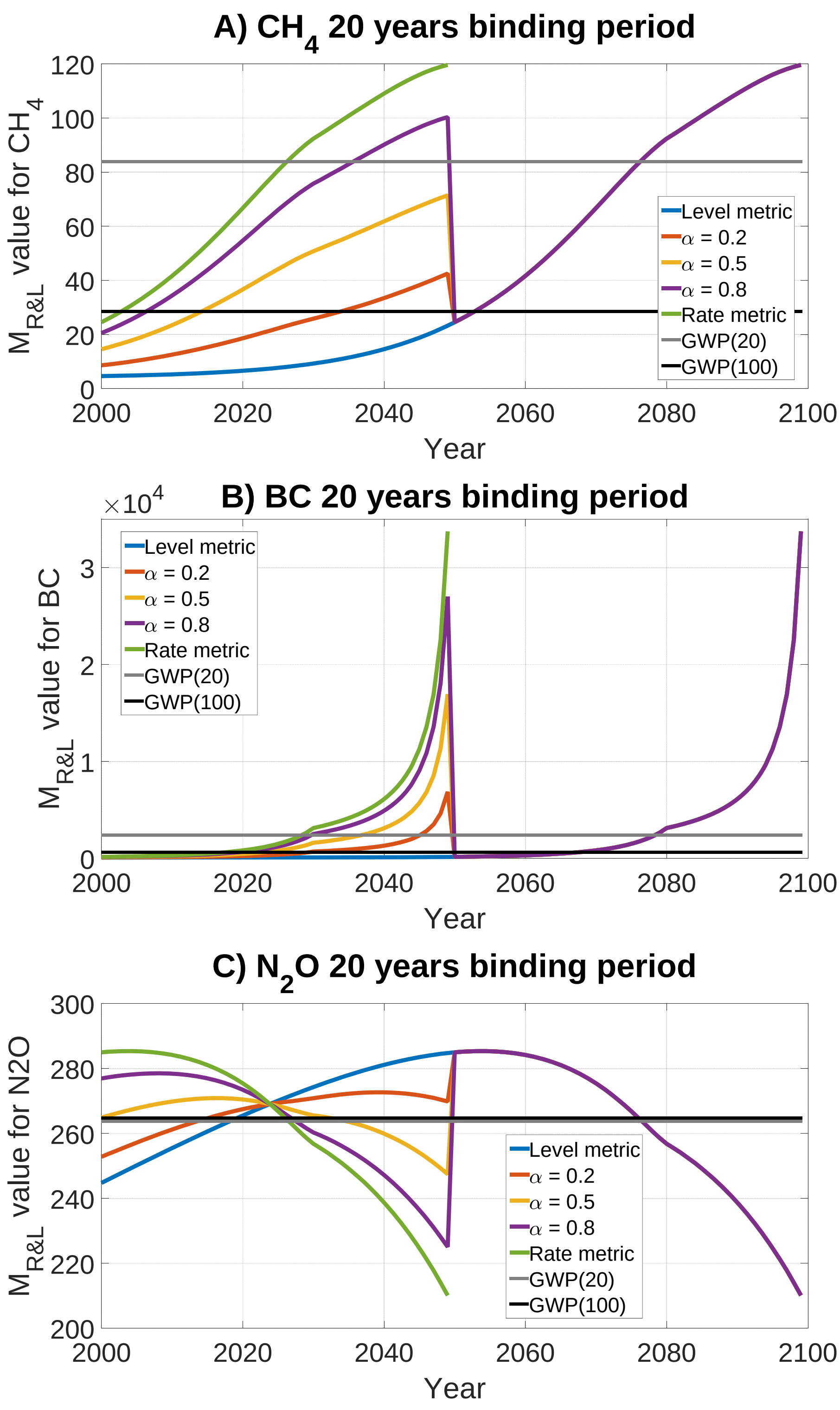

Figure S4: Metric values for the combined rate metrics for CH_4, BC, and N_2O given different weightings (α). The rate constraint is binding for the period 2030-2049, and the level reached in 2100, which is the same as in Figs. 3(A), 3(C), and 3(E). GWP(20) and GWP(100) values are given as reference.

6 Alternative combined metric

Figures 3(A), 3(C), and 3(E) present values for the combined metric. In Fig. S5, we present the same case with the alternative combined metric presented in Eq. (5).

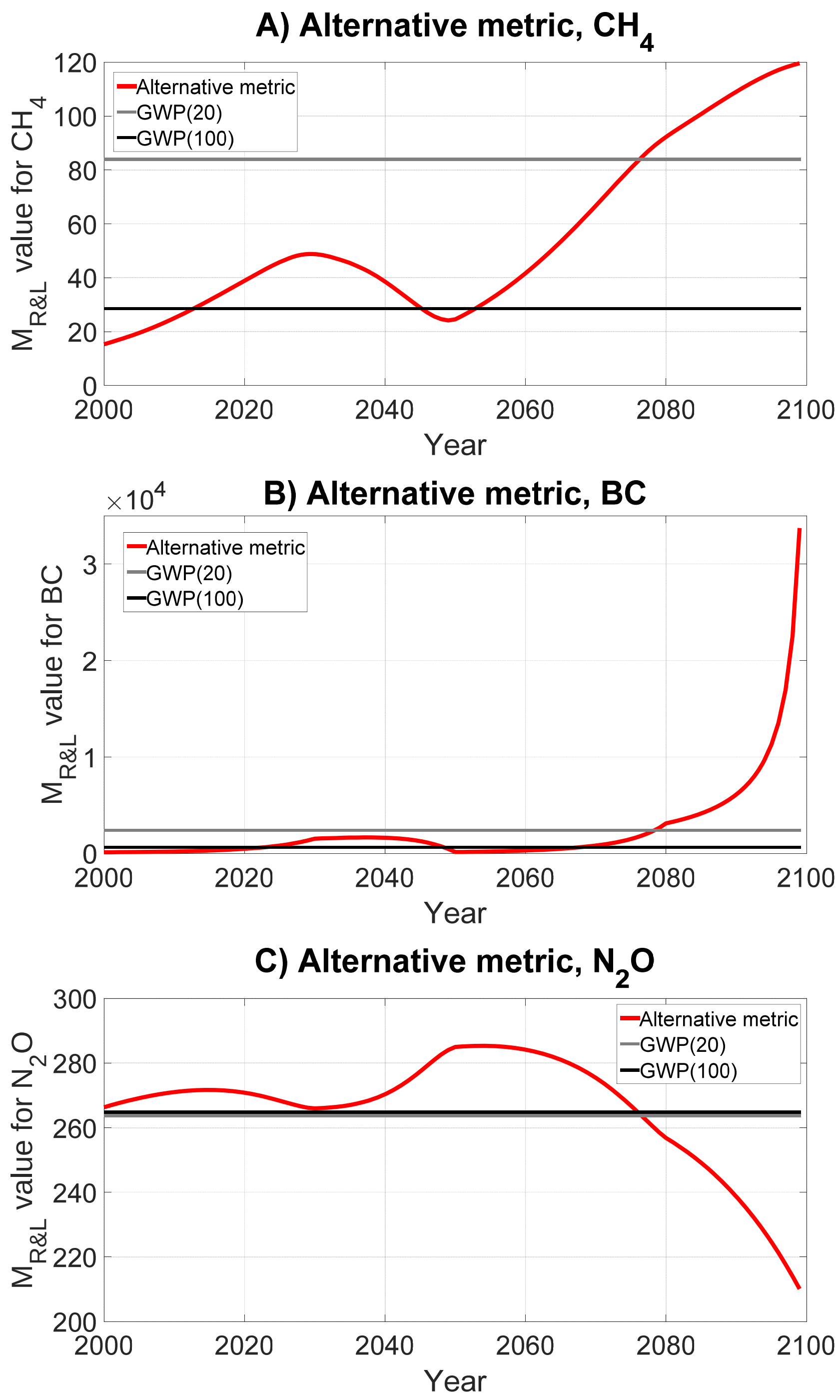

Figure S5: Combined metric values given the alternative formulation, Eq. (5). For comparison with our selected metric equation, see Figs. 3(A), 3(C), and 3(E).

7 Weighting global emissions

Figure 6 presents how global emissions of CO_2, N_2O, CH_4, and BC in 2008 are weighted according to the emission metric values given in Fig. 3. Here, we show how the emissions are weighted differently if we assume that these emissions occur in 2020, 2030, 2040, or 2049 (see Figs. S6(A), S6(B), S6(C), and S6(D)). Figures S6(E), S6(F), and S6(G) focus on the temporal change. In Figs. S6(E) and S6(F), emissions are assumed constant for the rest of the 21st century while applying the level metric and rate metric, respectively. The combined metric is used in Fig. S6(G) with varying emissions following the RCP6.0 (IPCC, 2013). In this emission pathway, the emissions of SLCFs (BC and CH_4) are reduced towards the end of the century while the emissions of LLGHGs (CO_2 and N_2O) are larger in 2100 than in 2008.

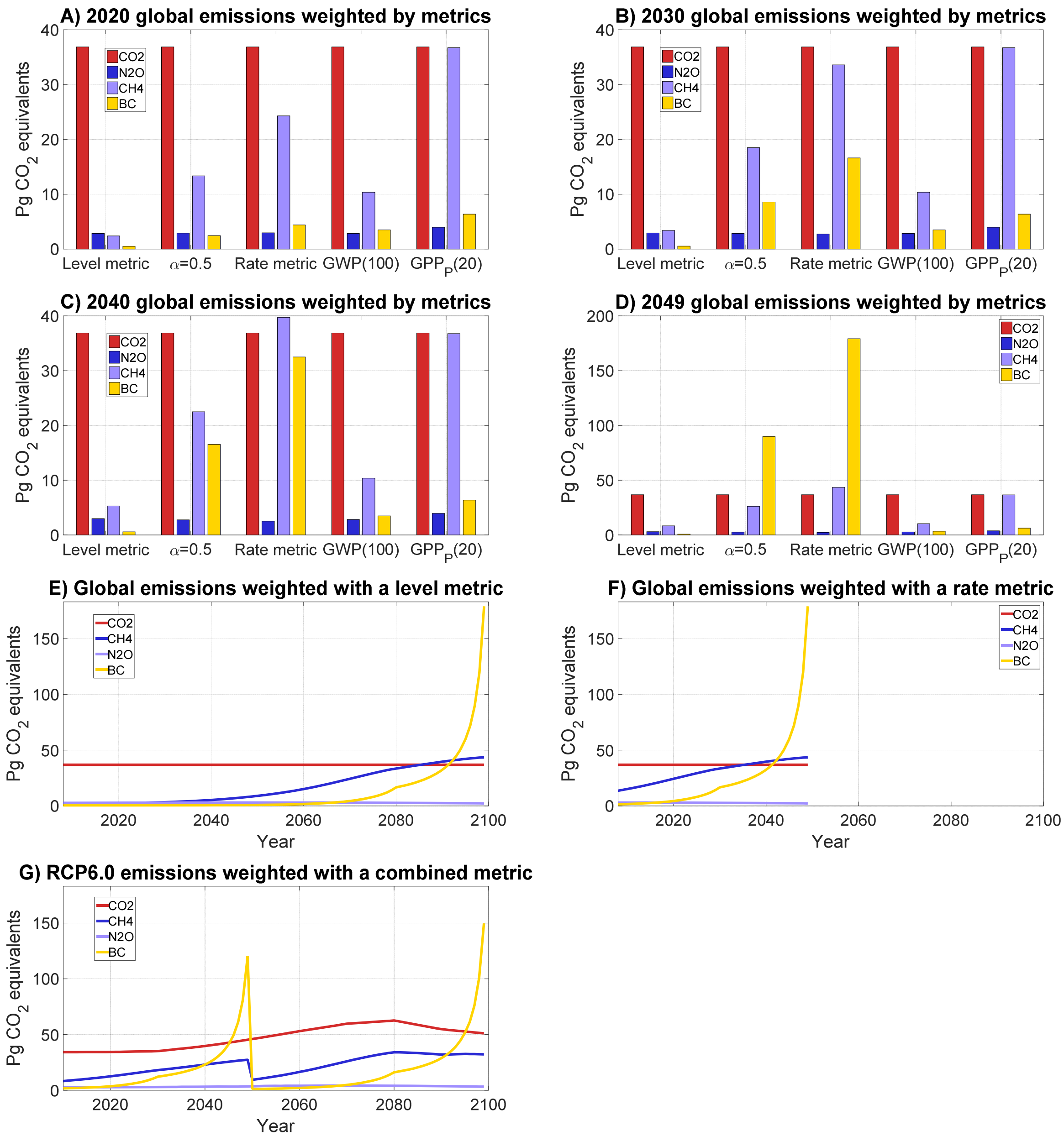

Figure S6: The weighted global emissions for different emission metrics and time horizons. Five different emission metrics are compared for global 2008 emissions occurring in 2020 (A), 2020 (B), 2040 (C), and 2049 (D). The calculations are based on Fig. 3, with the rate constraint binding for the 2031-2050 period and level reached for the 2081-2100 period. The level metric is here the same as α=0 and the rate metric equal to α=1. The combined metric is given with equal weight of α=0.5, while GWP(100) and $GPP_P(20)$ are shown for comparison. E and F show the temporal evolution based on the level metric and rate metric, respectively, while keeping the emissions constant at the 2008 level. G is based on global emissions according to the RCP6.0; thus, varying emissions until 2100.

8 Metric values based on RCPs

The article focuses on idealized examples of how the level, rate, and combined metrics can be applied. In the article, we shortly give some examples based on the RCPs. The RCPs are the most applied scenarios or pathways in the literature. Here are some illustrations of the metrics for CH_4 based on RCP4.5 and RCP8.5 (Fig. S7). For RCP4.5, a rate constraint of 0.2 ^{0}C/decade gives a binding rate metric until 2050. 0.15 ^{0}C/decade results in binding until 2070, and 0.1 ^{0}C/decade binding until 2080. The rate increase never reaches 0.25 ^{0}C/decade, thus, the total metric value in this case is only dependent on the level target. In RCP8.5, the rate constraint is binding towards the end of the century due to increasing rate of temperature increase. The 0.3 ^{0}C/decade threshold is reached in 2040, while increases of 0.4 ^{0}C/decade and 0.5 ^{0}C/decade starts occurring around 2050 and 2090, respectively. The target period for the temperature level is set to 2081-2100, which seems reasonable for RCP4.5, but not RCP8.5, given Fig. S2.

If RCP8.5 is applied (Fig. S7(B)), the combined metric is similar in shape as the level metric, just lifted. The earlier the start of the binding period of the rate constraint, the earlier the additional lift occurs. The later the binding starts, the smaller is the relative increase from a pure level metric. Metrics based on RCP4.5 are similar to those based on the baseline scenario presented in the article, but with slightly larger combined metric values in the beginning of the century as this period is rate constraint binding following RCP4.5, but not in the baseline scenario.

The paper selects 2081-2100 as the default target period for the level goal. If emissions follow RCP6.0 or RCP8.5, the temperature increase by the end of the 21st century will not have slowed down and is over 0.2 ^{0}C/decade and 0.5 ^{0}C/decade, respectively (see Fig. S2(B)). These trends indicate that temperature peaking will occur after 2100 and may warrant a time horizon for the level target sometime after 2100. Another viewpoint is a focus on limiting the global warming to 2 ^{0}C and applying a time horizon when this target is met (Joshi et al., 2011) regardless of whether the global temperature is predicted to continue its increase afterwards. In that case, 2 ^{0}C does not represent a level. Temperature increases of 3 ^{0}C, 4 ^{0}C, or some other value could also be defined as a target level for the level metric.

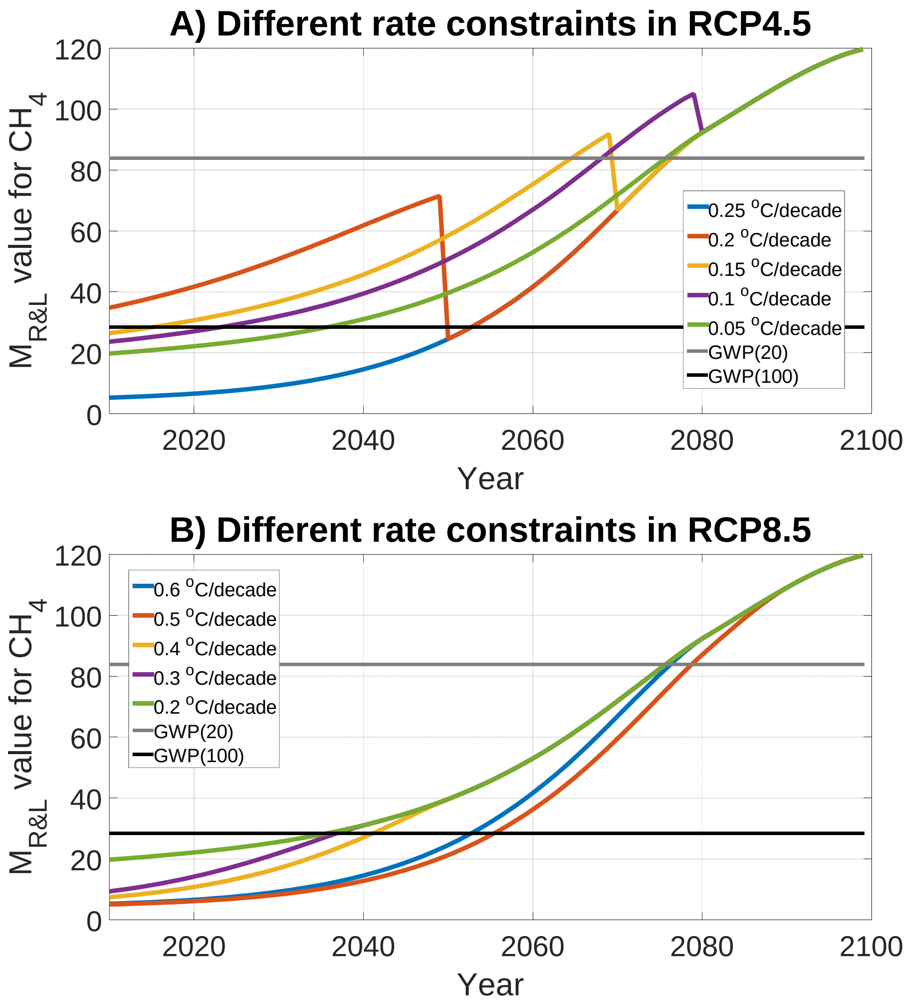

Figure S7: Combined metric values for CH_4 for RCP4.5 (A) and RCP8.5 (B) given an equal weight of rate and level metrics (α=0.5) for different rate constraints, indicated by the temperature rate increase per decade. 2081-2100 is set as the level target period. GWP(20) and GWP(100) values are given as reference.

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