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EDITED AND REVIEWED BY
Euan Nisbet,
Royal Holloway University of London,
United Kingdom

*CORRESPONDENCE
Fiona M. O'Connor
fiona.oconnor@metoffice.gov.uk;
f.m.oconnor@exeter.ac.uk

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Why methane matters

Fiona M. O'Connor[1,2]*

[1]Met Office Hadley Centre, Exeter, United Kingdom, [2]Department of Mathematics & Statistics, Global Systems Institute, University of Exeter, Exeter, United Kingdom

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A Viewpoint on the Frontiers in Science Lead Article
The methane imperative

Key points

- Atmospheric methane, an important trace gas from both a climate and air quality perspective, is rising at a rate unprecedented in the observational record.
- Alongside decarbonization, targeted measures to reduce anthropogenic methane emissions are important to limit climate change and improve air quality—a modest reduction in anthropogenic methane emissions of 45% by 2030 could, on an annual basis, prevent about a quarter of a million premature deaths and avoid 26 million tonnes of crop losses globally.
- Recent advancements in measuring and modeling emissions mean that individual emission sources can be identified successfully, and progress towards meeting emission reduction targets can be more accurately monitored.

Introduction

Methane (CH_4) gas is a major driver of climate change. It is second in importance only to carbon dioxide (CO_2) as a greenhouse gas and has contributed 0.5°C to the 1.07°C increase in global mean temperature observed between the pre-industrial (1850–1900) and the 2010–2019 period, as assessed by the Intergovernmental Panel on Climate Change (1). Methane also plays an important role in air quality as a precursor to tropospheric ozone (O_3), an air pollutant and another major greenhouse gas. Current concentrations of near-surface ozone are responsible for half a million premature deaths annually, with additional harmful effects on crops and ecosystem health on a global scale (2). Reducing methane emissions is therefore expected to bring benefits for climate change, global-scale air quality, human health, and terrestrial ecosystems.

Reaching net zero CO_2 emissions is a key milestone. The latest scientific knowledge concerning the Earth system response to zero future CO_2 emissions has shown that the best estimate for the amount of additional warming after net zero CO_2 emissions is zero (1), i.e., there is no substantial "warming in the pipeline" or "committed warming". However, the uncertainties around this estimate are large, such that additional warming or cooling after net zero could exceed 0.3°C for an initial warming of 2°C (3). In either case, there is an urgent need to achieve net zero CO_2 emissions. To maintain a stable climate within 1.5 or 2.0°C of the pre-industrial climate in accordance with the Paris Agreement, there is a limit to the amount of anthropogenic CO_2 that can be emitted in the future—this is referred to as the remaining carbon budget. As a result, countries are aiming to reduce their carbon emissions and to reach net zero CO_2 emissions by 2050.

However, since 2010–2019, greenhouse gas concentrations have continued to rise, global mean temperatures have increased by a further 0.12°C, and current warming has been increasing at an unprecedented rate (4). Methane has a much shorter lifespan than CO_2 (about a decade compared with centuries) and absorbs much more energy in the atmosphere than CO_2 per unit mass, making it a more powerful greenhouse gas. Reducing methane emissions, therefore, has the potential to reduce this unprecedented rate of warming. Despite its importance, however, Shindell et al. highlighted that methane mitigation has been neglected relative to CO_2 from both climate finance and policy mechanism perspectives (5).

Increasing methane emissions and the carbon budget

Methane emissions originate from a very diverse range of sources—both natural and anthropogenic. Natural emissions are dominated by emissions from wetlands, with freshwater bodies, such as lakes and rivers, being the second most important natural source. More minor sources include ruminant wild animals, terrestrial and marine seeps and volcanoes, termites, hydrates, and permafrost. For the 2008–2017 period, natural emissions accounted for approximately 50% of the total methane emissions into the atmosphere, with the remaining 50% coming from anthropogenic sources. Of these, agriculture and waste are the most important sectors, with fossil fuel extraction and processing being the second most important of the anthropogenic sources (6). The resulting atmospheric abundance and growth in methane concentrations are determined by the balance (or imbalance) between these sources and methane's sinks from the atmosphere—namely, chemical oxidation and consumption by methanotrophic bacteria in aerated soils. It is largely methane's chemical oxidation that determines its short atmospheric lifetime relative to CO_2, a process that is sensitive to the abundance of other ozone precursor trace gases such as nitrogen oxides.

Methane abundance in the atmosphere has increased by a factor of 2.5 due to industrialization, principally from emissions from fossil fuel production and use, livestock, and rice cultivation (7). Since 2006, and following a period of stagnation, there has been renewed growth in atmospheric methane at a rate that is unprecedented in the observational record. While anthropogenic emissions have increased substantially over the 2000–2017 period, the Global Carbon Project concludes that there has been no change evident in the strength of natural emissions (6). However, observations of atmospheric methane point to a change in the isotopic signature alongside renewed growth, suggesting a shift toward increasing emissions from microbial sources, particularly wetlands (8). Further growth in the methane burden has direct implications for the remaining carbon budget before reaching a temperature threshold of 1.5 or 2.0°C. Therefore, urgent action on methane is required to achieve the Paris climate goals.

Understanding the potential for climate feedbacks on natural sources and the relative roles of changes in anthropogenic emissions, natural emissions, and methane sinks on methane growth rates is critical. Indeed, any increase in the strength of existing natural sources and/or the emergence of any new sources (e.g., from permafrost thaw) may necessitate even greater anthropogenic methane emission reductions to reach a particular climate target.

Reducing methane emissions is crucial for human health and food security

Methane is one of a group of atmospheric constituents—which includes both trace gases and aerosols—known as near-term climate forcers (NTCFs). Being short-lived in the atmosphere, they have a cooling or warming impact on near-term climate and affect local air quality. Increases in anthropogenic methane emissions have contributed to warming, while increases in most aerosols have had a cooling effect (1). While reductions in future NTCF emissions will improve air quality, they may have conflicting impacts on near-term climate change. Nevertheless, numerous studies point to clear climate and air quality benefits from methane mitigation.

In a recent multi-model study, Allen et al. found that mid- and end-of-the-century global mean temperature would increase by over 0.2°C because of reductions in aerosol and non-methane ozone precursor emissions from air quality abatement policies (9). Including a reduction in methane burden, however, would improve air quality through further reductions in surface ozone and lead to an overall net climate benefit, with mid- and end-of-the-century reductions in global mean surface temperature of 0.15 and 0.50°C, respectively. It suggests that including strong action on methane in future policies on NTCF mitigation could result in a net climate benefit and maximize air quality co-benefits. Using the novel methane emission-driven capability of the UK's Earth System Model, Staniazsek et al. (10) examined a zero anthropogenic methane emissions scenario to quantify the maximum climate and air quality benefits from methane mitigation. They found that, in 2050, 1°C of global-mean warming and 690,000 premature deaths per year via surface ozone could be attributed to anthropogenic methane emissions in a high-end climate pathway. A more modest reduction in anthropogenic methane emissions by 2030 of 45% could, on a global annual basis, prevent over a quarter of a million premature deaths, reduce asthma-related hospital visits by three quarters of a million, and avoid 26 million tonnes of crop losses due to reductions in surface ozone (2). Therefore, methane mitigation has substantial co-benefits for air quality, human health, and food security.

Methane mitigation options

Considering the multiple benefits of methane emission reductions, the Global Methane Pledge was launched at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP26) in 2021. This international initiative aims to reduce global anthropogenic methane emissions by at least 30% from 2020 levels by 2030, avoiding 0.2°C of global warming by 2050. Since then, over 155 countries have signed up to the Pledge; together these countries account for more than 50% of global anthropogenic methane emissions.

Using bottom-up emission estimates based on activity data combined with emission factors, Shindell et al. identify the subsector with the largest technical mitigation potential in every country and provide an assessment of the abatement costs (5). For example, the online tool developed as part of the Shindell et al. study illustrates that up to 8% of the United Kingdom's year-2020 methane emissions could be mitigated at negative cost. Example mitigation measures include gas recovery from landfill sites for energy generation, improved feed practices for livestock, and replacing technologies in the gas industry, thereby providing sufficient and country-specific knowledge to make progress toward the Pledge's emission reduction target. With recent advancements in satellite measurements and inverse modeling of emissions, including the identification of fugitive emissions (11), individual emission sources can be identified successfully and progress towards meeting emission reduction targets can be monitored. However, atmospheric methane is rising rapidly, and methane observational capability could be enhanced—both spatially and isotopically—to improve our understanding of the methane budget and the role of potential climate feedbacks. Shindell et al. argue that, without urgent action, atmospheric methane will continue to rise (5).

Conclusion

Methane is a potent greenhouse gas with a relatively short atmospheric lifetime, so reducing methane emissions could have significant short-term benefits for climate stabilization. By leveraging technological advancements, enforcing robust policies, and fostering international cooperation through initiatives such as the Global Methane Pledge, substantial progress could be made in reducing methane emissions. However, recent observations indicate a lack of progress to date. More effort is essential not only for meeting climate targets and the goals of the Paris Agreement but also to ensure a healthier and more resilient environment for future generations.

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Author contributions

FO'C: Conceptualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

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