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• **News & Views** •

Negligible Warming Caused by Nord Stream Methane Leaks

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ABSTRACT

Unanticipated sabotage of two underwater pipelines in the Baltic Sea (Nord Stream 1 and 2) happened on 26 September 2022. Massive quantities of natural gas, primarily methane, were released into the atmosphere, which lasted for about one week. As a more powerful greenhouse gas than CO_2, the potential climatic impact of methane is a global concern. Using multiple methods and datasets, a recent study reported a relatively accurate magnitude of the leaked methane at 0.22 ± 0.03 million tons (Mt), which was lower than the initial estimate in the immediate aftermath of the event. Under an energy conservation framework used in IPCC AR6, we derived a negligible increase in global surface air temperature of 1.8×10^{-5} °C in a 20-year time horizon caused by the methane leaks with an upper limit of 0.25 Mt. Although the resultant warming from this methane leak incident was minor, future carbon release from additional Earth system feedbacks, such as thawing permafrost, and its impact on the methane mitigation pathways of the Paris Agreement, warrants investigation.

Key words: Nord Stream, methane leak, global warming potential, climatic impact

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On 26 September 2022, two subsea pipelines in the Baltic Sea, Nord Stream 1 and 2, used for transferring natural gas from Russia to Germany, were seriously sabotaged. After a series of explosions, huge bubbling disturbances ranging from 500 to 700 m across the water's surface above the pipeline ruptures were observed (Fig. 1). Four spill points were identified, and the visible leaks gradually stopped around 2 October. The primary component of natural gas is methane, which has a much stronger greenhouse effect than CO_2. Thus, this unprecedented methane leak has caused worldwide concern regarding its possible climatic and environmental impacts (Sanderson, 2022).

When the incident was reported by the world's media, experts immediately began to estimate the possible total amount of gas that would leak, based on a range of different platforms and methods (Table 1). Although the pipelines were not in operation at the time, initially, it was believed that the ultimate quantity of released methane may have been as large as 0.3 million tons (Mt) or even larger (up to 0.5 Mt), based on assumed pipeline volumes and the temperature, pressure and density of the gas. However, according to a specialist study reported by researchers from the Norwegian Institute for Air Research, the quantity of methane released into the atmosphere may only have been 0.056–0.155 Mt in total, suggesting an overestimation in the earlier calculations. They used an atmospheric transport model to retrieve the emissions from observations of atmospheric concentrations. This estimation was further updated to 0.22 ± 0.03 Mt on 26 October in a recent study led by researchers from Nanjing University (Jia et al., 2022). Two inversion methods, two meteorological reanalysis datasets, and multiple satellite-based observations were used in their study, which guaranteed the most up to date and accurate estimate so far.

High-resolution satellites play an important role in monitoring methane leaks (Sanderson, 2022). On 1 October, the first estimate of the emission rate by 30 September based on satellite observations was published by the Canadian satellite operator GHGSat. It reported that the leakage rate from a ruptured spot on the Nord Stream 2 pipeline was more than 20 t h^{-1}. However, based on data from China's Gaofen-5 02 satellite collected at the same location and at the same time, on 3 October a Chinese team reported a more accurate emission rate of 70 t h^{-1} (http://www.sitp.cas.cn/xwzx/kydt/202210/t20221003_6519940.html). Two days later, the GHGSat revised their estimate to 79 t h^{-1} (https://www.ghgsat.com/en/news-

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Fig. 1. Methane escaping from the Nord Stream 2 gas pipeline in the Baltic Sea (27 September 2022). Photo Credit: Danish Armed Forces.

Table 1. Estimated total quantity of leaked methane from the Nord Stream 1 and 2 pipelines based on different information sources.

Publication date	Estimated total emission (Mt)	Author and/or publisher	URL
2022.9.28	0.5 or 0.2	Associated Press	https://www.cbsnews.com/news/nord-stream-pipeline-record-leak-methane-baltic-seas-potent-greenhouse-gas/
2022.9.28	0.3	Umwelt Bundesamt	https://www.umweltbundesamt.de/en/press/pressinformation/leaks-in-nord-stream-1-2-will-cause-serious-climate
2022.9.29	0.18–0.27	Kelly Macnamara / Science Alert	https://www.sciencealert.com/experts-estimate-the-scale-of-the-nord-stream-pipelines-methane-leak
2022.9.30	0.115 (for Nord Stream 2 only)	Katharine Sanderson / Nature	https://doi.org/10.1038/d41586-022-03111-x
2022.10.4	0.2	Nick Ames / Energy Connects	https://www.energyconnects.com/opinion/features/2022/october/nord-stream-gas-pipeline-leaks-threaten-climate/
2022.10.5	0.07	Stéphane Orjollet / Phys.org	https://phys.org/news/2022-10-nord-stream-leaked-methane-atmospheric.html
2022.10.12	0.056–0.155	Christine Forsetlund Solbakken / Norwegian Institute for Air Research	https://www.nilu.com/2022/10/improved-estimates-of-nord-stream-leaks/
2022.10.26	0.19–0.25	Jia et al. (2022) / Environmental Science and Ecotechnology	https://www.sciencedirect.com/science/article/pii/S2666498422000667

room/ghgsat-nordstream). The total quantity of methane emitted into the atmosphere in the incident was roughly double that of the previous largest single emission from the oil and gas industry—namely, the Aliso Canyon disaster in 2015, in which approximately 0.1 Mt of methane leaked from an underground storage facility in California's Santa Susana Mountains (Conley et al., 2016).

Based on these expert estimations, this recent leakage from Nord Stream 1 and 2 could be one of the largest methane emission events in history. However, it is still trivial compared with emissions from other sources. During 2008–17, anthropogenic sources of methane amounted to around 360 Mt yr^{-1} (Canadell et al., 2021), mainly from agriculture and waste, fossil fuel–related industries, and biomass burning and biofuels. Even if only the oil and gas sectors are taken into account, emissions are still as high as 70 Mt yr^{-1}. If 0.25 Mt is chosen as an upper estimate of the methane leak in this incident, it is equivalent to only 1.3 days of emissions from the oil and gas sectors during 2008–17.

Although little climatic impact can be expected from this small-scale emission event (Sanderson, 2022), until now there had been no quantitative assessment of its warming effect. Here, we further estimate the possible warming potentially caused by the Nord Stream methane leaks in the near term (the next 20 years) under a framework of energy conservation and the concept of global warming potential (GWP). The absolute GWP (AGWP) is defined as the time-integrated radiative forcing after a pulse emission of unit mass, which represents the total energy trapped in the Earth system by a specific forcing agent (Myhre et al., 2013). Unlike the long-lived greenhouse gases such as CO_2, most atmospheric methane is gradually removed by reacting with hydroxyl radicals (Canadell et al., 2021). Based on the assessment in IPCC AR6, the methane perturbation lifetime is about 12 years. This means that the AGWP of methane will reach a maximum after a specific time, in contrast to the quasi-linear increase in CO_2 AGWP (Fig. 2).

The physical meaning of AGWP is straightforward, but the GWP is more commonly used, as a ratio of AGWP relative to CO_2. The GWP allows us to translate an emission from another forcing species to a CO_2 equivalent in the context of energy accumulation, and then estimate the corresponding climatic consequences using the well-established CO_2-oriented results. As a short-lived greenhouse gas, the GWP of methane depends strongly on the time horizon (Figure 2). Based on the latest assessed values in IPCC AR6 (Forster et al., 2021), the GWP in a 20-year time horizon is 82.5 ± 25.8, and this decreases to 29.8 ± 11 and 10.0 ± 3.8 for a 100- and 500-year time horizon, respectively.

Focusing on the 20-year time horizon, an upper limit of 0.25 Mt of leaked methane from the Nord Stream pipelines is equivalent to 20.6 Mt of CO_2. Such an amount would cause an increase in atmospheric CO_2 concentration of only $\Delta C = 2.6 \times 10^{-3}$ ppm (1 ppm ≈ 7.8×10^3 Mt CO_2). The logarithmic dependence of radiative forcing of CO_2 to concentration gives $\Delta F / F_{2\times} = \ln(1 + \Delta C / C_{\mathrm{ref}}) / \ln 2$ (Zhou and Chen, 2015), in which C_{ref} is a reference CO_2 concentration, set as the current value (410 ppm), and $F_{2\times}$ is the effective radiative forcing of a doubled CO_2 concentration relative to the pre-industrial period, which is 3.93 ± 0.47 W m^{-2}, according to the latest assessment in IPCC AR6 (Forster et al., 2021). Hence, the above equation derives an effective radiative forcing (ΔF) of only 3.6×10^{-5} W m^{-2} for the total leaked methane.

In the framework of energy conservation, the radiative forcing (ΔF) is nearly balanced by ocean heat uptake (ΔN) and enhanced outgoing radiation through increasing the global surface air temperature (ΔT). That is, $\Delta F = \Delta N - \lambda \Delta T$, in which λ represents the net climatic feedback, usually negative. The ocean heat uptake can also be simplified as a function of the temperature response, i.e., $\Delta N \approx \kappa \Delta T$, in which κ is the ocean heat efficiency. Thus, the transient temperature change, ΔT, can be estimated by $\Delta F / (\kappa - \lambda)$ (Zhou and Chen, 2015). The λ and κ reported in IPCC AR6 were −1.16 ± 0.40 W m^{-2} °C^{-1} and 0.84 ± 0.38 W m^{-2} °C^{-1}, respectively (Forster et al., 2021). Hence, the estimated transient global warming in a 20-year time horizon could be as low as 1.8×10^{-5} °C, which is trivial and negligible compared with the total warming trend and large internal

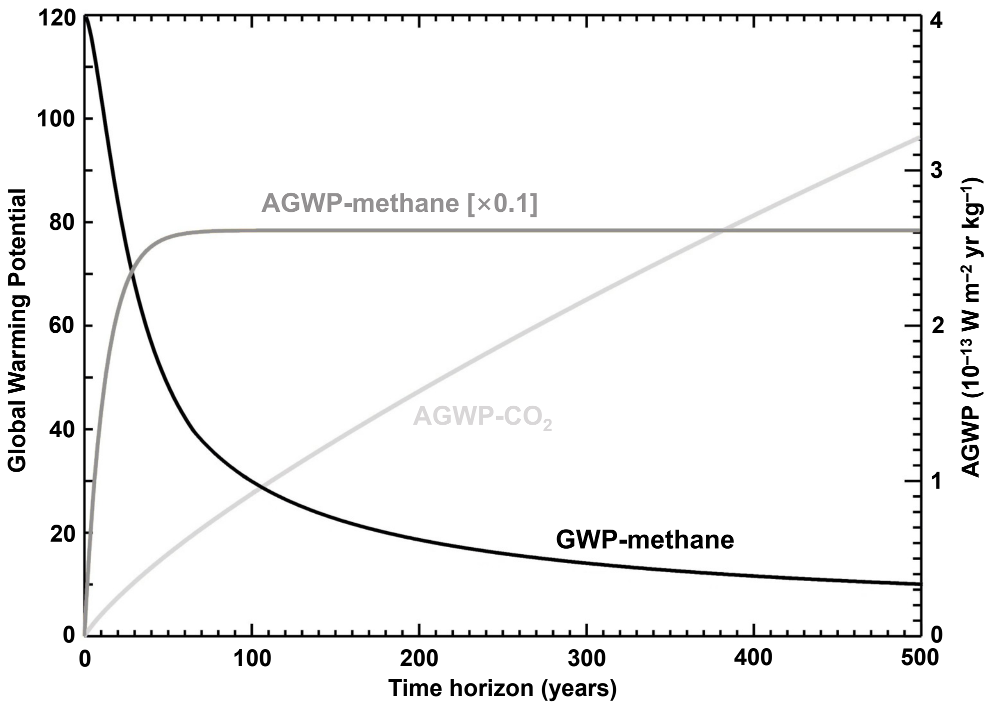

Fig. 2. Evolution of the AGWP (units: 10^{-13} W m^{-2} yr kg^{-1}) of methane and CO_2, and the GWP of methane with time horizon [modified from Fig. 8.29 in IPCC AR5 (Myhre et al., 2013), in which the GWP of methane was updated based on Table 7.15 in IPCC AR6 (Forster et al., 2021)].

variability of the climate system.

Although the methane leaks are unlikely to cause discernable climatic impacts, the total quantity of anthropogenic methane emissions is the second largest contributor to global warming (Forster et al., 2021). To realize the 1.5°C or 2°C warming target stated in the Paris Agreement, mitigation of methane emissions will play an important role in alleviating the additional warming caused by the mitigation of other short-lived climate forcers, such as aerosols and non-methane ozone precursors (Szopa et al., 2021). At the COP26 climate change conference in Glasgow last year, world leaders committed to slashing methane emissions by 30% by the end of this decade. With global warming, the thawed permafrost will also release carbon into the atmosphere, on a very large scale, at an estimated rate of 26 ± 97 Gt CO_2 °C^{-1} (Canadell et al., 2021). This means that the carbon emissions from thawing permafrost caused by an additional 0.5°C of warming could be 1000 times that of this Nord Stream leak incident. Such carbon emissions due to additional Earth system feedbacks will reduce the remaining carbon budget and pose huge challenges to achieving warming targets (Zhou and Chen, 2022). The feedbacks in the Earth system related to carbon reservoirs and methane removal methods are deserving of further study.

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