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BRIEF REPORT

Prioritize rapidly scalable methane reductions in efforts to mitigate climate change

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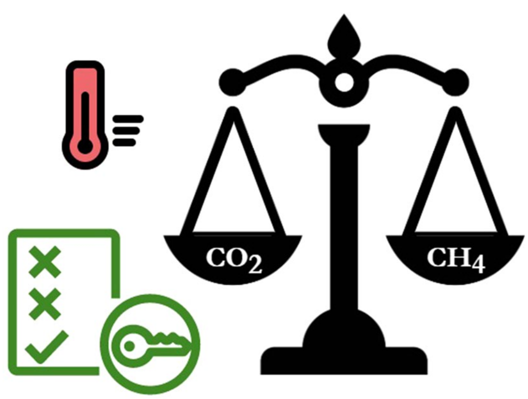
Abstract
Methane emission reductions are crucial for addressing climate change. It offers short-term benefits as it holds high short-term reductions in radiative forcing. Efforts towards the reduction of methane emissions are already underway. In this study, we compared and analyzed the mitigation benefits of cutting large amounts of methane emissions from the oil and gas sector on short-time scales with reducing an equivalent amount of carbon dioxide using carbon capture and storage (CCS). Characteristics of CCS are that it would require substantial infrastructure development and that it incorporates deployment delays. Results illustrate that prioritizing quickly deployable methane emission reduction alternatives that necessitate minimal construction is an efficient approach to achieve near-term climate change relief.

Graphical abstract



Keywords Climate change · Greenhouse gases · Short-lived climate pollutants · Methane · Emission reductions

Introduction

In November 2022, the U.S. Environmental Protection Agency (US EPA) proposed regulations that would reduce methane (CH_4) emissions from oil and gas supply chains in the U.S. by 87%, compared to 2005 levels (EPA, 2022). If emission reductions of this magnitude were deployed globally, they would result in reductions that could abate 80 Tg of CH_4 per year (IEA, 2022). Technologies capable of reducing these emissions already exist. In many cases, they are economically attractive because they reduce loss and leakage of salable product.

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Efforts to reduce CH_4 emissions from the oil and gas sector are already underway. The Global Methane Pledge and commitments at COP26 targeted 30% CH_4 emission reductions by 2030 (DOS, 2021). More recently, COP27 highlighted the importance of reducing CH_4 emission from oil and gas value chains for achieving net zero by 2050. In the US, the Inflation Reduction Act (IRA) 2022 incorporated fees for entities along the oil and gas supply chain that report CH_4 emissions above specified thresholds, starting in 2024 (H.R.5376, 2022). These efforts are part of a broader trend that emphasizes emission reductions of short-lived climate forcers like CH_4 (Solomon et al. 2010; Dreyfus et al. 2022; Singh et al. 2022). Reducing CH_4 emissions could bring benefits in the near-term when compared to reducing emissions of longer-lived climate forcers like CO_2 (Abernethy et al. 2021; Cain et al. 2022; Ming et al. 2022; Abernethy and Jackson 2022). Besides rapid deployment, CH_4 reductions in the energy sector have the additional advantage of high short-term reductions in radiative forcing.

In this paper, we compare the climate change mitigation benefits of cutting large amounts of CH_4 emissions from the global energy sector on short time scales with reducing an equivalent amount (on a global warming potential basis) of CO_2 using carbon capture and storage (CCS), a technology that would require significant infrastructure development. While both of these approaches can be pursued simultaneously, our analysis illustrates the short-term benefits of exploiting available, economically viable, and scalable CH_4 emission reduction technologies.

Methane and carbon dioxide reduction scenarios

Oil and gas CH_4 emissions are currently reported as approximately 80 Tg per year, although they may be 25 to 40% greater than this estimate (Hmiel et al. 2020). Our analysis, therefore, assumes a business-as-usual emissions level of 100 Tg of CH_4 per year. We then evaluated the changes in radiative forcing and consequent global-average surface temperature change from reducing these emissions by 30%, which is in line with current global targets. A second scenario assumes 80% emission reductions to highlight the advantages of pushing past current targets for achieving reductions similar to those proposed by the US EPA (EPA, 2022). To evaluate emission reduction scenarios that decrease an equivalent amount of CO_2, we converted CH_4 to CO_2 emissions using a fossil CH_4 GWP_{20} (global warming potential at year 20) of 82.5 as reported in the Sixth Assessment Report (IPCC, 2022). Table 1 describes the proposed scenarios.

Using CCS to reduce CO_2 emissions requires manufacturing of large-scale equipment, and construction of foundations, pipelines and auxiliary systems. Such activities generate additional GHG emissions that might vary depending on particular characteristics and these systems have a range of emission estimates reported in the literature. Manufacturing and construction emissions for CCS are reported to be between 0.07 and 0.33 Tg of CO_2 emitted per unit of throughput in Tg of CO_2 sequestered per year (Koornneef et al. 2008; Cuellar-Franca and Azapagic, 2015). We adopted the average of this range to develop the scenarios in Table 1, which include infrastructure emissions and construction times (Townsend and Gillespie 2020). These scenarios take account of the changes over time in emissions associated with manufacturing the steel and materials required to build CCS facilities.

CH_4 emission reduction technology options are less infrastructure-intensive than CCS. Nonetheless, we assessed whether we would need to include GHG emissions from infrastructure build out to deploy them. These options include replacing pneumatic pumps with electrical pumps, replacing pneumatic devices with mechanical controllers, and replacing high-bleed or high-emitting pneumatic devices

Table 1 Scenarios for emissions reductions of CH_4 and equivalent amount of CO_2 from business-as-usual[†] levels

Emission reduction target	GHG targeted	Description	Infrastructure construction emissions for CO_2 mitigation
30%	CH_4	Three-year linear reduction starting at year 0	–
	CO_2	Step-change reduction at year 5	1.20% of annual operations emissions spread evenly across years 0–5
80%	CH_4	Five-year linear reduction starting at year 0	-
	CO_2	Step-change reduction to 30% of business-as-usual emissions at year 5, and linear decrease over the next 10 years	Period of rapid build out in years 0–5 incurs 1.20% of annual operations emissions spread evenly across these years. Relatively slower build-out assumed for years 5–15 with 1.43% of annual operations emissions spread evenly across those years

[†]Business-as-usual levels: 100 CH_4 Tg/year; 8250 CO_2 Tg/year

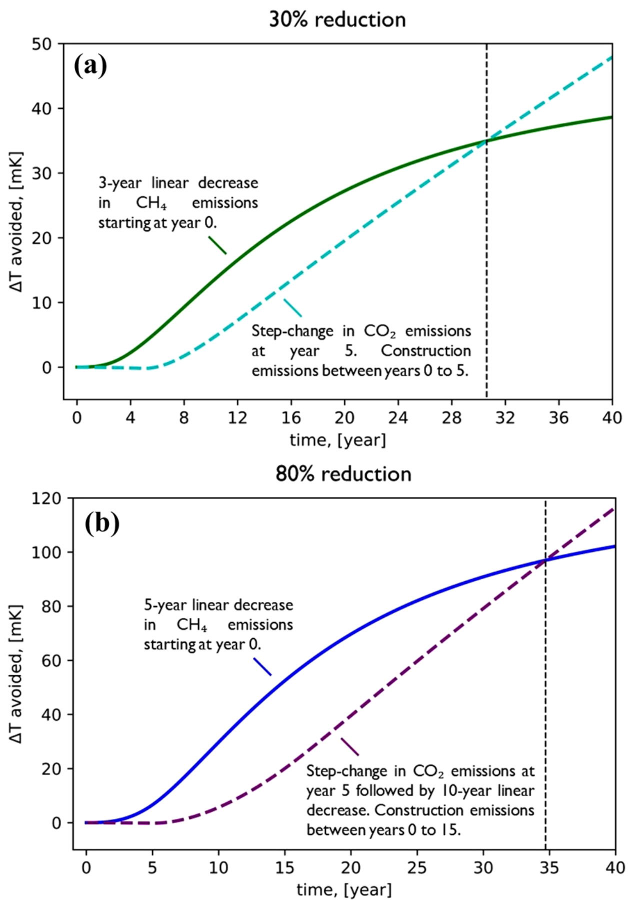

Fig. 1 Surface temperature change avoided relative to business-as-usual levels over a 40-year time horizon. Dashed vertical lines indicate the year at which ΔT avoided is equivalent for CH_4 and CO_2 reduction scenarios

with intermittent or low-bleed devices (Methane Guiding Principles 2022). We used the Economic Input–Output Life Cycle Assessment (EIO-LCA) model (Green Design Institute, 2022) and reported construction costs (Methane Guiding Principles 2022) to evaluate construction emissions associated with these transitions. Construction emissions are approximately 0.01% (installing electric pumps) to 0.5% (accelerated installation of low-bleed devices) of one year's worth of emissions reductions. In our analysis, these emissions are treated as negligible. Furthermore, CH_4 mitigation technologies applicable to the oil and gas sector are off-the-shelf with minimal lead time for construction. We, therefore, assumed installation could begin immediately.

The CH_4 and CO_2 mitigation scenarios in Table 1 were compared on the basis of relative global-average surface temperature increase avoided with respect to the business-as-usual scenario. The higher the value is, the better the mitigation effort. We used global surface temperature change models reported in the literature in our calculations (IPCC, 2022; Abernethy & Jackson 2022; Gasser et al 2017). The interested reader can find more information on the scenarios and modeling approach in the Supporting Information.

Rapidly scalable CH_4 reduction technologies outperform longer term options to cut CO_2 emissions

Figure 1 displays the effects of mitigation efforts over a 40-year time horizon. In interpreting this illustration, we focus on two primary results. First, the change in surface temperature increase avoided eventually levels off in the CH_4 reduction scenarios. This phenomenon reflects the short life of CH_4 in the atmosphere (half-life of 11.8 years) (IPCC, 2022). Given CH_4's short atmospheric lifetime, ultimately, the reduced CH_4 in the atmosphere leads to a reduction equivalent to technology-based emission reductions and the temperature change plateaus. Second, although the avoided surface temperature rise in CO_2 reduction scenarios is initially lower than in CH_4 reduction scenarios, eventually it catches up. After a crossover point, CO_2 emission reduction scenarios offer greater benefits. The dashed vertical lines in Fig. 1 mark this crossover point, which is on the order of decades.

Figure 1a compares the strategies that achieve 30% reduction in business-as-usual annual levels (100 Tg CH_4 or 8250 Tg CO_2). CH_4 reduction technologies are rapidly scalable and benefits associated with CH_4 reductions are evident beginning in year three. In contrast, the waiting period and emissions associated with construction of CCS facilities delay benefits from CO_2 emissions reductions until year eight. Accordingly, there is a five-year longer wait for any relief from climate change compared to its equivalent CH_4 scenario. Avoided temperature increases in the CH_4 scenario, however, begins to plateau after year 20. At this point, the temperature change avoided by CH_4 mitigation is 28 mK while the CO_2 mitigation scenario reaches only 20 mK. After about 31 years, the benefits of mitigating CO_2 exceed those of mitigating CH_4. At timescales beyond this point, the benefits of reducing CO_2 will outweigh those of reducing CH_4 by a large extent.

The trends in Fig. 1b, which reflect an aggressive 80% reduction in business-as-usual CH_4 emissions, are similar to those in Fig. 1a. However, global surface temperature change is more quickly avoided. For example, the first 20 mK of avoided surface temperature rise for CH_4 and CO_2 occur between years 14 to 20 when the emission reduction target is 30%, and between years 8 to 15 when it is 80%. The gap in the time required to achieve this benefit (between CH_4 and CO_2) is six and seven years, respectively. Avoided surface temperature rise takes 17 years longer to plateau in the 80% reduction scenario as compared to the 30% reduction scenario. The greater amount of CH_4 reduced (80% versus 30%)

causes benefits to accrue for longer. The benefits of reducing CO_2 emissions with CCS outstrip those of reducing CH_4 in the oil and gas sector in year 35 at 80% reductions. At this point, the avoided surface temperature rise is 97 mK, 62 mK greater than when the reduction target is 30%.

Relief from climate change comes sooner with scalable technology

Our analysis emphasizes two main points. First, construction and associated emissions delay the benefits of climate change mitigation technologies. Prioritizing quickly-deployable options that require limited construction helps to bring relief sooner. Second, GHG mitigation options that require longer to scale up can take decades to overtake quickly scalable solutions. The results we present add urgency to pursuit of rapidly scalable technologies.

One of the primary drivers of our analysis is the long lead times required for emissions from CCS to materialize. CCS is not unique in this regard. For example, transitioning from internal combustion engines to electric vehicles in the light-duty fleet will take decades. This transtition entails manufacturing and installation of charging infrastructure along with building factories to produce enough lithium-ion batteries to meet demand.

While our analysis emphasizes the importance of reducing CH_4 emissions in achieving short term climate goals, it is important to note that reducing CH_4 and CO_2 emissions does not require an either-or choice. CO_2 reductions provide long term benefits while CH_4 reductions provide near-term reductions in warming that will be important in mitigating the current impacts (Weiskopf et al. 2020; Sarkodie et al. 2022) of a changing climate.

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Data Availability Enquiries about data availability should be directed to the authors.

Declarations

Conflict of interest The authors have not disclosed any competing interests.

References

Abernethy S, Jackson RB (2022) Global temperature goals should determine the time horizons for greenhouse gas emission metrics. Environ Res Lett 17(2):024019

Abernethy S, O'Connor FM, Jones CD, Jackson RB (2021) Methane removal and the proportional reductions in surface temperature and ozone. Phil Trans R Soc A 379(2210):20210104

Cain M, Jenkins S, Allen MR, Lynch J, Frame DJ, Macey AH, Peters GP (2022) Methane and the Paris Agreement temperature goals. Phil Trans R Soc A 380(2215):20200456

Cuéllar-Franca RM, Azapagic A (2015) Carbon capture, storage and utilisation technologies: a critical analysis and comparison of their life cycle environmental impacts. J CO2 Util 9:82–102

Dreyfus GB, Xu Y, Shindell DT, Zaelke D, Ramanathan V (2022) Mitigating climate disruption in time: a self-consistent approach for avoiding both near-term and long-term global warming. Proc Natl Acad Sci 119(22):e2123536119

Gasser T, Peters GP, Fuglestvedt JS, Collins WJ, Shindell DT, Ciais P (2017) Accounting for the climate–carbon feedback in emission metrics. Earth Syst Dyn 8(2):235–253

Green Design Institute, Carnegie Mellon University (2022). Economic Input-Output Life Cycle Assessment (EIO-LCA). Available at: www.eiolca.net/ (Accessed Aug 2022)

Hmiel B, Petrenko VV, Dyonisius MN et al (2020) Preindustrial CH_4 indicates greater anthropogenic fossil CH_4 emissions. Nature 578:409–412

H.R.5376 – 117th Congress (2021-2022): Inflation Reduction Act of 2022 (IRA, 2022). (2022, August 16). http://www.congress.gov/. Accessed Aug 2022

Intergovernmental Panel on Climate Change (IPCC, 2022). Climate Change 2022 Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

International Energy Administration (IEA, 2022), Global Methane Tracker 2022, IEA, Paris. Available at: www.iea.org/reports/global-methane-tracker-2022 (Accessed August 2022).

Koornneef J, van Keulen T, Faaij A, Turkenburg W (2008) Life cycle assessment of a pulverized coal power plant with post-combustion capture, transport and storage of CO_2. Int J Greenhouse Gas Control 2(4):448–467

Methane Guiding Principles (2022). Reducing Methane Emissions: Best Practice Guide - Pneumatic Devices. November 2019. Available at: methaneguidingprinciples.org/wp-content/uploads/2019/11/Reducing-Methane-Emissions-Pneumatic-Devices-Guide.pdf (Accessed Aug 2022).

Ming T, Li W, Yuan Q, Davies P, De Richter R, Peng C, Zhou N (2022) Perspectives on removal of atmospheric methane. Adv Appl Energy. https://doi.org/10.1016/j.adapen.2022.100085

Sarkodie SA, Ahmed MY, Owusu PA (2022) Global adaptation readiness and income mitigate sectoral climate change vulnerabilities. Human Soc Sci Commun 9:113

Singh U, Algren M, Schoeneberger C, Lavallais C, O'Connell M, Oke D, Dunn JB (2022) Technological avenues and market mechanisms to accelerate methane and nitrous oxide emissions reductions. IScience. https://doi.org/10.1016/j.isci.2022.105661

Solomon S, Daniel JS, Sanford TJ, Murphy DM, Plattner GK, Knutti R, Friedlingstein P (2010) Persistence of climate changes due to a range of greenhouse gases. Proc Natl Acad Sci 107(43):18354–18359

Text – H.R.5376 – 117th Congress (2021–2022): Inflation Reduction Act of 2022 (IRA, 2022). (2022, August 16). http://www.congress.gov/ (Accessed August 2022)

Townsend A, Gillespie A (2020) Scaling up the CCS market to deliver net-zero emissions Thought Leadership Piece. Global CCS Institute, Beijing

U.S. Department of State (DOS, 2021). U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s. November 11, 2021. Available at: www.state.gov/u-s-china-joint-glasgow-declaration-on-enhancing-climate-action-in-the-2020s/. (Accessed May 2022)

U.S. Environmental Protection Agency (EPA, 2022), Biden-Harris Administration Strengthens Proposal to Cut Methane Pollution to Protect Communities, Combat Climate Change, and Bolster American Innovation. Available at: www.epa.gov/newsreleases/biden-harris-administration-strengthens-proposal-cut-methane-pollution-protect (Accessed November 2022)

Weiskopf SR, Rubenstein MA, Crozier LG, Gaichas S, Griffis R, Halofsky JE, Whyte KP (2020) Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. Sci Total Environ 733:137782