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RUSSIA'S METHANE EMISSIONS AND THE WAR IN UKRAINE

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Russia's invasion of Ukraine in February 2022 and the ensuing war have not only wreaked havoc in oil and gas markets, raising daunting energy and economic challenges for European and other energy-importing economies, but they have also spurred grave environmental and climate-related concerns. These arise in part from the impact of the conflict on import-dependent energy consumers, among whom record natural gas prices and heightened global competition for liquefied natural gas (LNG) supplies have encouraged a resurgence of coal burning and associated greenhouse gas (GHG) emissions, as well as a renewed policy focus on energy security, potentially at the expense of climate ambitions. But the conflict also raises serious concerns about the emissions trajectory of Russia itself, a top fossil fuel producer and leading GHG emitter. Even before the invasion, Russia counted among the world's main sources of anthropogenic methane (CH_4) emissions, a greenhouse gas whose short-term[1] warming power is more than 80 times that of carbon dioxide (CO_2). Since the invasion, the prospect of reducing these emissions has seemed increasingly unlikely. While the broader climate consequences of Russia's invasion of Ukraine have been debated at some length, neither its specific implications for Russia's methane outlook nor the mitigation options available to policy makers outside Russia have received the attention they warrant.

This commentary explores this issue with a focus on emissions from Russia's oil and gas sector. It begins with the question of how to quantify oil and gas methane emissions, including Russia's, then moves to Russia's responses to an evolving international methane regulatory environment, and concludes by evaluating the present and potential future effects of Russia's invasion of Ukraine on methane emissions and suggesting policy responses to these effects.

Sources of Methane Emissions

Over the last few years, discussions of the threat of GHG emissions to the stability of earth's climate have moved from an almost exclusive focus on carbon dioxide to the meaningful inclusion of methane, as exemplified during the 2021 United Nations Climate Change Conference (COP26) in November 2021 with the launch of the Global Methane Pledge[2] and the US-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s.[3] These measures were followed more recently by the US Inflation Reduction Act (IRA), which for the first time puts a price on methane and slaps a fee—rising from $900 per ton in 2024 to $1,500 per ton from 2026 onward—on methane emissions from certain oil and gas facilities.[4]

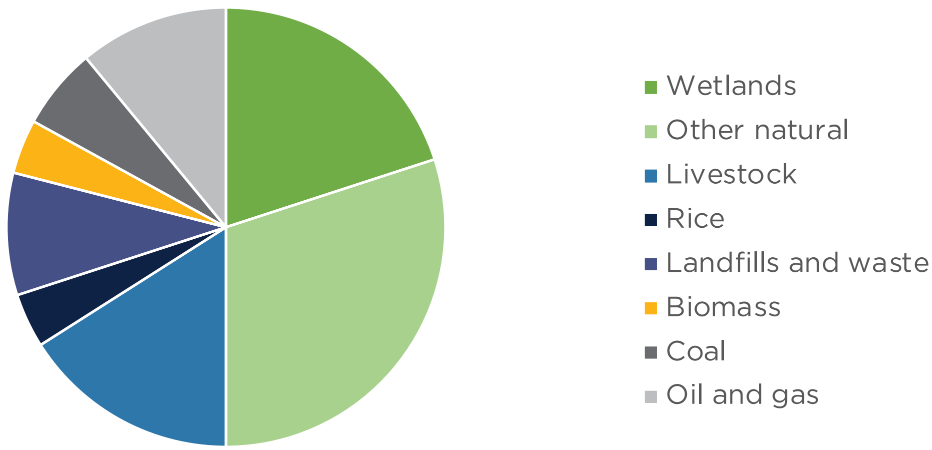
The earlier attention paid to CO_2 was understandable: CO_2 is the most important long-term atmospheric cause of climate change, and its drivers have long been well understood. By comparison, knowledge of methane emissions was paltry—until recently. It has now become apparent that methane, whose global warming power is more than 80 times that of CO_2 in the first 20 years, will contribute to *short-term* warming almost as much as CO_2 and that the only way to affect earth's average temperature between now and 2050 is to reduce emissions of methane.[5]

The alarming and accelerating rate of methane emission growth is another reason why these emissions have moved, so to speak, to the front burner. According to the International Energy Agency (IEA), "Today's concentrations of methane in the atmosphere are higher than at any time in at least 800,000 years, and methane has contributed around 30 percent of observed global warming to date."[6] US National Oceanic and Atmospheric Administration's (NOAA) newest data on methane emissions[7] shows movement in the wrong direction, meaning that the rate of change of global average temperature is likely to increase, not decrease, between now and 2050.

Finally, these emissions are in many ways easier to curb than those of carbon dioxide. The best current estimates[8] suggest that about half of methane emissions are from natural sources such as wetlands ("swamp gas") and the other half are due to human activity, including herds of cattle, landfills, wastewater treatment, and the fossil fuel sector. About a third of the human contribution, or 17 percent of total methane emissions, is associated with the production, transportation, and use of coal, oil, and natural gas (see Figure 1).

Recent research shows that the most practical and efficient way of curbing methane emissions is to target these latter emissions, which can be abated far more easily than those from other sources, and often at a low cost, through better operating practices and available technology.[9] Abating them now would help forestall the most catastrophic effects of climate change and open up the carbon space needed to work out longer-term solutions to carbon abatement.

Figure 1: Global inventory of methane emissions



Note: Natural sources are in green; anthropogenic sources are in other colors.
Source: Jackson et al. 2020.

Important factors to consider related to methane include the following:

- Unlike carbon emissions, methane emissions are not an inevitable outcome of fossil fuel consumption, nor are they a necessary by-product of fossil fuel production.
- An estimated 8 to 12 percent of methane emissions from oil and gas come in the form of so-called superemitters or ultraemitters, which are sporadic events in which methane is emitted for a brief period of time at a highly concentrated rate of tens to hundreds of tons per hour.[10] Such events can release as much CO_2 in a few hours as tens or hundreds of thousands of cars over a full year. Most can be avoided easily with existing, affordable technology.
- Methane is the primary constituent of natural gas, a valuable and widely marketed fuel.
- Under certain assumptions, some methane-mitigation measures carry the added benefit of paying for themselves.[11]
- Oil and gas supply chains are mostly managed by large industrial organizations that are technically sophisticated and well capitalized. A notable exception is the relatively small, privately owned companies that account for a large share of production from the Permian Basin and other US tight oil and gas basins and for a disproportionate share of these basins' methane emissions.
- Emissions from natural sources, agriculture, landfills, wastewater treatment, and biomass burning are deemed harder to control.

Attributing Methane Emissions: Problems and Potential Solutions

While global measurements of atmospheric concentrations of methane, such as those reported by NOAA, are very accurate, attributing methane to specific countries and facilities and quantifying how much is emitted by each source is more difficult. National inventories reported to the United Nations Framework Convention on Climate Change (UNFCCC) are engineering estimates—essentially spreadsheet exercises based on "emission factors"—that fail to account for downtime, maintenance, equipment failure, and other sources of emissions. Extensive surveys based on new technologies have shown that the emission factor method dramatically underestimates actual emissions.[12]

In addition to aerial surveys (by planes or drones) and ground sensors, a growing number of earth-orbiting satellites are measuring methane emissions with various combinations of sensitivity, geographic coverage, revisit frequency, and spatial resolution.[13] Even as this expanding fleet has been beaming a growing mass of raw data back to earth, advances in image processing, powered by artificial intelligence and made possible by the growth in computing capacity and the increasing affordability of data storage, have helped extract ever more precise signals from these images. Working in parallel, teams of data scientists have exploited input from two high-frequency satellites from the European Space Agency's Copernicus constellation, Sentinel-5 Precursor and Sentinel-2. Their research has shed light on so-called superemitters, leading to the identification, quantification, and attribution of thousands of these very large but intermittent plumes of methane caused by fossil fuel extraction and transportation.[14] Satellite imaging also enables basin-level emission estimates for many, though not all, producing regions.[15]

Despite these advances, satellites still have blind spots, notably in offshore, very humid, and/or snowy areas, and exhibit strong biases at very high and very low latitudes. It is thus broadly acknowledged in the scientific community that while satellite imaging can produce basin-level inversions for various producing regions, it is not yet ready for global-scale inversions.[16] Satellite detection is also limited by relatively high detection thresholds that limit its ability to capture small but steady leaks or to measure emissions from cattle farming, other human activities, or natural causes.[17] Due to the albedo[18] and latitude effects, there is currently no valid, comprehensive satellite-based estimate of Russian methane emissions at the country level, even as a great wealth of knowledge exists about many individual methane emission events in Russia.

While there is still much to be discovered about anthropogenic methane emissions, the knowledge already accumulated is more than sufficient to enable effective abatement measures. The cross-referencing of various studies and measurements performed by different teams has permitted the crystallization of a scientific consensus around the accuracy of recent methane detections. This was reflected in 2021 by the launch of the International Methane Emissions Observatory (IMEO), a new multilateral organization initiated by the UN Environment Program and the European Commission to serve as a global clearinghouse of methane measurements.[19] In conjunction with national and regional initiatives such as the methane provisions of the US IRA and the EU methane strategy, the launch of the IMEO sets the stage for more active international coordination of methane abatement efforts. This could include a system of border adjustment mechanisms to level the international playing field and curb methane "leakage" or the offshoring of methane emissions from economies with strong methane regulations to more permissive ones.

Estimating Russia's Methane Emissions

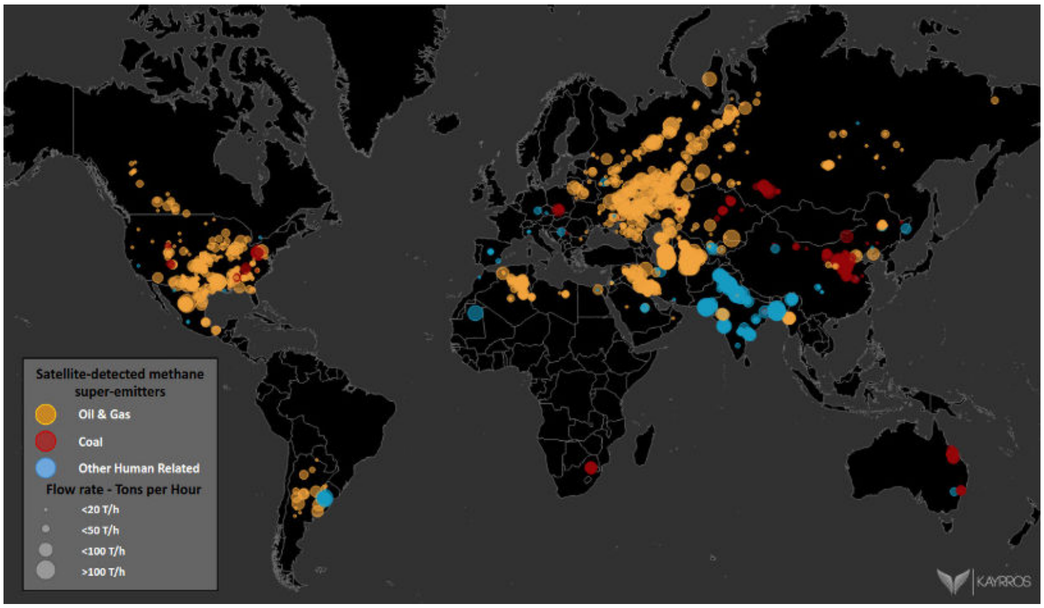
According to the IEA Global Methane Tracker, Russia ranks first in terms of volume of methane emissions from oil and gas operations and use,[20] closely followed by the United States. Of the estimated 80 million tons of methane globally emitted by extracting, processing, and transporting oil and natural gas, Russia and the United States are each responsible for about 14 million tons.

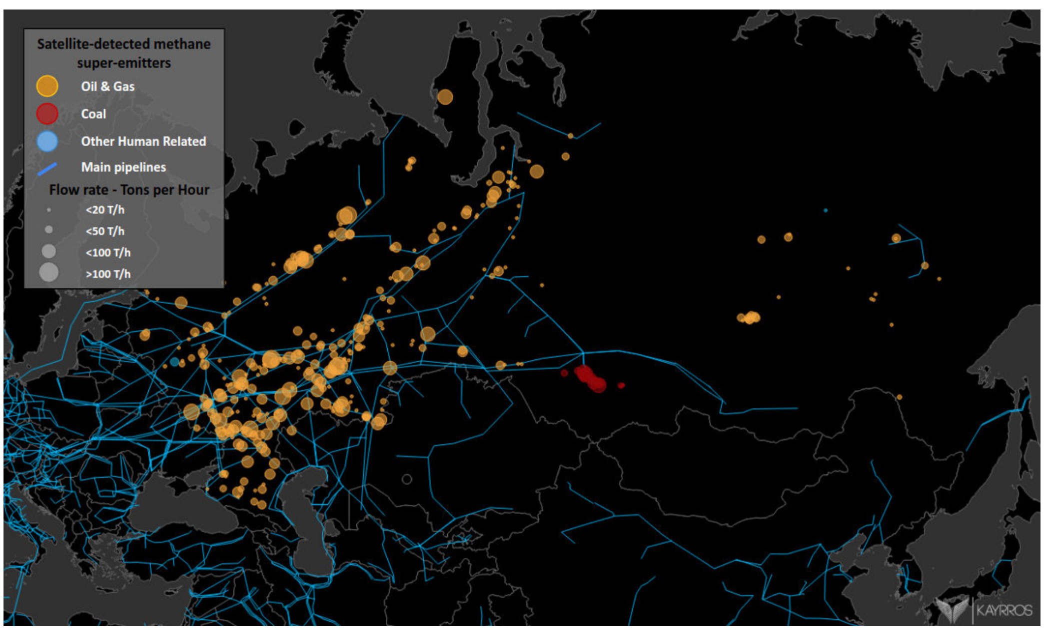
As a UNFCCC Annex 1 country, Russia submits an annual report to the UNFCCC Secretariat detailing its GHG emissions.[21] In 2021, Russia reported four million tons of methane emissions from its oil and gas sector—30 percent of the IEA estimate. Although no one should be better positioned to monitor the operations of the very large and far-flung Russian oil and gas industry than Russia itself, it is hard to take Russian methane emission reports seriously, if only because the numbers change substantially from year to year. Russia has also repeatedly changed how it estimates its methane emissions.[22]

Satellite monitoring provides a measure for independently, if partially, assessing and benchmarking Russia's methane performance. This measure is so far limited to superemitters, which account for only a fraction of the total methane emissions attributable to the country's fossil fuel industry—albeit a large and relatively easy to abate one. Moreover, in Russia, satellite monitoring likely only captures a fraction of all superemitters, due to the ineffectiveness of satellites in snowy offshore regions like northern Russia. Nevertheless, according to a recent study of some 1,800 superemitters identified by analyzing atmospheric methane images sampled by the TROPOspheric Monitoring Instrument, a sensor carried by the Sentinel-5P satellite of the European Space Agency, in 2019 and 2020 a large proportion of these events were concentrated in Russia,[23] mainly near the Yamal and Brotherhood pipelines, which bring Russian gas to European markets. The database analyzed by that study has since been updated. Based on the new data, from January 2019 to mid-September 2022, Russia alone was responsible for roughly 16 percent of the world's superemitters attributed to the oil and gas sector (330 out of 2,127 events) and 10 percent of the superemitters attributed to the coal sector (52 out of 511).[24]

Detections of Russian superemitters have attracted growing media interest. In response, Russia's main gas producer, Gazprom, which has been surprisingly forthcoming about its pipeline emissions, has often taken pains to corroborate news reports about these emissions, explaining they were deliberate releases performed during maintenance operations, and in some cases even providing specific estimates of the total volumes released into the atmosphere.[25]

Figure 2: Global methane superemitters, January 2019 to September 2022





Source: Images courtesy of Kayrros (containing modified European Space Agency Copernicus data).

Russia's Stance on Methane Emissions Prior to the War

The invasion of Ukraine came at a time when Russian energy companies were increasingly waking up to the need to reduce their climate footprint and thus preserve their export markets and license to operate. As noted above, Moscow refrained from joining the Global Methane Pledge at COP26. As early as 2018, however, Russian oil and gas–producing companies started to join global initiatives by the oil and gas industry to reduce its methane footprint. That year, state-owned Gazprom, the country's dominant gas producer and gas pipeline monopoly, joined the Methane Guiding Principles partnership, an international coalition of industry and civil-society organizations established at the end of 2017 to provide guidelines on reducing methane emissions along the natural gas value chain.[26] It has since accelerated its plans to ratchet down its methane emissions,[27] including by purchasing five mobile compressor stations, in addition to its existing fleet of 10 units, to reduce the need for venting during pipeline maintenance.[28] In October 2020, private Russian gas producer Novatek likewise joined the Methane Guiding Principles and has since taken steps to report and reduce its methane emissions and to document its progress in doing so.[29]

At a global summit on climate convened by US President Joe Biden in April 2021, President Vladimir Putin, under pressure from satellite detections of Russian methane leaks, departed from his previous stance on climate change by drawing attention to the warming impact of methane emissions and urging international cooperation on their abatement.[30] This reversal may well have been more reactive than proactive. In other words, President Putin might have been responding to commercial concerns among Russia's industrial leaders—the need to maintain market share and export revenues and preserve their license to operate—rather than environmental ones. In the two years preceding the invasion of Ukraine, Russia had been at the receiving end of European pressure to reduce its methane footprint. In October 2020, the European Commission launched its methane strategy, the methane piece of the broader European Green Deal that was unveiled a year earlier, in December 2019.[31] Given that until the invasion of Ukraine, Europe was by far the largest market for Russian exports of both oil and gas, changes in its emissions policies carried momentous implications for Russia's main export industry. In 2021 and into 2022, the European Commission considered a carbon border adjustment mechanism (CBAM) to mitigate carbon leakage from its Emissions Trading System (ETS). As the gases covered by the EU ETS include CH_4 in addition to CO_2, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, the European Commission naturally considered including CH_4 in the scope of its prospective CBAM.[32] Both Gazprom and Novatek understood that an EU CBAM could penalize Russian gas exports if the latter were deemed to have a high methane intensity. As a Gazprom executive explained to one of the authors at the company's biannual environmental and climate conference in Moscow in December 2021, "If Russia wants to keep selling gas to Europe, it has to cut methane."[33] By threatening to put a price on methane, EU legislation turns the methane intensity of natural gas as a competitive factor for producers seeking to gain or maintain access to the European market. Similarly, in late 2020 the French government canceled a long-term gas supply contract between French utility Engie and US supplier NextDecade, a decision widely reported as inspired by concerns over the methane footprint of US natural gas.[34]

The Impacts of Russia's Invasion on Methane Emissions

The shock of Russia's invasion of Ukraine on February 24 triggered a movement by Europe, historically the main market for Russian oil and gas, to rapidly reduce its dependence on Russian energy. In the immediate aftermath of the invasion, several European oil and gas companies, including bp, Shell, and TotalEnergies, announced that they would divest their Russian oil and gas assets and wind down their purchases of Russian oil and gas. On March 8, the EU pledged to cut Russian gas imports by two-thirds before the end of the year. The European Commission has also said it wanted Europe to stop buying fossil fuels from Russia by 2030.[35] (According to recent data, the EU imports around 45 percent of its natural gas and 25 percent of its oil from Russia.[36]) More recently, the EU took an even tougher stance, adopting a full ban on imports of Russian crude starting December 5, 2022. A similar ban on refined products will follow in February 2023. The Group of Seven has likewise been considering steps that, if implemented, would impose a ceiling on Russian crude and product prices, effectively capping Russia's oil export revenue without curtailing all Russian oil supplies to the global market.

Meanwhile, Moscow has been diligently weaponizing its gas exports, playing on European (and global) fears of a supply shortfall to undermine European support for Ukraine. Gazprom started restricting westward gas exports even before the invasion, as early as the fall of 2021, keeping European prewinter gas reserves artificially low, boosting gas prices, and exacerbating the continent's dependence on continued Russian shipments to keep the lights, and heaters, on in the winter. Since the invasion, it has repeatedly curtailed exports via the Nord Stream pipeline. On August 31, Gazprom halted Nord Stream gas shipments to Europe, ostensibly for three days of planned maintenance, a shutdown it subsequently extended indefinitely, in open retaliation against European sanctions. On September 27, three underwater blasts ripped through both stems of the Nord Stream pipeline, causing a massive methane release and potentially severe structural damage to the lines and further extending their shutdown—effectively downgrading Russia's export capacity to Europe for the foreseeable future. On October 1, Gazprom further restricted its exports by halting deliveries to Italy on grounds of "Austrian regulatory changes."[37] Russia's weaponization of its gas exports along these lines, however effective or ineffective it may prove in the short term, is bound in the longer run to drive Russian oil and gas out of what had traditionally been Russia's commercial backyard.[38]

Although methane emissions may not be "top of mind" for either party of this conflict, these moves by Europe and Russia carry the risk of upending any earlier momentum toward methane abatement in Russia, a prospect made more likely by the underwater blasts that crippled the Nord Stream gas pipeline.[39] There are three reasons for this: first, Russia's pivot to the east and other countries in search of new market outlets will likely mean less pressures for methane abatement; second, Western sanctions and the progressive deterioration of Russia's economy will severely constrain its technical capacity to control and reduce its emissions; and third, a looming reduction in overall exports and production capacity will likely come hand in hand with increased venting and flaring.

On the oil front, Russia has the option of redirecting its exports away from Europe, toward India, China, and other developing countries, and has already started doing so. These markets may not be as set as Europe on pressuring Russia to reduce its emissions. On the gas front, Russia has no such flexibility. Existing gas pipelines to the Far East, which are still ramping up to capacity, are designed to handle eastern production and cannot accommodate additional volumes from historical western fields and the Yamal Peninsula that are normally exported to Europe. Russia lacks the connectivity to easily switch piped exports from west to east. The outlook for Gazprom's methane footprint postinvasion looks as uncertain as its ability to find buyers for the gas it is diverting from Europe. Russia's future participation in international pipeline and LNG consortia based on clear and transparent emission-verification protocols now looks doubtful, and best practices seem unlikely to be systematically adopted.

Novatek, which exports its gas in liquefied form, is better positioned than Gazprom because it benefits from the inherent flexibility of LNG markets and may wish to keep its LNG production compliant with the highest environmental, social, and governance standards in order to command the highest prices, to the extent that non-European buyers are willing to pay such a premium. The company currently appears to account for only a small proportion of the overall emissions from Russia's gas sector. In the longer run, Russia's LNG export plans also face significant challenges. Russia's liquefaction equipment is largely imported, while a looming recession puts domestic gas demand at risk.

In this situation of impending gas glut, any financial incentive to reduce Russia's methane footprint by capturing fugitive emissions looks compromised. In a worst-case scenario, Russia could resort to routine flaring or venting of associated gas from critical oil production sites that it doesn't wish to idle. It could also opt to chronically flare or vent nonassociated gas in response to shifts in domestic demand, causing some wells to temporarily shut in the absence of export outlets, as a way to relieve any dangerous buildup of gas pressure that would normally feed into compression facilities. In June 2022 and again in August 2022, Gazprom's suspension of gas exports via Nord Stream already resulted in temporary but dramatic increases in flaring at Portovaya, the pipeline's loading point on the Finnish border.[40]

Mounting economic pressures will compound the effect of resource depletion to further cloud methane-abatement prospects. Amid deepening economic sanctions, it will become increasingly difficult for Russian companies to procure methane-emission-controlling equipment. Currently, most of the sensors, drones, software, and other tools used for methane detection and abatement are imported, and tools labeled as Russian made are typically assembled in Russia but made of now-restricted foreign-made parts.[41]

On the oil side, there is already a significant backlog in reducing methane emissions. At certain oil fields with no direct way of using associated petroleum gas (APG), significant amounts are still vented or flared. Russian oil companies are already facing production decline and expect more in the future, and they would be hardly able, let alone inspired, to invest in new APG-utilization projects, at least for the foreseeable future.[42]

Policy Options

Russia's methane-abatement efforts are just one of the many potential casualties of the war waged by Moscow in Ukraine. At the time of writing, the number of uncertainties surrounding the conflict is mind boggling. The outcome of the war remains unsettled, along with Russia's willingness to deploy nuclear or other nonconventional weapons, its longer-term sociopolitical stability, and the ability of the Putin regime to survive repeated military setbacks and heavy losses in Ukraine as well as rising discontent at home following a disorderly, precipitous, and highly unpopular mobilization. Assuming the current regime remains in place, the prospect of continued or even rising methane emissions in Russia, whether due to deteriorating conditions on the ground or an export shift toward more permissive markets, threatens to severely undermine global emission-abatement efforts.

The West's ability to nudge Russia toward better climate stewardship has clearly suffered a setback, but it has not altogether vanished. While Europe can no longer use CBAM directly to influence Russia, Western countries can still leverage CBAM indirectly by targeting exports of manufactured goods from large consumers of unabated Russian oil and gas. In effect, Europe and other importers can delegate to these third-party countries the responsibility of demanding stronger climate stewardship from Russia or face price adjustments for their own exports of energy-intensive goods.

Furthermore, recent developments in remote sensing and earth observation technologies enable Western countries to independently monitor the climate performance and GHG emissions of Russia and its trading partners. Although these technologies still have some blind spots, the mass of independent, science-based information they provide in near real time is more than sufficient to be actionable. These robust, verifiable data can form the basis of border adjustments.

Finally, Western countries can preserve the option of direct incentives for good Russian climate performance by committing to resume energy trade relations with Russia and help Russian companies reduce their footprint in the event of a policy shift in Moscow.

Notes

The authors would like to thank Anne-Sophie Corbeau and the anonymous reviewers for their helpful input.

1. Over a 20-year period.

2. Global Methane Pledge, https://www.globalmethanepledge.org.

3. While China did not join the Global Methane Pledge, its bilateral declaration with the US is heavily focused on finding a clear and concrete pathway for substantial methane abatement. See US Department of State, "U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s," press release, November 10, 2021, https://www.state.gov/u-s-china-joint-glasgow-declaration-on-enhancing-climate-action-in-the-2020s.

4. The IRA methane charge only applies to facilities that are mandated to report their GHG emissions to the Environmental Protection Agency's Greenhouse Gas Emissions Reporting Program (GHGRP). Since 2011, nearly 8,000 such facilities have reported their emissions to the GHGRP. Among those facilities, the methane charge only applies to those that emit at least 25,000 million metric tons of CO_2e (mtCO_2e) per year and to emissions that exceed a certain threshold that varies by facility type: for oil and gas production facilities, emissions that exceed 0.2 percent of the natural gas sent to sale from such a facility; for nonproduction facilities, such as gathering and boosting facilities, emissions that exceed 0.05 percent of the natural gas sent to sale; and for gas transmission facilities, emissions that exceed 0.11 percent of the gas sent for sale from the facility. The Congressional Research Service (CRS) estimates that based on 2019 reported emissions, roughly 43 mtCO_2e would be subject to the fee, bringing a gross revenue of $1.13 billion in 2026 and $1.87 billion two years later. However, the data geo-analytics firm Kayrros reckons that based on satellite measurements of methane emissions, many more facilities would be required to report to the GHGRP than is currently the case based on corporate self-reporting. Furthermore, most of the qualifying facilities emit far more than is generally reported. Thus, the potential revenue brought by the methane fee, based on current emission rates, could be at least three times as much as estimated by the CRS "if the industry fails to adopt preventative measures in the form of the latest satellite technology." See Jonathan Ramseur, *Inflation Reduction Act Methane Emissions Charge: In Brief*, Congressional Research Service, updated August 29, 2022, https://crsreports.congress.gov/product/pdf/R/R47206; and Andrew Freedman, "Tracking the Oil Industry's Methane Exposure," Axios Generate, September 19, 2022, https://www.axios.com/newsletters/axios-generate-258137e8-7db5-43a3-b3b6-3d0da0c9c3ce.html.

5. Drew Shindell, Johan C. I. Kuylenstierna, Elisabetta Vignati, Rita van Dingenen et al., January 13, 2012, "Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security," Science 335: 183–9, https://science.sciencemag.org/content/335/6065/183/.

6. International Energy Agency, "Overview," Global Methane Tracker 2022, https://www.iea.org/reports/global-methane-tracker-2022/overview (accessed May 1, 2022).

7. National Oceanic and Atmospheric Administration, "Increase in Atmospheric Methane Set Another Record during 2021," April 7, 2022, https://www.noaa.gov/news-release/increase-in-atmospheric-methane-set-another-record-during-2021.

8. Robert B. Jackson, Marielle Saunois, P. Bousquet, Josep G. Canadell et al., "Increasing Anthropogenic Methane Emissions Arise Equally from Agricultural and Fossil Fuel Sources," *Environmental Research Letters* 15, 071002 (2020); 2017 bottom-up estimates. https://doi.org/10.1088/1748-9326/ab9ed2.

9. See, for example, International Energy Agency, Global Methane Tracker 2022, "Based on recent elevated natural gas prices, almost all of the options to reduce emissions from oil and gas operations worldwide could be implemented at no net cost" (https://www.iea.org/reports/global-methane-tracker-2022/overview).

10. Thomas Lauvaux, Clément Giron, Matthieu Mazzolini, Alexandre d'Aspremont et al., "Global Assessment of Oil and Gas Methane Ultra-Emitters," *Science* 375 (2022): 557–61, https://www.science.org/doi/10.1126/science.abj4351.

11. International Energy Agency, "Strategies to Reduce Emissions from Fossil Fuel Operations," Global Methane Tracker 2022, https://www.iea.org/reports/global-methane-tracker-2022/strategies-to-reduce-emissions-from-fossil-fuel-operations (accessed May 1, 2022).

12. See, for example, R. A. Alvarez, Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley et al. 2018, "Assessment of Methane Emissions from the U.S. Oil and Gas Supply Chain," Science 361, no. 6398 (June 21, 2018), https://science.sciencemag.org/content/361/6398/186; and Clean Air Task Force, "The IEA's Methane Tracker Shows Massive Underestimation of Methane Emissions in National Inventories," April 8, 2022, https://www.catf.us/2022/04/ieas-methane-tracker-shows-massive-underestimation-methane-emissions-national-inventories/.

13. Daniel J. Jacob, Daniel J. Varon, Daniel H. Cusworth, Philip E. Dennison et al., "Quantifying Methane Emissions from the Global Scale Down to Point Sources Using Satellite Observations of Atmospheric Methane," *Atmospheric Chemistry and Physics* 22, no. 14 (July 29, 2022), https://doi.org/10.5194/acp-22-9617-2022.

14. Lauvaux, Giron, Mazzolini, d'Aspremont et al., "Global Assessment of Oil and Gas Methane Ultra-Emitters."

15. See Steven Mufson, "World Pledged to Cut Methane. Emissions Are Rising Instead, Study Finds," *Washington Post*, June 27, 2022, https://www.washingtonpost.com/climate-environment/2022/06/27/methane-emissions-rising-report/. For disclosure, one of the authors of this paper, Antoine Halff, is a cofounder and employee of Kayrros, a company that uses satellite imagery and analytics to measure methane emissions.

16. "Inversion" refers here to the process of converting atmospheric measurements of methane concentrations into measurements and attributions of actual *emissions*, using sophisticated dispersion models that factor in prevailing meteorological conditions (e.g., wind) and the dispersive properties of methane under different weather conditions.

17. R. L. Kleinberg, "Methane Emissions from the Fossil Fuel Industries of the Russian Federation," in preparation.

18. The albedo effect refers to the reflection of sunlight on marine or snow-covered areas, which interferes with satellite detections and undermines satellite-based measurements of methane emissions. Studies led by a team of scientists at the Valencia Polytechnic University in Spain have recently detected large offshore methane leaks in the Gulf of Mexico. These were one-off detections that benefited from favorable weather conditions and cannot yet be replicated at scale as part of an ongoing monitoring system, however. See European Space Agency, "Methane Emissions Detected over Offshore Platform in the Gulf of Mexico," September 6, 2022, https://www.esa.int/Applications/Observing_the_Earth/Methane_emissions_detected_over_offshore_platform_in_the_Gulf_of_Mexico.

19. European Commission, "International Methane Emissions Observatory Launched to Boost Action on Powerful Climate-Warming Gas," October 31, 2021, https://ec.europa.eu/commission/presscorner/detail/en/IP_21_5636. See also https://www.unep.org/explore-topics/energy/what-we-do/methane.

20. International Energy Agency, "Overview," Global Methane Tracker 2022, https://www.iea.org/reports/global-methane-tracker-2022/overview.

21. United Nations Framework Convention on Climate Change, "National Inventory Submissions 2003–2021," https://unfccc.int/ghg-inventories-annex-i-parties/2021.

22. Steven Mufson, Isabelle Khurshudyan, Chris Mooney, Brady Dennis et al., "Russia Allows Methane Leaks at Planet's Peril," Washington Post, October 19, 2021, https://www.washingtonpost.com/climate-environment/interactive/2021/russia-greenhouse-gas-emissions/.

23. "Estimated emissions from O&G ultra-emitters rank highest for Turkmenistan…followed by Russia, the US (excluding the Permian basin), Iran, Kazakhstan, and Algeria." In Lauvaux, Giron, Mazzolini, d'Aspremont et al., "Global Assessment of Oil and Gas Methane Ultra-Emitters."

24. Data from Kayrros Methane Watch platform consulted on September 18, 2022 (www.kayrros.com).

25. See, for example, the above-mentioned *Washington Post* article, "Russia Allows Methane Leaks at Planet's Peril," which US Special Climate Envoy John Kerry referenced when he presented the Global Methane Pledge at COP26 in Glasgow. Among media groups, Bloomberg News stands out for the scope of its reporting on methane emissions, including several stories focused on emission events in Russia. These include "Russia's Gazprom Released Five Methane Plumes during Pipe Repairs," Bloomberg News, April 4, 2022, https://www.bloomberg.com/news/articles/2022-04-04/russia-s-gazprom-released-five-methane-plumes; Aaron Clark and Irina Reznik, "Big Methane Plume Seen from Space on Day of Russian Pipe Repair," Bloomberg News, October 25, 2021, https://www.bloomberg.com/news/articles/2021-10-25/big-methane-plume-seen-from-space-on-day-of-russian-pipe-repair; and Aaron Clark and Dina Khrennikova, "Huge Methane Leak Spotted by Satellite Came from Gazprom Pipeline," Bloomberg News, June 18, 2021, https://www.bloomberg.com/news/articles/2021-06-18/gazprom-admits-to-massive-methane-leaks. In 2021, Bloomberg News' methane reporting won a Society for Advancing Business Editing and Writing award for international reporting and the following year was a finalist for the 2022 Gerald Loeb Explanatory Award.

26. The eight founding signatories of the Methane Guiding Principles include seven European oil and gas companies—BP, ENI, Repsol, Statoil, Shell, TotalEnergies, and Wintershall—and one US company, ExxonMobil. Its five principles are as follows: continually reduce methane emissions; advance strong performance across the gas supply chain; improve accuracy of methane emissions data; advocate sound policy and regulations on methane emissions; and increase transparency. (See https://www.methaneguidingprinciples.org; and CCAC Secretariat, "Eight Energy Companies Sign Guiding Principles to Reduce Methane

Emissions," November 22, 2017, https://www.ccacoalition.org/en/news/eight-energy-companies-sign-guiding-principles-reduce-methane-emissions.)

27. Methane Guiding Principles, "Methane Guiding Principles Signatory Reporting: Gazprom," January 15, 2021, https://methaneguidingprinciples.org/wp-content/uploads/2021/01/Methane-Guiding-Principles_Reporting-Gazprom.pdf.

28. Statement by Alexander Ishkov, Gazprom's energy conservation and environment chief, at Gazprom's Seventh International Environmental Safety in the Gas Industry Conference (ESGI-2021), reported in Interfax: "Gazprom prepared to share data with critical environmentalists from Kayrros, set on 'objective cooperation,'" December 7, 2021 (available at https://interfax.com/newsroom/top-stories/73327/).

29. Methane Guiding Principles, "Methane Guiding Principles Signatory Reporting: PAO Novatek," January 2022, https://methaneguidingprinciples.org/wp-content/uploads/2022/01/NOVATEK_Methane-Guiding-Principles-Reporting-2022.pdf.

30. Joe Lo, "Putin Sounds Methane Alarm, under Satellite Surveillance and EU Pressure," Climate Home News, April 27, 2021, https://www.climatechangenews.com/2021/04/27/putin-sounds-methane-alarm-satellite-surveillance-eu-pressure/.

31. European Commission, "Reducing Greenhouse Gas Emissions: Commission Adopts EU Methane Strategy as Part of European Green Deal," press release, October 14, 2020, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1833.

32. Jana Titevskaia and Henrique Morgado Simões, with Alina Dobreva, "EU Carbon Border Adjustment Mechanism: Implications for Climate and Competitiveness," European Parliamentary Research Service, July 2022, https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698889/EPRS_BRI(2022)698889_EN.pdf.

33. The conversation took place at the Moscow headquarters of Gazprom VNIIGAZ LLC on December 7, 2021. On that occasion, Gazprom went public with its intention to collaborate with climate data company Kayrros on measuring its methane emissions. See Interfax, "Gazprom Prepared to Share Data with Critical Environmentalists from Kayrros, Set on 'Objective Cooperation,'" December 7, 2021, https://interfax.com/newsroom/top-stories/73327/. The article also reports that in October 2021, Novatek signed an agreement with Kayrros "on a joint pilot project to improve the methodology for tracking, detecting, monitoring and measuring methane emissions at Novatek's fields."

34. See, for example, Collin Eaton and Sarah McFarlane, "France's Engie Backs Out of U.S. LNG Deal," *Wall Street Journal*, updated November 3, 2020, https://www.wsj.com/articles/frances-engie-backs-out-of-u-s-lng-deal-11604435609 (accessed November 23, 2022). "Last month," the article explains, "Politico and French news outlet La Lettre A reported that the French government, which owns about 24% of Engie, had pushed Engie to delay or cancel the deal over concerns about the environmental and climate impact of fracking, and related emissions of methane, a potent greenhouse gas."

35. Silvia Amaro, "EU Pledges to Cut Russian Gas Imports by Two-Thirds before the End of

the Year," CNBC, March 8, 2022, https://www.cnbc.com/2022/03/08/eu-pledges-to-cut-russian-gas-imports-by-two-thirds-before-next-winter.html.

36. See IEA, "How Europe Can Cut Natural Gas Imports from Russia Significantly within a Year," March 3, 2022, https://www.iea.org/news/how-europe-can-cut-natural-gas-imports-from-russia-significantly-within-a-year; and World Economic Forum, "How Much Energy Does the EU Import from Russia?," March 17, 2022, https://www.weforum.org/agenda/2022/03/eu-energy-russia-oil-gas-import/.

37. S&P Global, "Russia's Gazprom Halts Gas Supplies to Italy Due to Austrian 'Regulatory Changes,'" October 3, 2022, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/100122-russias-gazprom-halts-gas-supplies-to-italys-eni-due-to-austrian-regulatory-changes.

38. See, for example, the IEA's latest "World Energy Outlook," which forecasts a steep drop in Russian energy exports to Europe across all its scenarios. IEA, "World Energy Outlook 2022 Shows the Global Energy Crisis Can Be a Historic Turning Point towards a Cleaner and More Secure Future," October 27, 2022, https://www.iea.org/news/world-energy-outlook-2022-shows-the-global-energy-crisis-can-be-a-historic-turning-point-towards-a-cleaner-and-more-secure-future.

39. Richard Milne, David Sheppard, and Guy Chazan, "Denmark, Germany and Poland Warn of 'Sabotage' after Nord Stream Leaks," *Financial Times*, September 27, 2022, https://www.ft.com/content/85f24052-10a6-48de-8eb1-7a6f8be95759.

40. BBC, "Climate Change: Russia Burns Off Gas as Europe's Energy Bills Rocket," August 26, 2022, https://www.bbc.com/news/science-environment-62652133.

41. This issue was already discussed in December 2021 at Gazprom's aforementioned ESGI-2021, attended by one of the authors. Although the gathering took place prior to the invasion of Ukraine, the constraining impact of international sanctions on the company's ability to detect and abate its methane emissions already came up in the presentation–ns of some of the participants, including managers of this far-flung gas production operation. In this case, the speakers were referring to sanctions imposed in retaliation for Russia's annexation of Crimea in 2014.

42. In a recent interview, Russian energy minister Nikolay Shulginov thus highlighted the difficulty of disposing of associated gas due to problems with the sale of liquefied petroleum gases. "Companies need to make a decision: either to reduce production, or to increase the flaring of associated oil gases....On the one hand, we have an environmental agenda; on the other hand, we should not worsen the operating conditions for companies with fines in this difficult time. There is no solution yet." Irina Tsyruleva and Elena Likhomanova, "Constructively Minded Countries Are Exploring the Possibility of Paying in Rubles," Izvestia, April 13, 2022 (in Russian). Available at https://iz.ru/1319679/irina-tcyruleva-elena-likhomanova/konstruktivno-nastroennye-strany-izuchaiut-vozmozhnost-oplaty-v-rubliakh (accessed November 22, 2022).

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