Methane

How does it compare to CO_2, how is it reported, and what does this mean for limiting global warming?

FAQ

The Agile Initiative
May 2025

About this document

This frequently asked questions (FAQ) document was written by John Lynch and Xiao Zhang (researchers at the Agile Initiative, University of Oxford), with feedback from Patrick Savage of the Department of Agriculture, Environment and Rural Affairs of Northern Ireland (DAERA) and editorial input from Heather Stallard (Agile Initiative).

This document builds on work done for the Agile Sprint project "How can we manage uncertainties in habitat greenhouse gas emissions?" and was supported through the Agile Community Impact Acceleration Fund. It is intended to provide an explanation of how and why carbon dioxide and methane differ, and explore some of what this could imply for climate policy, particularly in relation to agriculture. Many of the questions explored here are of interest to farmers, land managers and others working in food and agriculture, but we hope the document will prove informative and useful for anyone interested in the topic.

The Agile Initiative at the Oxford Martin School (funded by the Natural Environment Research Council) aims to transform how research responds to the needs of policymakers through timely, policy-oriented research Sprints that focus on critical environmental issues.

Suggested citation:
Lynch, John & Xiao Zhang. 2025. "Methane: How does it compare to CO_2, how is it reported, and what does this mean for limiting global warming?" Agile Initiative, University of Oxford. Oxford, UK. https://www.agile-initiative.ox.ac.uk/wp-content/uploads/2025/05/FAQ_Methane.pdf

Questions

Glossary

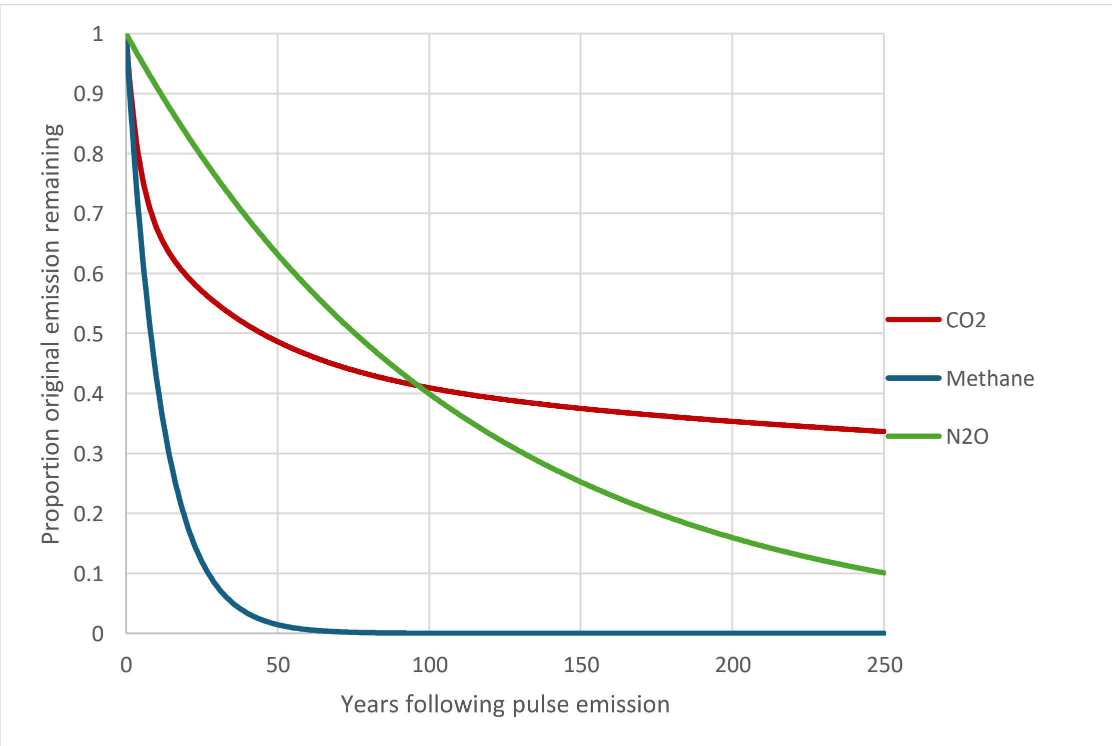
CO_2e:	Carbon dioxide equivalent
CO_2we:	Carbon dioxide warming equivalent
GWP100:	100-year Global Warming Potential
GWP*:	Global Warming Potential-star
CH_4:	Methane
CO_2:	Carbon dioxide
N_2O:	Nitrous oxide

1. How long does methane last in the atmosphere and how does this compare to carbon dioxide?

Soon after we emit any methane into the atmosphere, it reacts and starts to break down. Just over a decade after a large methane emission, around 50% will no longer be present (see figure). Methane warms up the atmosphere a lot, but then breaks down into substances with a lower impact (see Q.2).

Carbon dioxide, on the other hand, can persist in the atmosphere, as it is a stable gas that does not decay into other compounds. CO_2 can leave the atmosphere when it gets absorbed into 'carbon sinks' on land and in oceans. For example, it can be fixed in additional plant growth, enter soil carbon, dissolve in the sea, and eventually become stored in rocks such as limestone. These processes are complex, with some of these sinks only able to absorb atmospheric carbon slowly, or only able to absorb a limited amount of it. Of a tonne of CO_2 emitted today, around 40% will remain in the atmosphere after 100 years, but the rate of removal slows down greatly after that, and a significant proportion will persist and continue to contribute to warming for multiple thousands of years.

The figure below shows how CO_2, methane and N_2O in the atmosphere declines over time:



Nitrous oxide (N_2O) is another key greenhouse gas associated with agriculture, mostly arising from application of nitrogen fertilisers (both natural and synthetic). Nitrous oxide is also chemically broken down in the atmosphere, like methane, but after a much longer time: its average lifetime is just over a hundred years. So although nitrous oxide is still quite different from CO_2, it is not 'short-lived' in the way that methane is, and so most of the implications around methane noted in the questions below do not apply for nitrous oxide (at least in understanding global warming over the next few decades).

2. Does methane break down into carbon dioxide?

Yes, methane naturally breaks down primarily into carbon dioxide and water.

Does this mean that methane is part of a natural carbon cycle?

Our methane emissions come from different sources:

fossil methane (natural gas) and biogenic methane (agriculture, landfills)

Fossil methane, in common with coal and oil, was previously locked underground, before we extracted it to burn for energy. Some of the methane gas we extract for this purpose leaks out, contributing to increases in atmospheric methane. When this breaks down into CO_2, this represents an addition of CO_2 to the atmosphere, raising concentrations and therefore contributing a further, long-term warming effect associated with the fossil methane, even after the methane itself has broken down.

Biogenic methane is a part of shorter-term cycle. Plants photosynthesize, using sunlight to convert atmospheric CO_2 into organic matter ('biomass'). Cows and sheep (ruminant animals) consume these plants. Some of the plant biomass is converted into methane by microbes living in the ruminants' digestive systems, or in manures, which is then emitted to the atmosphere, increasing methane concentrations. When this methane breaks down into CO_2, we do not have to consider the CO_2 as 'additional' to the atmosphere, as it completes the cycle that began when the plant originally fixed CO_2.

However, this does not mean that the *methane* itself can be ignored as a 'natural' emission that does not add to global warming. Since methane takes time to decay, it does still contribute a significant amount of warming before it breaks down. Sustained agricultural methane emissions mean a large amount of methane staying in the atmosphere – concentrations are continuously 'topped up' by ongoing emissions balancing these automatic removals – and so cause a continued contribution to global warming (see questions 4 and 5).

There are also different views on how 'natural' the cycle is when it involves livestock. If we didn't have ruminant livestock, instead of CO_2 being fixed into grass, eaten then converted to methane, *monogastric* animals (those with a single stomach), would cycle plant biomass back to CO_2 *without* the highly warming methane 'step'. As well, without ruminant livestock in a given area, trees and shrubs could overtake grassland, likely meaning that a greater (though still finite) amount of carbon would be stored in plant biomass, reducing atmospheric CO_2. It is occasionally argued that to some degree, livestock may just be displacing the wild ruminants who would have contributed to the same cycle. However, humans have greatly increased the overall amount of grassland area and the amount of biogenic methane in the atmosphere, thus contributing to much more warming than in the truly 'natural' system.

3. What impact is methane having on global temperatures?

Methane is a greenhouse gas which traps energy from the sun in the Earth's atmosphere: this results in global warming. Overall, methane has the second largest warming impact (behind CO_2). In their most recent assessment, the Intergovernmental Panel on Climate Change (IPCC) estimate that methane was responsible for around 1/3 of the total increase in global temperature due to human activities (see: https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers/figure-spm-2).

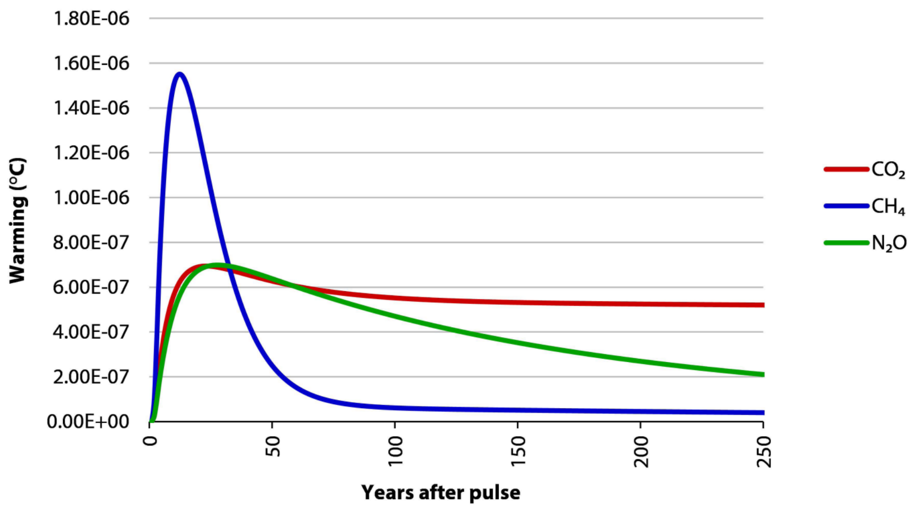
On top of this, methane emissions continue to increase, meaning the quantity of methane in the atmosphere also increases, and so does the amount of warming caused. To successfully mitigate climate change and keep global warming within agreed upon temperature thresholds, it will be essential to limit methane emissions.

4. Do methane and CO_2 contribute to global warming in the same way?

Methane and CO_2 are both greenhouse gases and both contribute to warming the planet.

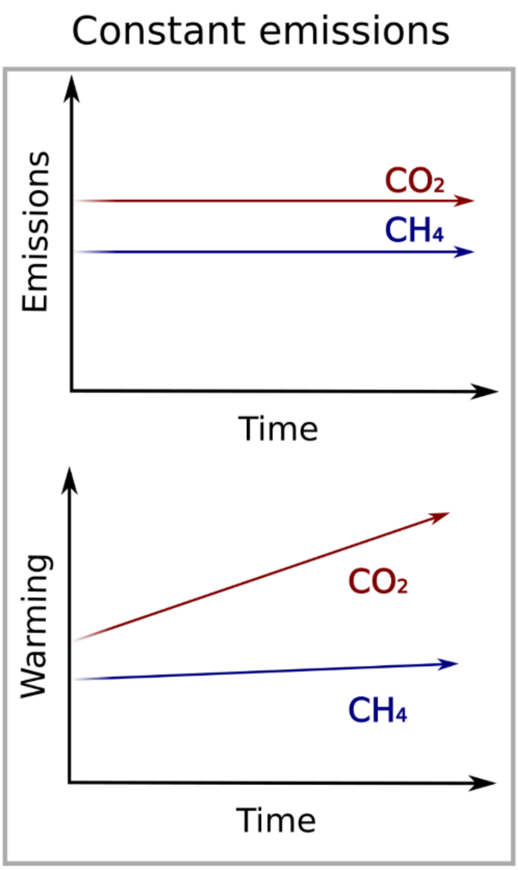
There are aspects in which the gases differ, however. Methane is a stronger greenhouse gas than CO_2: for the same increase in atmospheric concentration, methane will have a stronger effect in trapping energy and warming the Earth. But because methane also has a much shorter lifespan, after the gas is emitted, it gradually breaks down, and the lower its warming impact becomes. For CO_2, the warming caused by emissions persists into the very-long term, causing quite a stable amount of warming.

So for 'one-off' emissions of the different gases, the warming over time will change, as illustrated in the figure below, reproduced from the UK Committee on Climate Change report 'Land use: Policies for a Net Zero UK'. Here, 'equivalent' quantities of each gas (1 million tonnes 'CO_2-equivalent' of each as defined using the 100-Year Global Warming Potential (see Q.6) are emitted in year 0. They all have the same impact on the changing Earth's energy balance when averaged over 100-years after the emission, but we can see this happens in quite different ways. For methane, there is an initial, strong warming, but this declines over time, whereas for CO_2, the warming from an emission persists.



If we consider that emissions occur continuously, year-after-year, these differences in the duration of warming also have implications for how the gases contribute to overall global temperature increases.

As shown in the figure below (reproduced from here), if emissions of CO_2 are maintained at a constant rate, warming will continue to increase, because each new emission will add an extra incremental increase to temperatures that persists into the long-term.



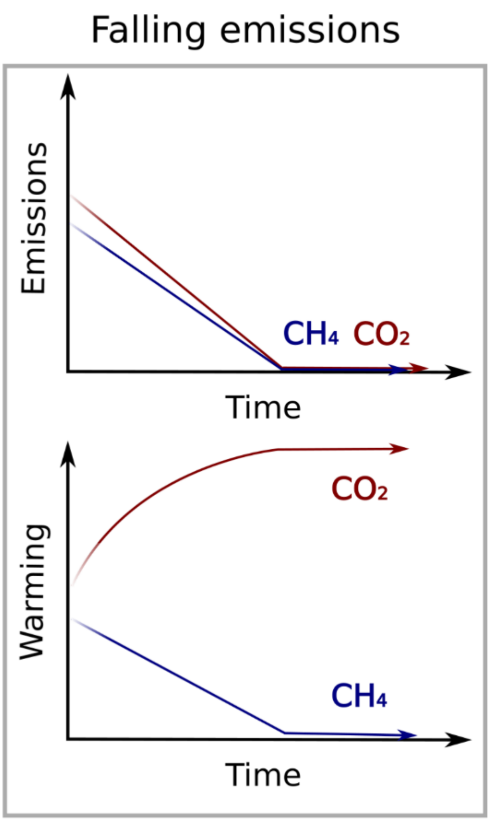
Constant emissions of methane will result in relatively stable, rather than continuously increasing, amounts of warming, because after a few decades each new emission replaces methane that has subsequently broken down in the atmosphere. This means that the overall warming impact also remains fairly stable.

Note, however, that there would still be some ongoing temperature increases from constant methane emissions. This is because the warming caused by an individual methane emission does not entirely go away, even if the gas is no longer present in the atmosphere, due to longer-term components in the Earth system like the oceans storing heat for a very long time.

So, if our goal is merely to 'stabilise' warming at or below a certain temperature limit, then we need zero CO_2 (or net-zero, with any emissions balanced by removals), but we don't necessarily need net-zero methane: the same climate outcomes can be achieved as long as methane emissions gradually decline. It has been estimated that methane emissions need to decrease by around 10% over 30 years to result in the same temperature stability that results from net-zero CO_2.

5. What happens if methane emissions are reduced?

As methane is a greenhouse gas, reducing emissions will mean there is less warming.



It is worth considering what will happen over time if methane emissions are reduced, and how this compares with CO_2.

Reducing emissions of CO_2 can slow down the rate of warming. However, because each emission still adds a long-term incremental increase to temperature, global warming will continue to increase unless emissions are brought down to net-zero.

Reducing emissions of methane will mean past emissions are being broken down in the atmosphere, and not replaced by the same amount of new methane, and so the amount of warming will reduce.

These dynamics are illustrated in the figure to the left.

Methane emissions would need to be reduced by more than 10% over 30 years to reduce warming in this way (following the point discussed in Q.4).

Bringing down the level of temperature increase caused by past CO_2 emissions can only be achieved by actively removing CO_2 from the atmosphere.

6. Do the current methods used to report methane emissions overstate its impacts?

Greenhouse gas emissions are typically reported as 'carbon dioxide equivalent' (CO_2e) quantities that describe how much CO_2 would have the same impact on the climate as the gas in question. However, gases differ both in their atmospheric lifetime and greenhouse 'strength', so there are different ways to approach this comparison.

Because of methane's short lifetime, the warming effect of a one-off methane emission decreases with time, and the impact of methane on the climate is heavily dependent on the timescale used in the evaluation.

Immediately following a one-off emission, methane is so much stronger than CO_2 that it would take more than 120kg CO_2 to have the same effect on the climate as 1kg methane. Over time, the methane pulse decays and its effect on trapping energy in the atmosphere declines, while more of the CO_2 remains, so the further ahead we look after the emission, the less CO_2 we need to result in the same 'equivalent' impact across whatever amount of time we are interested in.

At present, most greenhouse gas reporting uses a metric called the 100-year Global Warming Potential, or GWP100. This looks at the total greenhouse effect for the 100-year after an emission of a greenhouse gas, and would describe 1kg methane as being equivalent to 28kg of CO_2. (These values are regularly updated over time in line with the latest science: a GWP100 for methane of 28 is from the Intergovernmental Panel on Climate Change 5th Assessment Report, which the United Kingdom and many other countries use for official reporting purposes.)

If evaluated over a shorter time interval, such as 20 years, 28 Kg of CO_2 is an undervaluation, and 1Kg of methane is reported as being 'equivalent' to 84 Kg of CO_2. Over longer periods, both of these might be thought of as greatly overstating how damaging methane is compared CO_2: the 500-year GWP of methane is 8. All of these ways of reporting methane in terms of CO_2 are built on the same physical understanding of the climate, along with other approaches that base their comparison on different parts of the climate response (for example, the 100-year Global Temperature change Potential, or GTP, looks at how much temperatures increase due to a methane emission *after* 100 years, rather than effects *across* the whole 100 years, and would describe 1kg methane as being equivalent to 4 kg CO_2). GWP100 has largely been settled upon as a way of reporting methane that, it has been argued, balances shorter- and longer-term timescales to provide a simple way of implying relative impacts or direct efforts to reduce emissions.

Beyond the subjective nature of what timeframe to use, more fundamental concerns have also been raised about *any* approach that reports methane as being directly 'equivalent' to a certain amount of CO_2 (such as GWP, and under any time horizon, so including the GWP100). The issue is that by describing methane as directly equivalent to CO_2 (regardless of whether the 'equivalent' quantity is 4, 27, 84, etc.), it obscures the fact that they behave quite differently over time, and particularly that one gas has impacts that are mostly reduced automatically, while the other gas's effects are largely permanent.

As a consequence, using approaches that describe emissions as like-for-like equivalents will also be unable to capture the different outcomes of stable or decreasing emissions for methane compared to CO_2, as shown above in Qs. 4 and 5. By extension, if we deal with different emissions as directly analogous amounts in line with the GWP100 and other metrics that work in the same way, it is impossible to infer the fact that to achieve any given climate outcome (such as keeping global warming below a certain amount), you do not need to set the same targets (i.e. net-zero) for both methane and CO_2.

The problem is therefore not really that the current methods over- or understate the impacts of methane, but that they are unable to fully reveal the different behaviours of different gases. There are different views as to whether or not this is a problem in relation to reporting emissions and setting targets.

7. How would reduction targets be different if other metrics such as GWP* were used?

'Global Warming Potential-star', or GWP*, takes a different approach to describing emissions of methane as 'equivalent' amounts of CO_2.

By its design, GWP* avoids describing one emission of methane as being equivalent to any single amount of CO_2. Instead, it treats an indefinitely ongoing source of methane emissions as being more equivalent to a one-off CO_2 emission. Alternatively, if GWP* is used to report an individual methane emission, it would be reported as a large emission of CO_2, followed by a large automatic removal later on. GWP* is a short equation, rather than a single number weighting methane to CO_2, and needs to be applied to a series of methane emissions over time, not just a one-off release of the gas. To try and differentiate from the more longstanding metrics that always report emissions of one gas as fixed amounts of 'CO_2 equivalents', CO_2e, and show that GWP* is fundamentally quite distinct, it has sometimes been suggested GWP* instead reports a 'CO_2-warming-equivalent' (CO_2we).

This enables the reporting of methane emission scenarios, in a manner that can reveal the trends highlighted in Q.4 and 5. Slowly declining, but non-zero, methane emissions can be reported as 0 CO_2we, indicating that this methane emission scenario would result in no additional temperature increase from the methane (but they are still causing warming that could be reduced by lowering emissions, as discussed below) in line with reaching net-zero CO_2. Reducing methane emissions more strongly can end up reporting negative CO_2we, indicating that in this scenario, whatever entity was emitting this methane can end up causing less warming than it did previously, in an analogous way that a CO_2 emitter can start to reverse their warming contributions by actively removing CO_2 overall.

In setting emission reduction targets, then, GWP* could reframe things, revealing that temperature stabilisation can be achieved without totally eliminating or having to offset methane, in a way that is not possible for CO_2. In this manner, '0 GWP* CO_2we' might be an alternative way of setting expectations for different emitters that will result in the same physical outcomes.

This is not the end of the story, however. While reaching 0 reported emissions under GWP* means that, for any particular a methane emitter (for example, an individual farm, the agricultural sector in a given region, or a whole country) its own warming contribution has stabilised, there is still the potential for it to contribute even more to climate change mitigation by further reducing its methane emissions. A merely stabilised warming contribution from global agricultural methane will almost certainly be insufficient to meet our commitments to keep overall global warming to 1.5-2°C, as agreed upon in the Paris Agreement.

It remains the case that each individual methane emission still contributes to global warming, and has an impact that could be avoided if the emission was not permitted. The conventional metrics, such as GWP100, highlight this aspect of any emissions, and so reduction targets can be set using them, reporting the climate impacts that could be avoided (as defined by the metric in question).

GWP* can also be used to reveal the benefits of avoiding methane emissions: if we calculate the potential near-term climate impacts avoided by stopping any ongoing methane emissions, the GWP* CO_2we reported is very large: much greater than the GWP100 or even GWP20 would indicate, because it can reveal an even shorter-term emphasis.

Furthermore, as many reporting and policy expectations already use GWP100, some also argue there is significant value in keeping this metric in target setting: especially in contexts like the United Kingdom, where it is part of legislative requirements that an eventual net-zero GWP100 balance is achieved.

Debate over which metric should be used in target-setting and why is still playing out. From a physical perspective, some even question the extent to which we need any emission metrics for target-setting purposes. While it appears likely that the overall expectations regarding the use of GWP100 will remain, some of the implications over what different sectors can and should do as part of 'net-zero' have only recently started to be considered in detail. Under any metric approach, methane emission reductions are still required.

Authors

John Lynch

Oxford University

Xiao Zhang

Oxford University

For More Information

John Lynch john.lynch@oxfordmartin.ox.ac.uk

The Agile Initiative agile@oxfordmartin.ox.ac.uk

www.agile-initiative.ox.ac.uk

www.linkedin.com/company/agile-initiative

UKRI Natural Environment Research Council

The Agile Initiative is supported by the Natural Environment Research Council as part of the Changing the Environment Programme – NERC grant reference number NE/W004976/1

Agile Initiative | Oxford Martin School | University of Oxford

The Agile Initiative
Oxford Martin School
34 Broad Street
Oxford, OX1 3BD, UK