Global methane pledge versus lower CO_2 emissions

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Abstract

Methane (CH_4) is a potent greenhouse gas whose contribution to anthropogenic radiative forcing of the climate system is second only to carbon dioxide (CO_2). CH_4 emission reduction has become central to global climate mitigation policy, resulting most notably in the Global Methane Pledge (GMP), pledging a 30% reduction of CH_4 emissions by 2030. Methane is, however, much shorter-lived in the atmosphere than CO_2, so emissions reductions may have different impacts on global warming over time. We quantify the difference over time in global annual mean surface temperature of the GMP versus the equivalent amount of CO_2 emission reduction. The avoidance of CH_4 emissions in the 2020s due to the GMP initially results in greater relative cooling than the avoidance of the equivalent amount of CO_2 emissions over the same period, but less relative cooling after ~2060, when almost all CH_4 emitted during the 2020s has been removed from the atmosphere but much of the CO_2 emitted during the 2020s remains. However, the GMP placing the world on a lower CH_4 emissions trajectory after 2030 results in a persistently and substantially greater reduction to global warming than the equivalent change in the CO_2 emissions trajectory, with a maximum difference of 0.22 ± 0.06°C in 2055 and relative cooling for well over a century. This equates to a large difference in avoided climate change damages. While the greatest reduction in warming is obtained by reducing both CH_4 and CO_2 emissions, our results underscore the striking global societal benefits of sustained reduction in CH_4 emissions.

Mitigation of climate change is principally achievable by reducing emissions of greenhouse gases. The two greenhouse gases primarily responsible for anthropogenic radiative forcing of the climate system to date are carbon dioxide (CO_2) and methane (CH_4) [1]. In recent years there has been an increased focus on methane emission reduction. This is because of methane's large greenhouse effect per molecule, because an appreciable fraction of this emission reduction can be achieved revenue-neutrally e.g. by sealing holes in gas pipelines, and because reduction in methane emissions may help offset anticipated decreases in short-lived cooling aerosol emissions as the world transitions to a zero-carbon economy. The focus on methane emission reduction has most notably resulted in the Global Methane Pledge (GMP), whereby over 100 countries committed at COP26 to reduce global methane emissions 30% by 2030, from 2020 levels. By COP27 the number of countries committed to the GMP increased to over 150.

While the GMP is a laudable global climate policy commitment, the relative benefits of CH_4 versus CO_2 emission reduction have not yet been quantified. Given that methane has an atmospheric lifetime of <12 years whereas CO_2 is much longer-lived in the atmosphere [1], the global temperature reduction benefits over time of emissions reductions of these two greenhouse gases may be quite different. It is thus critical to understand the relative impacts of the emissions reductions in each over time.

Here we quantify the difference over time in global annual mean surface temperature (T [°C]) resulting from GMP-like CH_4 emission reduction versus the equivalent reduction in CO_2 emissions. Our analysis is based on a widely used simple climate model [2] with parameters calibrated to mimic the response of more complex Earth System Models (see

Methods in Supporting Information, SI). We use a large ensemble of simulations to quantify uncertainty related to the climate system's response to different emissions trajectories. This approach thereby estimates how state-of-the-art climate models would differentiate the effects of CH_4 versus CO_2 emission reduction in the 2020s and beyond. We superimpose a GMP-like reduction in CH_4 emissions on different emissions time-series from Shared Socioeconomic Pathways (SSPs), using SSP2-4.5 as our baseline. We also superimpose the equivalent CO_2 emission reduction, using the conversion factor that the global warming potential (GWP) of CH_4 on a 20-year timescale is 82.5 times that of CO_2 [1]. This corresponds to a 21% reduction in global CO_2 emissions by 2030 from 2020 levels. (We also try different conversion factors (SI).) For each greenhouse gas, we consider a linear decrease in emissions from 2020 levels down to a 30% reduction in CH_4 emissions, or the equivalent CO_2 reduction. We then consider either that emissions return to what they would have otherwise been in 2031 and thereafter, in order to isolate the effect of the emissions avoided in the 2020s, or that emissions of either greenhouse gas follow the same relative emissions reductions in 2031 and thereafter as they would otherwise, in order to quantify the effect of an emissions reduction strategy changing the pathway of emissions over time (Figure 1, top). In other words, in the second case, if CH_4 emissions reduce in a given year after 2030 by a given percentage in a given SSP, we specify that CH_4 emissions decrease by the same percentage in the same year, just starting from a lower level. Both of these scenarios after 2030 are idealised and somewhat artificial, but allow us to explore the temperature effects of emissions reductions in the 2020s alone, and the longer term benefits of altering the emissions pathway. We also consider simultaneous emission reduction in both greenhouse gases combined, i.e. the above emissions reductions in both CO_2 and CH_4 at once. For a given SSP we thus test seven scenarios: the control and the CH_4, CO_2 and combined emissions reductions in the 2020s alone as well as continuing beyond 2030. We compare the T trajectories resulting from the different emissions trajectories, and also translate these into climate-change-related damages to the global economy avoided by emissions reductions using standard economic formulas (SI) [3, 4].

As expected from the short atmospheric lifetime of methane, the benefits of global temperature reductions of methane emissions in the 2020s alone are short-lived (Figure 1, middle and bottom). GMP-like CH_4 emissions reductions result in less warming initially, with a maximum difference of 0.06($\pm$0.01°C; $\pm$ herein refers to half the 66% range, corresponding approximately to $\pm$1 standard deviation) in 2034 ($\pm$1 year). As methane is rapidly removed from the atmosphere but CO_2 persists, however, the warming in the CH_4 emission reduction scenario equals that of the equivalent CO_2 reduction scenario by 2057 ($\pm$3 years). By the end of the century, the CO_2 emissions reduction scenario results in less warming by 0.016$\pm$0.005°C. This latter difference is because nearly all CH_4 emitted in the 2020s has been removed from the atmosphere by natural processes by 2100, regardless of the amount of those 2020s emissions; in contrast, much of the CO_2 emitted in the 2020s will persist in the atmosphere in 2100. In essence this illustrates that CH_4 emission reductions have a more powerful short-term effect, but that this effect is not as long-lasting.

However, reducing emissions over a given decade benefits long-term climate mitigation not only by avoiding emissions in that particular decade, but also by placing the world on a lower-emissions trajectory thereafter. The long-term benefit of the GMP will be to reduce CH_4 emissions compared to what they otherwise would be beyond 2030, yielding persistent

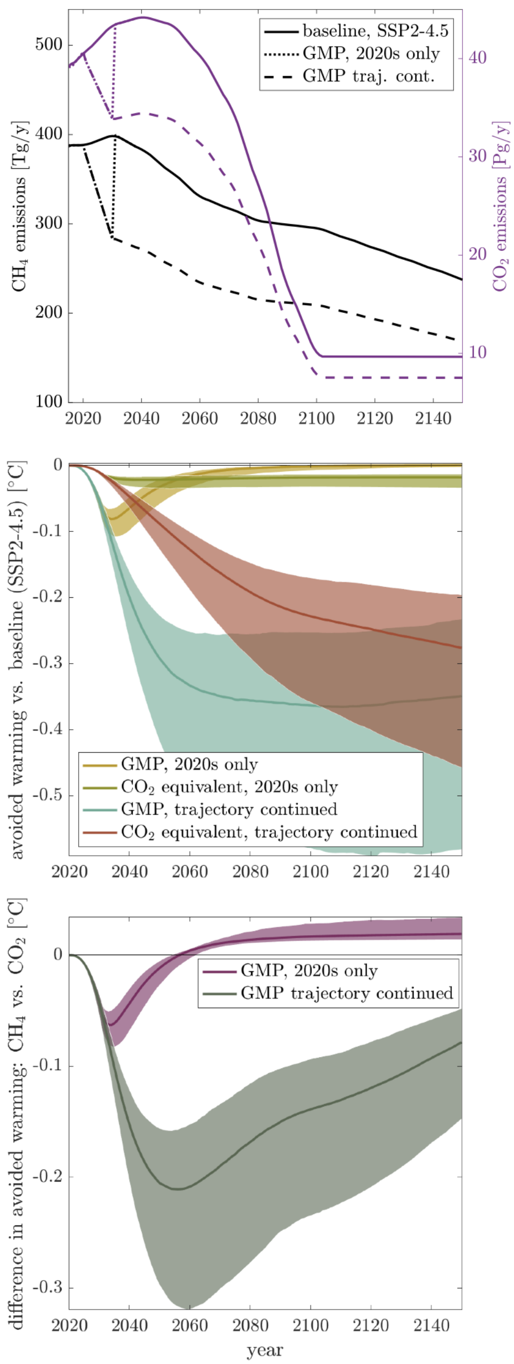

Figure 1: Top: CH_4 (black) and CO_2 (purple) emissions under the baseline case (solid) SSP2-4.5, the global methane pledge or equivalent CO_2 emissions reductions in the 2020's only (dotted), or the continuation of this emissions trajectory after 2030 (dashed). The dotted lines follow the solid lines after 2030. Middle: avoided warming (i.e. temperature minus baseline case) for CO_2 and CH_4 emissions reductions in the 2020s only and continued after 2030. Bottom: the global annual mean surface temperature in the CH_4-emission-reduction scenario minus that of the equivalent CO_2-emission-reduction scenario for just the emission reductions in the 2020s (purple) and the continuation of these emissions trajectories after 2030 (green). For middle and bottom, solid lines correspond to the median; shaded area corresponds to the 10th–90th percentile.

benefits. In contrast to the short-lived gains from methane emissions avoided in the 2020s, the benefits of altering this CH_4 emission path are strikingly persistent and large (Figure 1 bottom, green line and shading). Following the GMP and then afterwards following the same relative reductions in CH_4 emissions as specified in SSP2-4.5 produces a much greater, persistent reduction in global warming than doing the same for equivalent CO_2 emissions. The maximum difference occurs in 2056 (±3 years), with 0.21±0.06°C less global warming in the CH_4 emissions reduction scenario. The greatest reductions to global warming are of course when both CO_2 and CH_4 are reduced simultaneously, however; following both the GMP-like emissions reductions in CH_4 and the equivalent CO_2 emissions reductions (Figure 1, top) results in a further 0.11±0.08°C reduction in global warming in 2056. Notably, the CH_4 emission reduction results in less global warming for well over a century. This effect is similar but exacerbated when considering GWPs on longer timescales, e.g. the 100-year GWP of CH_4 is 40, roughly half of its 20-year GWP of 82.5. Even a 30% reduction in CO_2 emissions by 2030 from 2020 levels, corresponding to a 117:1 ratio of CO_2 to CH_4 emission reduction (consistent with using a 10-year GWP timescale for CH_4) reduces global warming less than the GMP-like 30% reduction in CH_4 emissions until 2129 (±5 years), with a maximum difference of 0.17±0.04°C in 2051 (±2 years). The persistent relative benefits of CH_4 emission reduction are therefore simply due to its greater short-term potency. These differences are robust across SSPs, and correspond to $10±5Trn in additional climate change damages avoided using middle-of-the-road economic assumptions (i.e. a 2% discount rate and the preferred non-catastrophic damage function from the meta-analysis in [3]), varying from $3.5±1.8Trn to $15±8Trn under different economic assumptions (Methods).

The emissions trajectories explored here are of course highly idealised scenarios – the global methane pledge does not commit global methane emissions to decrease linearly over the 2020s; after the global methane pledge, emissions will surely not return in 2031 to what they otherwise would have been; and some fractions of different greenhouse gases' emissions are more challenging to reduce than others, such that the same relative decreases in 2031 and beyond with or without the global methane pledge or its carbon dioxide equivalent are not equally achievable or plausible. Nonetheless these scenarios do allow us to compare the global temperature effects over time of different emissions reduction strategies. Successfully mitigating climate change to meet the Paris agreement will require a mixture of strategies including the reduction of both methane and carbon dioxide emissions, with emissions reductions providing greater benefits the larger they are and the sooner they occur; carbon dioxide emissions will always play a central role in any suite of climate mitigation policies. These results underscore the complementary role that methane emission reduction can play, and how much of a reduction in global warming can be achieved by altering the methane emissions trajectory along the lines of the global methane pledge. We hope that in future work, the effects of reducing different greenhouse gases' emissions can be compared via intercomparison of simulations using more complex Earth System Models, including the investigation of spatial differences and interannual variability.

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Extended Methods

We rely on the widely-used two-layer model [2] to simulate the climate system response to anthropogenic forcing:

$$c\ dT/dt = F + \lambda T - \gamma(T - T_D), \qquad c_D\ dT_D/dt = \gamma(T - T_D)$$

where T [K] is the Earth's global mean surface temperature, F [W/m^2] is anthropogenic radiative forcing, c [J/m^{2}K] is the heat capacity of the active surface layer of the climate system whose temperature is represented by T, λ [W/m^{2}K] is the climate feedback, and T_D [K] is the temperature of a deep ocean layer with heat capacity c_D [J/m^{2}K] and with which the surface layer mixes heat diffusively at a rate determined by the mixing coefficient γ [W/m^{2}K]. This physical model is widely used in integrated assessment modelling [7]. To quantify uncertainty in the response of the climate system to different forcing scenarios, we generate an ensemble of 10,000 parameter quadruplets $(c, c_D, \lambda, \gamma)$ by taking the parameter estimates of this model tuned to match the response of 30 CMIP6 Earth System Models (`https://github.com/mark-ringer/cmip6`, accessed 14.11.2022), estimating the mean and covariance properties of the parameters from the mean and covariance of these 30 parameter combinations, and sampling 10,000 parameter combinations from a multivariate Gaussian distribution with the same mean and covariance. Using the CMIP5 model parameter estimates in [5] did not change our conclusions.

We take our control F and CO_2 and CH_4 emissions and concentration time-series from the Reduced Complexity Model Intercomparison Project [6]. We use SSP2-4.5 as our baseline scenario, but perform the same calculations for SSP1-2.6 and SSP3-7.0 to explore the sensitivity of our results to SSP scenario. Results are very similar for different SSPs and results from SSPs other than SSP2-4.5 are therefore not discussed further. We find non-CO_2-non-CH_4 radiative forcing in each case by subtracting the CO_2 and CH_4 forcing from the total F, and add these forcings to all CO_2 and CH_4 forcing in all cases without further alteration. We relate CO_2 and CH_4 concentrations to forcing by fitting the forcing ϕ vs. concentration κ values from all scenarios and years with functions of the form $\phi = p_1\kappa^{p_2} - p_3$, which results for both CO_2 and CH_4 in an $r^2 > 0.9999$ and a root-mean-square-error of <0.0025 W/m^2. We then generate CO_2 and CH_4

concentration time-series based on different emissions pathways, and translate these into total F. For all CO_2-reduction scenarios, from these emission and concentration time-series we compute the fraction of cumulative emitted CO_2 that remains in the atmosphere as a function of time under each SSP, and assume that this does not change with the adjustments to total CO_2 emissions considered. In other words, if 50% of cumulative emitted CO_2 is in the atmosphere at a certain year for a certain SSP, reducing the CO_2 emissions in that year by 1PgCO_2 will result in 0.5PgCO_2 less CO_2 in the atmosphere. This assumption is justified by the fact that we are interested in enough perturbations to total overall emissions small enough not to appreciably change the air-sea-land-balance of anthropogenic carbon.

For each SSP we consider two forms each of CO_2 and two forms of CH_4 emission reduction. CH_4 emissions are reduced linearly from 2020-2030 by a final total of 30%, and CO_2 emissions are reduced by the same amount multiplied by the 20-year global warming potential (GWP) value of CH_4 of 82.5 [1]. Using other GWP timescales, e.g. 100-years, changed the results quantitatively as expected; GWPs over different timescales are calculated using the standard definition [1]. CH_4 emissions are either then returned to the same emissions after 2030 in order to isolate the effect of the avoided emissions in the 2020s, or continue on the same relative trajectory thereafter to quantify the effect of changing the emissions trajectory. In other words, in the latter case, an $X\%$ emission reduction in 2040 in the baseline SSP would correspond to the same $X\%$ emission reduction in 2040 in the GMP-continued-trajectory scenario, where 2040 CH_4 emissions are reduced by 30% relative to the baseline due to emissions reductions in the 2020s. In the corresponding CO_2 emissions reduction scenario, CO_2 emissions are reduced in the same relative amount each year to the baseline SSP CO_2 emissions in the same way. If emissions reach zero at any year under any scenario, the emissions trajectories with and without emissions reductions in the 2020s are the same thereafter.

For each CO_2 emission reduction scenario and SSP, we i) release the emissions of CO_2 each year to the climate system, ii) partition $f(t)$ of this previously stored CO_2 into the atmosphere, iii) determine the difference in CO_2 in the atmosphere each year in this case versus the baseline SSP scenario, and iv) subtract this difference from the baseline SSP scenario's atmospheric CO_2 concentration. For each CH_4 emission reduction scenario and SSP, we i) release the emissions of CH_4 each year to the atmosphere, ii) remove CH_4 from the atmosphere according to simple exponential decay with an atmospheric lifetime of 11.8 years [1], iii) determine the difference in CH_4 in the atmosphere each year in this case versus the baseline SSP scenario, and iv) subtract this difference from the baseline SSP scenario's atmospheric CH_4 concentration. These concentrations are then converted into F time-series, and Eq. 1 is then forced with these F time-series to determine $T(t)$. F time-series start at 1750 and we initialize Eq. 1 with $T(1750) = T_D(1750) = 0$.

For the economic calculations, we use a 2020 global purchasing-power-parity-adjusted global domestic product of 85 trillion USD as reported by the World Bank (`https://data.worldbank.org/indicator/NY.GDP.MKTP.CD`, accessed 14.11.2022). We use a baseline discount rate $r = 2\%$ as in [4], which reflects a combination of the pure rate of time preference ρ, the elasticity of the marginal utility of consumption η, and an underlying rate of consumption growth g according to $r = \rho + \eta g$; we also assess sensitivity to discount rate by performing the same calculations with $r = 1\%$ and $r = 3\%$. We use the damage function that the percentage of global gross domestic product lost as damages to climate change D [%] is equal to $D = 0.7438T^2$. This was identified as the preferred model for non-catastrophic damages in a meta-analysis [3]; it is also the median damage function, over 0-6°C, of the damage functions considered therein. We also assess sensitivity to discount rate by performing the same calculations with higher and lower damage functions of $D = 1.145T^2$ and $D = 0.267T^2$ from the same meta-analysis, which correspond respectively to including catastrophic damages and productivity loss or to more optimistic assumptions about the nature of climate change impacts on the global economy.

References

[1] V. Masson-Delmotte et al. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 2021.

[2] Jonathan M Gregory. "Vertical heat transports in the ocean and their effect on time-dependent climate change". In: *Climate Dynamics* 16.7 (2000), pp. 501–515.

[3] Peter H Howard and Thomas Sterner. "Few and not so far between: a meta-analysis of climate damage estimates". In: *Environmental and Resource Economics* 68.1 (2017), pp. 197–225.

[4] Kevin Rennert et al. "Comprehensive evidence implies a higher social cost of CO2". In: *Nature* 610.7933 (2022), pp. 687–692.

[5] Nicholas J Lutsko and Max Popp. "Probing the sources of uncertainty in transient warming on different timescales". In: *Geophysical Research Letters* 46.20 (2019), pp. 11367–11377.

[6] Zebedee RJ Nicholls et al. "Reduced Complexity Model Intercomparison Project Phase 1: introduction and evaluation of global-mean temperature response". In: *Geoscientific Model Development* 13.11 (2020), pp. 5175–5190.

[7] Raphael Calel and David A Stainforth. "On the physics of three integrated assessment models". In: *Bulletin of the American Meteorological Society* 98.6 (2017), pp. 1199–1216.