FCRN Food Climate Research Network

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A free and evolving resource to empower informed discussion on sustainable food systems

Agricultural methane and its role as a greenhouse gas

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Written by

Dr John Lynch, Department of Physics, University of Oxford

Reviewed by

Helen Breewood, Food Climate Research Network, University of Oxford

Dr Michelle Cain, the Environmental Change Institute and the Oxford Martin School, University of Oxford

Walter Fraanje, Food Climate Research Network, University of Oxford

Dr Tara Garnett, Food Climate Research Network, University of Oxford

Dr Martin Persson, Department of Space, Earth & Environment, Chalmers University of Technology

Dr Elin Röös, Division of Agricultural Engineering, the Swedish University of Agricultural Sciences

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Food Climate Research Network, **Environmental Change Institute**, University of Oxford
Tel: +44 (0)20 7686 2687

Contents

Why should you read this explainer?

There has recently been a lot of focus on methane, as it is an important contributor to climate change. The food system is one of the largest emitters of methane, and the gas is particularly associated with ***ruminant*** livestock (cattle, sheep and goats) and with rice production. Despite its significance as a greenhouse gas, there is also considerable confusion over how we should quantify the climate impacts of methane emissions. This is because there are important differences in how methane and carbon dioxide – the major human-generated greenhouse gas – affect the climate.

This explainer provides an overview of the key points about methane, and addresses some common areas of confusion, covering:

1. What is methane and how does it affect the climate?
2. Where do methane emissions come from?
3. What happens to these methane emissions?
4. How has agriculture contributed to recent increases in atmospheric methane?
5. What does all this mean for how we consider methane emissions, particularly in relation to carbon dioxide (CO_2)?

At the end of this explainer, there is also a glossary that collects and provides additional detail for some of the more technical terms.

1. What is methane and how does it affect the climate?

Methane is a very simple molecule, composed of one carbon and four hydrogen atoms (Figure 1), hence its chemical formula CH_4.

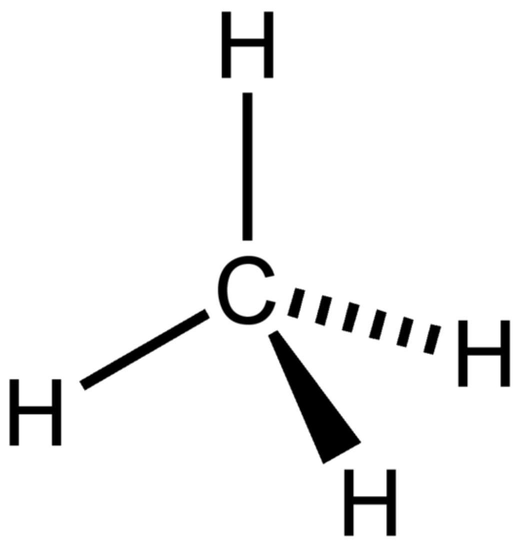

Figure 1. A methane molecule (Benjah-bmm27 - public domain)

Methane is an important ***greenhouse gas (GHG)***, second only to carbon dioxide (CO_2) in terms of its overall contribution to human-driven climate change (1). GHGs affect the climate by changing the balance between incoming and outgoing energy (incoming from the sun, outgoing back from the Earth). As GHG concentrations in the atmosphere increase, a larger proportion of outgoing radiation is now absorbed by these GHGs, some of which is re-emitted back towards the Earth's surface rather than carrying on out to space. This change in the atmospheric energy balance is known as ***radiative forcing*** (or simply 'forcing', see glossary), and the Earth warms up in response.

Methane is also a powerful greenhouse gas, much stronger than CO_2. If atmospheric concentrations of methane and CO_2 increased by the same amount (on a per molecule basis), the increase in methane would lead to around 26 times more forcing than the increase in CO_2 (2). This property is known as the ***radiative efficiency*** of a gas, and can also be thought of as representing the 'strength' of the direct climate impact per molecule or tonne of each gas in the atmosphere. Methane also has an indirect impact on the climate through the generation of ozone and water vapour, which are also greenhouse gases (covered further below).

2. Where do methane emissions come from?

Methane emissions are generated by a number of processes, both natural and resulting from human activity ('anthropogenic').

Most natural methane emissions arise from microbial decomposition of organic material (for example, decaying plants) in ***anaerobic*** ('lacking oxygen') conditions in wetlands.

There are a number of sources of anthropogenic methane emissions. Fossil-fuel methane (commonly referred to as 'natural gas') may be emitted to the atmosphere in the process of extracting coal or oil, or from leakage during the extraction, storage or distribution of natural gas. The waste sector is another source of methane, which arises when microbes digest organic matter in the waste. But agriculture is the activity responsible for the single largest share of anthropogenic methane emissions, estimated in one recent study at around 44% of anthropogenic methane in 2012 (3).

The biggest source of agricultural methane emissions is ***enteric fermentation***, which is the digestive process by which microbes in the guts of ruminant livestock break down plant matter, enabling it to be absorbed into the animals' bloodstream, and producing methane as a by-product. Almost 30% of total anthropogenic methane in 2012, or about two thirds of the agricultural total, is from this source. Significant amounts of methane are also emitted where rice is grown in flooded paddies (11% total anthropogenic methane in 2012), where the anaerobic conditions facilitate microbial methane-generation similarly to natural wetlands. A third major source of agricultural methane emissions arises from losses of organic matter in manures (from both ruminant and non-ruminant livestock) (3% total anthropogenic methane in 2012), and a small amount of methane is emitted from the burning of agricultural wastes (0.5%).

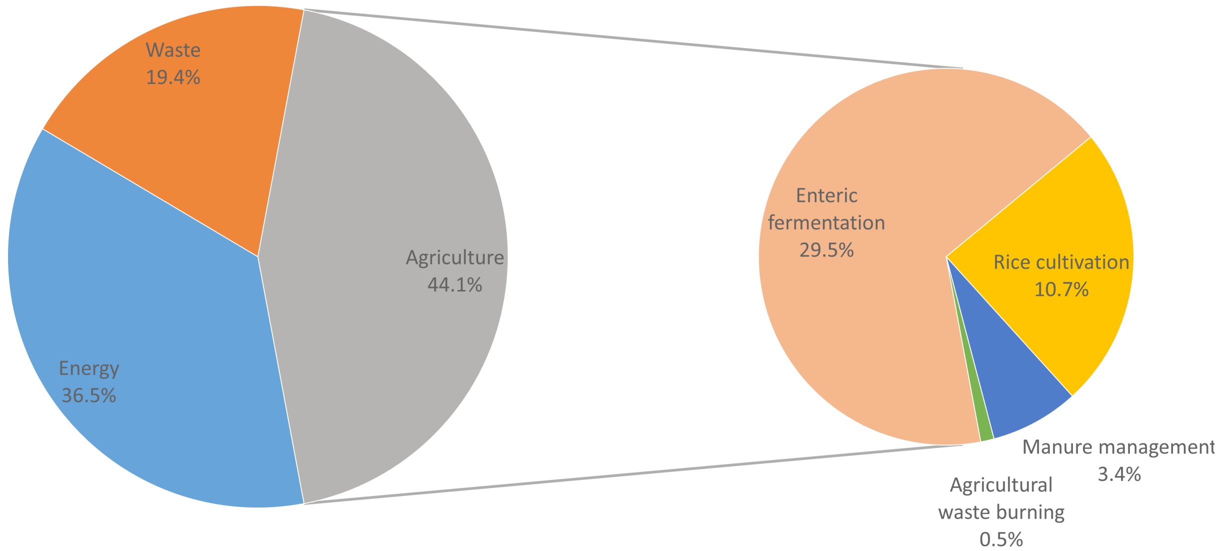

Figure 2. Main anthropogenic methane emissions by sector in 2012, and main sources within agriculture. Data: https://www.earth-syst-sci-data-discuss.net/essd-2017-79/

3. What happens to these methane emissions?

As well as the strength of each GHG (their ***radiative efficiency***), to understand how emissions will impact the climate, we also need to know how long these emissions will last in the atmosphere (their 'atmospheric lifetime'). This is particularly important for methane, as it is a relatively short-lived GHG, with emissions breaking down after an average of around 10 years. In contrast, a significant proportion of our CO_2 emissions are expected to persist in the atmosphere for centuries, or even longer.

Approximately 95% of the methane is 'removed' or broken down in the atmosphere itself. Most of this (84% of total removals) is in the lower atmosphere ('troposphere'), and results from a reaction with ***hydroxyl (OH) radicals*** – highly reactive molecules that play an important role in the removal of many other atmospheric pollutants in addition to methane. Ultimately, as a result of this process, much of the methane is broken down into CO_2. However there is still some scientific uncertainty over exactly how much of the methane is finally converted to CO_2 and how much might remain as other intermediate carbon-containing compounds without a significant direct effect on the climate (4).

In the case of agricultural methane, this resultant CO_2 is essentially replacing that which was first fixed as plant ***biomass*** via photosynthesis. As such, it does not need to be considered as an *additional* source of CO_2, for the same reason we do not consider CO_2 from livestock (or human) respiration (breathing out) as an extra greenhouse gas emission. Importantly, this also means that methane from agriculture is different from fossil fuel methane (see above), because for fossil fuel methane this CO_2 is an additional input to the atmosphere, which had previously been locked away underground (2).

A smaller proportion (8%) of methane is also oxidised by OH radicals in the upper atmosphere ('stratosphere'); there is also thought to be an additional small amount of removal (around 4%) of atmospheric methane by reaction with chlorine radicals.

It is important to note that these reactions between methane and OH radicals produce ***ozone*** and stratospheric water vapour as by-products. Both ozone and water vapour are also greenhouse gases (see note)[1], and add an indirect effect that increases the ***radiative forcing*** due to methane emissions by around a third more than the direct effect of the methane itself (2). Increased concentrations of ozone at the Earth's surface also reduce plant growth, with potentially significant implications for total carbon budgets (5) by reducing the rate at which plants can remove CO_2 from the atmosphere, and causing crop yield reductions of up to 10% (6).

The remaining 5% of atmospheric methane removal occurs in soils. Although relatively small compared to atmospheric removals, there is potentially scope to increase this removal effect by a small degree, since different land-uses and management can change the balance between microbes in the soil that either produce or remove methane ('methanogenic' and 'methanotrophic', respectively). In general, it is thought that agricultural soils have lower methane removal rates compared to soils with native vegetation, and in some cases these agricultural soils end up producing rather than removing methane (7). However, agricultural soils can also act as methane sinks (8), and it may be possible to increase removal rates through management interventions such as adding appropriate composts (9). There could therefore be a potential role for agricultural management to maintain or enhance soil methane removals. However, there has been relatively little research into this topic, and soil removals will likely remain a small proportion of methane removals.

4. How has agriculture contributed to recent increases in atmospheric methane?

Over the last decade methane concentrations have increased rapidly (Figure 3). It is difficult to confirm exactly how much of this increase is due to agriculture, to other anthropogenic sources, and to increases in natural methane emissions; or whether there are more complex changes in the atmospheric chemistry of methane at play, slowing down the rate at which it is broken down. Increases in agricultural methane could explain some of the increase; however it has not yet been possible to precisely quantify the different source contributions. What is certain is that actions to reduce any anthropogenic methane emissions present important opportunities for reaching our climate mitigation targets (10).

1 Although often an area of confusion, the impacts of water vapour as a greenhouse gas are well-understood and included in climate models as an important climate-feedback.

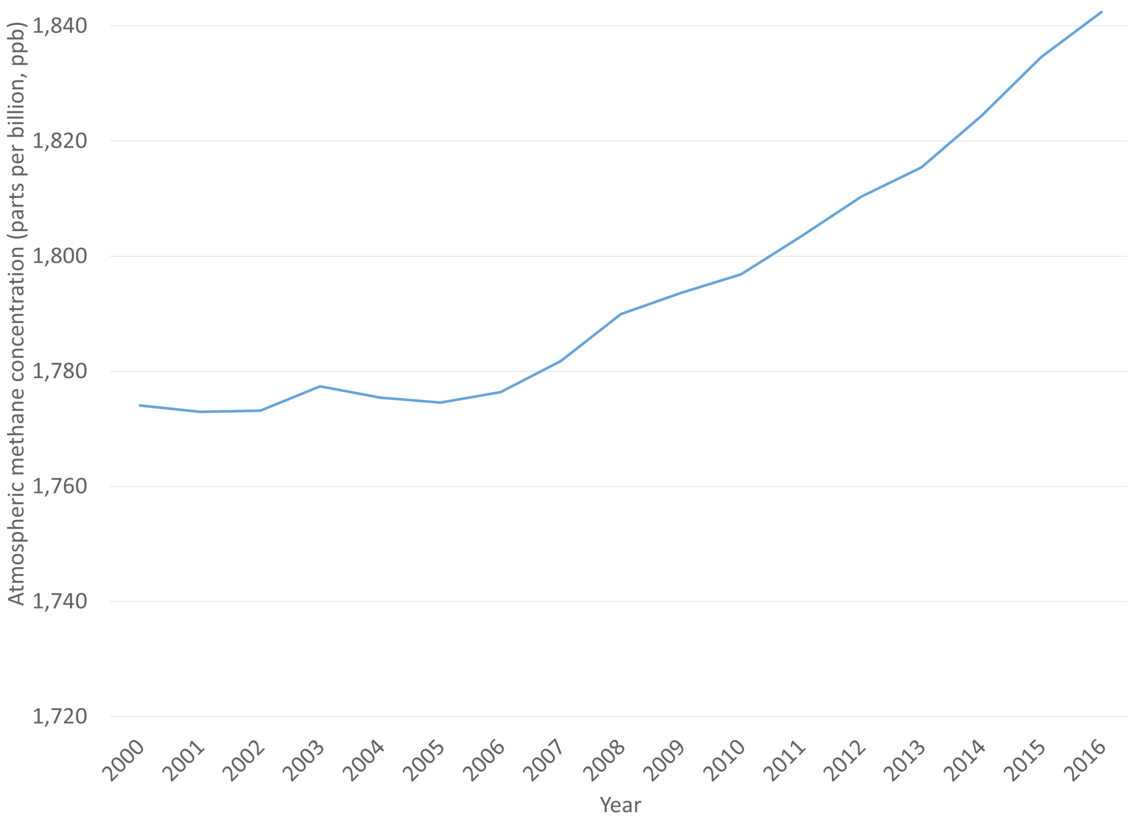

Figure 3. Changes in atmospheric concentrations of methane since 2000. Following an apparent 'pause' from around 1998-2007, the concentration of methane has increased rapidly over the past decade. Data: https://www.eea.europa.eu/data-and-maps/daviz/atmospheric-concentration-of-carbon-dioxide-4#tab-chart_6

Can we identify the individual sources for methane in the atmosphere?

Ongoing research can help to overcome some of the uncertainties over how different sources contribute to recent changes in global methane concentrations in the atmosphere. We can get a better picture of how much methane real-life agricultural systems are emitting using monitoring techniques (a method called ***eddy covariance***), to, for example, detect and quantify methane from rice paddies (11, 12) and grazing ruminants (13, 14). At larger scales, subtle differences between the types of methane emitted from different sources – the ***isotopic signature*** – can be used to show what broad source category atmospheric methane came from. This approach points to biological sources, such as agriculture (15), wetlands (16) or both (17), as a key driver of recent atmospheric increases, but increases in fossil-methane sources cannot be ruled out as important contributors to the trend (17). There is still a lot about methane emissions that we don't know, but continued research from atmospheric monitoring to agricultural management is helping to improve our understanding.

5. What does all this mean for how we consider methane emissions, particularly in relation to carbon dioxide (CO_2)?

Because CO_2 emissions last in the atmosphere for so long, we have to consider them as a *cumulative* pollutant – i.e. new emissions are added on top of those that were previously emitted, leading to increases in the total atmospheric stock of CO_2.

In contrast, because it breaks down rapidly, methane emissions do not act cumulatively. For a constant rate of methane emissions, one molecule in effect replaces a previously emitted one that has since broken down. This means that for a steady rate of methane release – as emitted by a constant number of cattle, for example – the amount of methane in the atmosphere stays at the same level, but does not increase.

To illustrate by way of an analogy: imagine a bath filling with water. In the case of CO_2, we have a constant 'flow' of water representing ongoing emissions, but the drain is mostly blocked, and so the bathwater will steadily increase for as long as the tap is running. For methane, if we turn on the tap (i.e. start emitting methane) the bath water will initially fill to a high level, but after a short delay the bath can start to drain (the removals described in section 3 above) at a rate that balances the ongoing flow. This means that provided the tap is not opened further (i.e. the rate of flow remains constant), the bathwater remains at that high water level, but without filling further.

This concept is illustrated in Figure 4 below (18).

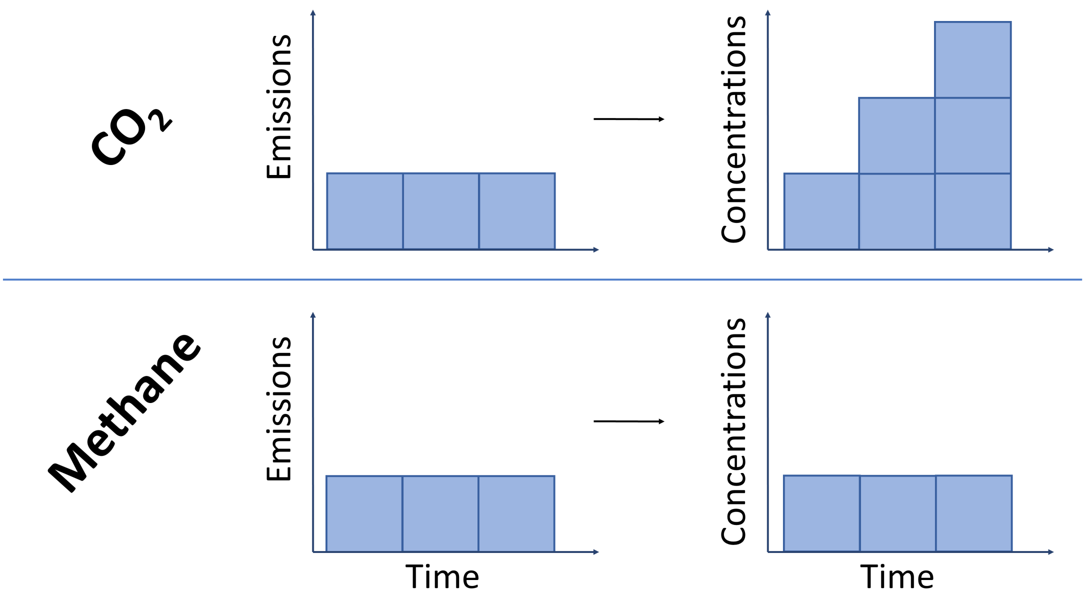

Figure 4. A simplified illustration of the impact of sustaining emissions of either carbon dioxide (CO_2) or methane. For CO_2, ongoing emissions add cumulatively to the amount of CO_2 in the atmosphere, so concentrations keep on increasing as long as emissions continue. But for methane, the gas breaks down relatively quickly, so the atmospheric concentration reflects the continued rate of emissions. Figure based on illustration in (18).

This means that to stop further warming, we need to bring emissions of CO_2, and other long-lived greenhouse gases, down to net-zero (i.e. zero emissions; or else any remaining emissions are offset by removals from the atmosphere). For methane, however, it is possible to have ongoing emissions that do not result in continuing increases in temperature.

But this does not mean we can ignore methane. Even if stable, the ongoing methane emissions maintain elevated concentrations, and hence a continued – even if not significantly increasing – impact on the climate.

And increasing methane emissions result in increasing atmospheric concentrations. Since methane has a powerful effect as a greenhouse gas, even relatively small increases in concentration can have a major climate impact, making the recent observations of increasing atmospheric methane highly concerning. The reverse is also true. Because of its short atmospheric lifetime, if we reduce methane emissions, we expect the atmospheric concentration would fall relatively quickly (Figure 5). So reducing methane emission rates presents an important mitigation opportunity which could reverse some of the warming we already experience.

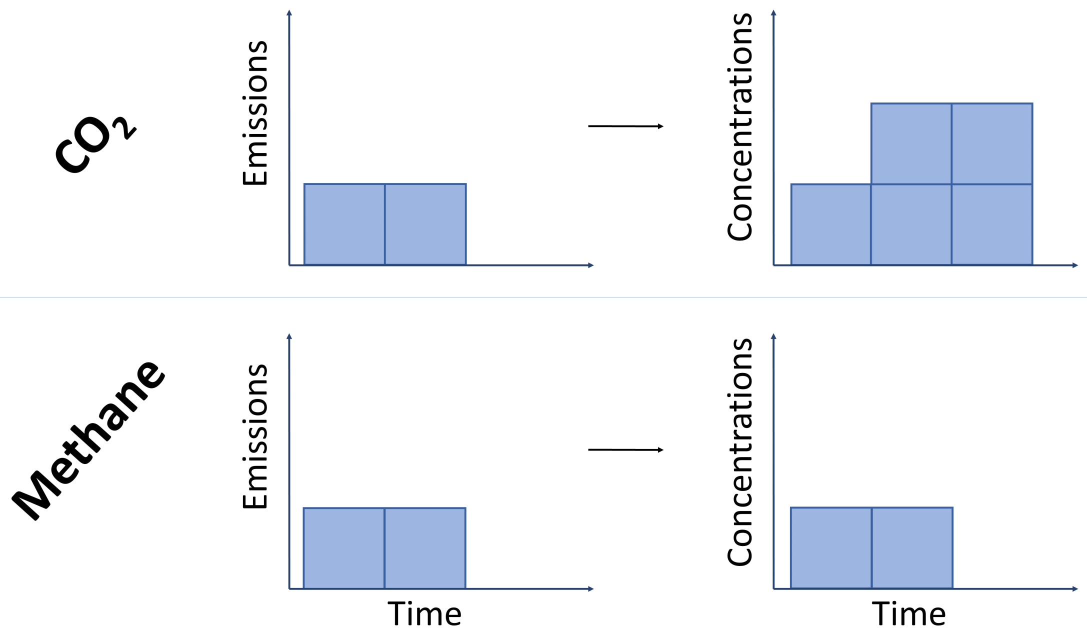

Figure 5. A simplified illustration of the impact of stopping emissions of either carbon dioxide (CO_2) or methane. For CO_2, once emissions stop, atmospheric concentrations remain approximately fixed at the amount reached (for centuries – without active steps to remove this CO_2). For methane, as it breaks down quite quickly, stopping emissions can reverse the increased concentration.

What does this imply for the way we assign numerical values to methane and carbon dioxide?

It is well recognised that these important differences between the two gases are not captured well in the way we currently describe emissions of different gases as ***carbon dioxide equivalents*** (CO_2e) using the ***100-year Global Warming Potential (GWP_{100})***. Various other metrics have been proposed, including recently the ***GWP****. GWP* focuses on the *change in rate* of methane emissions, compared to the *total amount* of CO_2 (and other long-lived gases) (19). Using GWP*, changing the rate of methane emissions is assigned *a much higher CO_2-equivalence* than it is under GWP_{100}; as such it better captures the risks of increasing and the benefits of decreasing methane emission rates. But maintaining emissions at the same rate for more than a couple of decades is valued as *a lower equivalent* amount of CO_2 than under GWP_{100}, reflecting the non-cumulative impacts of stable methane emissions noted above

The GWP* approach offers a very different way of thinking about methane emissions than the conventional GWP approach, as employed in typical reporting of emissions. Some of the possible implications for agriculture are only just starting to be explored, and this topic will be revisited in further pieces from the FCRN.

Glossary

Anaerobic
Anaerobic processes occur in the absence of oxygen. For example anaerobic respiration occurs when oxygen is not present.

Biomass
Biomass refers to dry weight of plant-based material that has been harvested or is available on an area of land. Typically, it refers to the use of plants not for food or fibre, but rather for (bio)energy.

Carbon dioxide equivalents (CO_2e)
A commonly used means of expressing different greenhouse gas emissions (i.e. methane) as an 'equivalent' quantity of carbon dioxide (CO_2). This is generally calculated using the 100-year ***Global Warming Potential***, but other methods have also been proposed, and can give a very different picture of the impacts of different activities.

Eddy Covariance
A meteorological monitoring technique that can be used to measure the movement of different gases in situ. Applications include, for example, to measure the concentration of methane in the air near agricultural sources.

Enteric fermentation
Enteric fermentation is a natural part of the digestive process of ruminant animals (e.g. cattle and sheep) where microbes decompose and ferment the food present in large rumen portion of the stomach. As a byproduct of this fermentation process, some bacteria species in the stomach produce methane.

GHGs
GHGs is an abbreviation for greenhouse gases. These include gases such as carbon dioxide, methane, and nitrous oxide, which affect outgoing radiation, leading to global warming.

Global Warming Potential (GWP)
A commonly used means of quantifying the strengths of different greenhouse gas emissions relative to carbon dioxide (CO_2). Derived from estimating the total change in atmospheric energy balance resulting from a pulse emission of the gas, relative to CO_2, over a specified time-frame (typically 100 years).

GWP*
An alternative application of ***Global Warming Potentials*** to derive ***carbon dioxide equivalents*** (referred to as CO_2e* if using GWP*) that primarily relates the change in the rate of short-lived greenhouse gases (such as methane) to a fixed quantity of CO_2, rather than a direct equivalence between emissions of both short- and long-lived greenhouse gases, as is the case for conventional use of the 100-year Global Warming Potential.

Hydroxyl (OH) radicals
A highly reactive molecule responsible for the initial reaction leading to most methane destruction in the atmosphere, and also important for the removal of many other atmospheric pollutants. Radicals are molecules or atoms with an unpaired electron, often making them very reactive.

Isotopic signature
The ratio of different isotopes. *Isotopes* are atoms which have a different number of protons and neutrons. For example, most carbon (C) has 6 protons and 6 neutrons, giving it an atomic weight of 12. This form of carbon is known as carbon-12 (or ^{12}C). Another stable form of carbon exists with 6 protons and 7 neutrons, giving it a molecular weight of 13, hence it is known as carbon-13 (or ^{13}C). Different sources of methane emissions can be composed of different proportions of ^{12}C and ^{13}C, with fossil fuel sources often containing relatively more ^{13}C than biological sources.

Ozone
A molecule consisting of three oxygen atoms (chemical formula O_3; 'trioxygen'). In the upper atmosphere ('stratosphere') ozone plays an important role in absorbing ultraviolet radiation from the sun, but is also a greenhouse gas, and at the surface has negative impacts on human health and plant growth. Ozone is also one of the by-products from atmospheric methane oxidation.

Ruminant
A ruminant is a mammal with a four-compartmented stomach which enables it to acquire nutrients from plant-based food such as grasses, husks and stalks. Examples of ruminants include cattle, sheep, goats, deer, giraffes and camels. After swallowing, microbes in the ruminant's rumen (its first stomach compartment) begin fermenting the food. This process generates fatty acids (nutrients which the ruminant absorbs through its rumen walls) and methane, which the ruminant eructs or burps. Through this process, ruminants are able to digest coarse cellulosic material which monogastrics and people cannot. Methane emissions from ruminants are a significant source of greenhouse gasses from ruminant-based livestock systems.

Radiative Efficiency
A measure of 'greenhouse strength' for different greenhouse gases, defined as the change in radiative forcing per change in atmospheric concentration of a gas (in Watts per metre square per part per billion; $W\ m^{-2}\ ppb^{-1}$).

Radiative Forcing
The measure of how different factors (including greenhouse gases) change the balance between incoming and outgoing energy in the atmosphere. Expressed as the change in energy balance per unit area (in Watts per metre square; $W\ m^{-2}$) over a given timeframe – typically contemporary compared to preindustrial conditions.

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