

Advances in Satellite-Based Methane Monitoring for the Oil and Gas Sector: Global Trends, Governance Strategies, and China's Response

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How to cite this paper: Yuan, S., & Yang, N. F. (2025). Advances in Satellite-Based Methane Monitoring for the Oil and Gas Sector: Global Trends, Governance Strategies, and China's Response. *Journal of Geoscience and Environment Protection*, 13, 301-320. <https://doi.org/10.4236/gep.2025.138016>

Received: July 24, 2025

Accepted: August 25, 2025

Published: August 28, 2025

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Abstract

Methane (CH₄), the second most significant greenhouse gas after carbon dioxide, is characterized by its strong short-term radiative forcing, making it a priority target for global climate mitigation efforts. Due to its high emission intensity and strong technical controllability, the oil and gas sector has become a key focus for methane reduction initiatives. This study systematically reviews the current state of global methane emissions, major emission sources, and advances in satellite remote sensing technologies. It also summarizes recent policy developments and legislative measures in Europe and the United States, along with strategic practices of five major international oil and gas companies. The findings indicate that global methane emissions have continued to increase in recent years, with fugitive emissions, venting, and flaring during oil and gas operations being major contributors. Technologically, satellite remote sensing has emerged as a critical tool for identifying methane point sources, estimating emission quantities, and tracking trends at scale. Observation satellites such as Sentinel-5P, GHGSat, and MethaneSAT have continuously improved in monitoring capabilities, spatial resolution, and application scope—facilitating a shift from regional assessments to facility-level quantification. On the policy front, Western countries have strengthened methane governance in the oil and gas industry through legislation, financial incentives, and data transparency, gradually forming institutionalized and operational frameworks that continue to evolve. As a major methane emitter, China has released its Methane Emissions Control Action Plan, but still faces challenges such as insufficient policy specificity, uneven technological capacity, and low data transparency. Moving

forward, efforts should focus on setting clear reduction targets, enhancing satellite monitoring capabilities, promoting coordinated industry governance, and drawing on international best practices.

Keywords

Methane, Satellite Remote Sensing, Oil and Gas Companies, Monitoring, Carbon Neutrality

1. Introduction

Climate change is one of the most pressing global challenges today. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), methane emissions have contributed approximately 0.50°C of warming since the pre-industrial era (compared to around 1.30°C total warming from all greenhouse gases), while carbon dioxide has contributed about 0.8°C. Although methane (CH₄) exists at much lower atmospheric concentrations than carbon dioxide, its global warming potential over a 100-year period is roughly 28 times that of CO₂ (Intergovernmental Panel on Climate Change, 2021). Due to its strong greenhouse effect and relatively short atmospheric lifetime (around 12 years) (Climate and Clean Air Coalition & United Nations Environment Programme, 2021), methane is considered a critical target for near-term climate mitigation strategies.

Since the Industrial Revolution, atmospheric methane concentrations have risen from about 700 ppb to over 1900 ppb—an increase of more than 2.6 times (Saunio et al., 2025). Notably, concentrations have shown a sustained upward trend since 2007, with a record-high annual growth rate in 2020 despite the economic slowdown caused by the COVID-19 pandemic; the yearly increase still reached 15.65 ppb (Earth System Research Laboratories/Global Monitoring Laboratory, 2025). According to the International Energy Agency (IEA), the climate impact of annual methane emissions, expressed in CO₂-equivalent terms, is now approaching that of carbon dioxide, underscoring methane's significance in the global climate system.

Among anthropogenic methane sources, the oil and gas industry is a major contributor. IEA data indicate that the global energy sector emits around 130 million tonnes of methane annually, with the oil and gas industry accounting for approximately 81 million tonnes per year. These emissions primarily arise from fugitive leaks, venting, and incomplete combustion during the extraction, processing, transportation, and storage of natural gas (International Energy Agency, 2022). Research suggests that reducing methane emissions from the oil and gas and agriculture sectors could lower the rate of global warming by nearly 30% within a decade—providing critical time to meet the goals of the Paris Agreement.

In terms of mitigation pathways, establishing a high-resolution, globally com-

prehensive methane monitoring system has become an international consensus. In recent years, satellite remote sensing has played an increasingly vital role in methane detection due to its broad coverage, temporal-spatial consistency, and traceability. Compared to ground-based sensors or drone-based “device-level” monitoring, satellite technologies offer continuous cross-regional and cross-border observation capabilities, making them suitable for identifying point sources and estimating emissions from oil and gas facilities. Currently, multiple methane-detecting satellites—such as Sentinel-5P, GOSAT, GHGSat, and MethaneSAT—are in operation, with steadily improving monitoring precision and timeliness.

Meanwhile, global methane governance is rapidly shifting from “voluntary commitments” to “regulatory enforcement”. The European Union has introduced the EU Methane Strategy, while the United States has implemented the Inflation Reduction Act, requiring companies to enhance emissions monitoring and accountability. The Global Methane Pledge has mobilized over 150 countries to commit to emission reductions. Major international oil and gas companies—including Shell, BP, TotalEnergies, and ExxonMobil—are also accelerating their deployment of satellite monitoring networks to improve data transparency and drive innovation in methane reduction.

This review is based on a structured literature search conducted using databases including Web of Science, Scopus, and Google Scholar. The search covered publications from January 2010 to June 2025, using keywords such as “methane emissions,” “satellite remote sensing,” “oil and gas,” and “methane monitoring technologies.” Peer-reviewed journal articles, policy reports, and technical white papers were included, with selection criteria focusing on technological developments, industrial applications, and regulatory practices. Studies that focused solely on agricultural methane or lacked methodological transparency were excluded to maintain relevance to the oil and gas sector.

This paper aims to systematically review the development of satellite-based methane monitoring technologies, with a focus on their practical applications in the oil and gas industry. Drawing on policy experiences from Europe and the United States, it explores the implications for building a governance framework—offering actionable insights for Chinese oil and gas enterprises seeking to establish scientifically robust and efficient methane monitoring and mitigation systems.

2. Global Methane Emissions and the Responsibility of the Oil and Gas Sector

2.1. Global Methane Emission Structure and Evolution Trends

Methane (CH₄) is the second most significant greenhouse gas (GHG) contributing to global warming after carbon dioxide (CO₂), with a climate impact that far exceeds its proportion of total emissions. According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, methane has a Global Warming Potential (GWP) 27.2 times that of CO₂ over a 100-year timeframe and up to approximately 80.8 times over a 20-year period ([Intergovernmental Panel on Cli-](#)

mate Change, 2021). Although annual methane emissions account for only about 1% of global CO₂ emissions by mass, methane is responsible for roughly 30% of global warming, exerting a profound influence on the climate system (Climate and Clean Air Coalition & United Nations Environment Programme, 2021).

In terms of emission sources, methane originates from both natural and anthropogenic sources. Natural sources include emissions from wetlands, lakes, permafrost, and wildfires. Anthropogenic sources mainly comprise agriculture, fossil fuel extraction, landfills, and wastewater treatment activities (Saunio et al., 2025). Recent studies indicate that human activities account for more than 60% of total global methane emissions annually. Agriculture is the largest contributor—particularly due to rice paddy drainage and enteric fermentation in ruminant animals. This is followed by the energy sector, where incomplete combustion, equipment leakage, and venting within oil, gas, and coal systems are key issues. According to the International Energy Agency (IEA), anthropogenic methane emissions totaled approximately 380 million tonnes per year as of 2022, with an accelerating upward trend since 2000 (International Energy Agency, 2022).

2.2. Characteristics of Methane Emissions in the Oil and Gas Sector

In recent years, the oil and gas sector has become a major focus of methane reduction efforts due to its high emission intensity, concentrated distribution of leakage sources, and strong technical controllability. It is regarded as one of the sectors with the greatest mitigation potential. On the one hand, methane emissions in oil and gas systems occur through multiple pathways, including fugitive emissions, venting, equipment leaks, and flaring. On the other hand, as methane is the main component of natural gas with significant economic value, mitigation efforts in this sector offer a favorable balance between environmental and economic benefits (International Energy Agency, 2022; United Nations Environment Programme & Climate and Clean Air Coalition, 2021).

According to the International Energy Agency (IEA), methane emissions from the energy sector total around 130 million tonnes per year, with the oil and gas industry accounting for the majority—approximately 81 million tonnes annually (International Energy Agency, 2022). These emissions are mainly concentrated in upstream operations, especially during onshore oil extraction processes such as drilling, gas lifting, hydraulic fracturing, and dehydration. Studies have shown that methane emissions from the exploration and production stages account for over 75% of total emissions across the oil and gas supply chain (Zhang & Li, 2021; Zhang et al., 2024).

From a structural perspective, the primary upstream emission sources include dehydration units, pneumatic pumps, flare systems, and primary gathering facilities. In the midstream and downstream stages—such as transport and processing—emissions mainly come from compressor stations, pipeline connections, and metering and pressure-regulation equipment. In the natural gas industry, leakage during storage, transportation, and distribution can account for 35% to 50% of

total methane emissions, and in some countries, it may even exceed upstream emissions. In contrast, methane emissions in the oil industry are mostly concentrated in the extraction phase, with other stages contributing less than 1% (Zhang & Li, 2021; Zhang et al., 2024).

Moreover, the presence of intermittent equipment-level leaks across oil and gas facilities poses a significant challenge for monitoring and mitigation. Because of the dispersed nature of leak sources and the lack of continuous detection, traditional methods often fail to capture high-emission events in a timely manner—especially the “super-emitter events”. One study monitoring oil and gas operations in the six highest-producing regions of the United States found that fewer than 2% of emission sources were responsible for 50% to 80% of total methane emissions (Sherwin et al., 2024). This underscores the critical importance of accurately identifying and addressing high-risk emission sources to achieve effective methane control.

2.3. Regional and National Differences in Responsibility

On a global scale, methane emissions exhibit significant regional and national disparities, primarily due to variations in energy structures, oil and gas industry distributions, and governance capacities across countries. Emissions from the oil and gas sector are mainly concentrated in resource-rich regions such as North America, Eurasia, and the Middle East. These regions not only have a strong foundation for large-scale oil and gas production but also face substantial challenges in leakage control and emissions management (Figure 1).

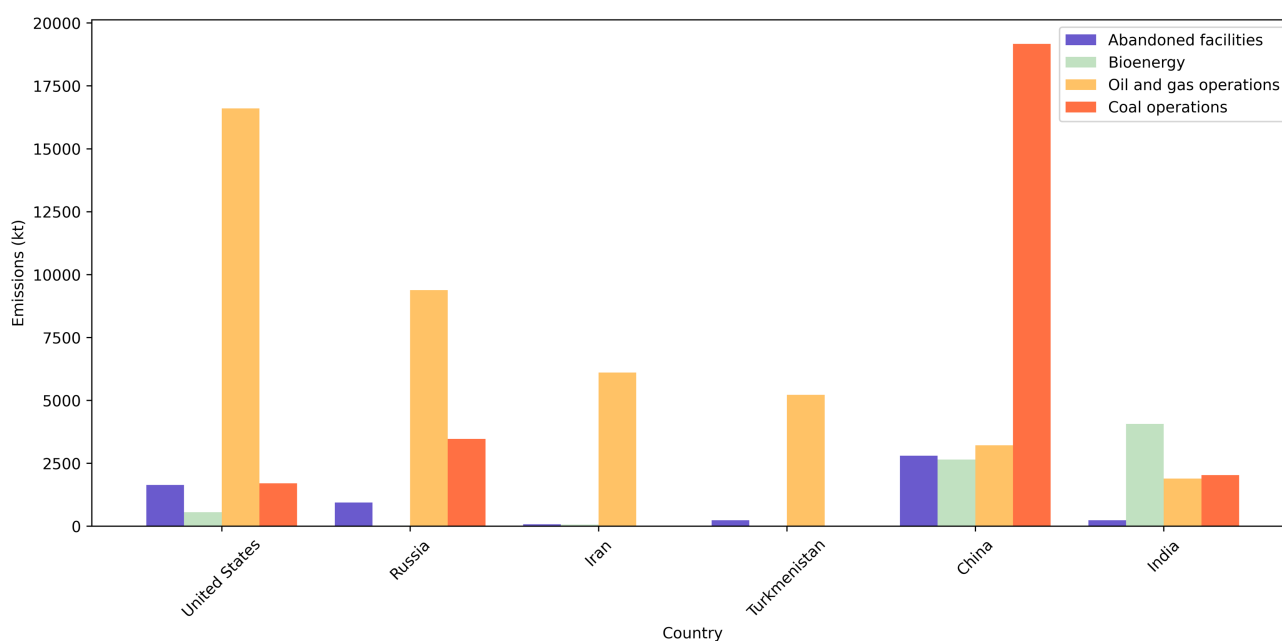


Figure 1. Energy methane emissions by country and category (Source: IEA methane emissions 2024 (IEA, 2025)).

The Permian Basin and the Appalachian Shale region in the United States are

among the most active oil and gas production zones globally but are also high-risk areas for methane leakage (Shindell et al., 2021). In 2024, methane emissions from U.S. oil and gas operations reached 16.6 million tonnes, the highest in the world (International Energy Agency, IEA, 2025). Russia's emissions are more volatile due to fluctuations in its resource-dependent economy. Aging pipeline infrastructure and frequent flaring in the West Siberian Basin are the main contributors to the country's persistently high methane levels. In 2024, methane emissions from Russia's oil and gas sector totaled approximately 9.38 million tonnes, ranking second globally (IEA, 2025).

Iran, as one of the world's major oil and gas producers, faces prominent issues with methane leakage and venting due to outdated technology and inadequate facility maintenance, largely resulting from long-term international sanctions. Some oilfields lack effective recovery and utilization systems, further exacerbating emissions. In 2024, total methane emissions from Iran's oil and gas activities reached 6.10 million tonnes (IEA, 2025). Turkmenistan also faces severe emission issues, primarily due to aging infrastructure, weak leak detection systems, and widespread flaring and venting. Recent satellite-based studies have revealed frequent "super-emitter" events in the country, highlighting significant gaps in technical capacity and regulatory oversight. In 2024, methane emissions from Turkmenistan's oil and gas sector amounted to 5.21 million tonnes (IEA, 2025).

In recent years, China's oil and gas consumption has continued to grow, leading to a sharp increase in methane emissions. In 2024, methane emissions from China's oil and gas sector totaled approximately 3.21 million tonnes, accounting for about 12% of the country's total energy-related methane emissions (IEA, 2025). Western regions such as the Ordos and Tarim basins have emerged as new regional emission hotspots. Additionally, leakage issues at the downstream end of the natural gas supply chain—such as at compressor stations and LNG refueling stations—are gaining increased attention.

In contrast, India's methane emissions are predominantly from agriculture and waste management, with relatively lower contributions from the oil and gas sector. However, with ongoing growth in oil and gas consumption, the expansion of urban gas distribution networks, and the development of natural gas infrastructure, methane emissions from India's oil and gas sector are showing a gradual upward trend.

3. Satellite Remote Sensing for Methane Monitoring

Establishing a scientifically sound and effective methane monitoring system is essential for clarifying emission responsibilities in the oil and gas sector, quantifying mitigation performance, and promoting international cooperation. As a colorless and odorless gas, methane is characterized by sporadic, intermittent, and spatially heterogeneous emissions, making it difficult to regulate effectively through traditional inspection and spot-check methods (Da et al., 2023).

Currently, methane monitoring technologies are typically categorized into

three tiers based on their accuracy, coverage, and application objectives: atmospheric-level, site-level, and equipment-level monitoring (Wang et al., 2022). Atmospheric-level monitoring utilizes satellite remote sensing and other techniques to detect emissions on regional or global scales; site-level monitoring relies on drones or vehicle-mounted systems to assess emissions from specific groups of oil and gas facilities, while equipment-level monitoring involves deploying high-precision sensors to continuously monitor key leakage points. Each monitoring tier has distinct advantages in terms of resolution, frequency, and cost. As a result, building a multi-tiered, integrated monitoring network has become a global consensus for enhancing methane governance capacity in the oil and gas industry.

3.1. Principles of Satellite Remote Sensing for Methane Monitoring

Satellite remote sensing is a key method for monitoring methane emissions based on the characteristic absorption of solar radiation by methane molecules in the infrared spectrum—primarily at 2.3 μm , 3.3 μm , and 7.6 μm wavelengths (Cao et al., 2022). When light passes through a methane-rich region or is reflected from the Earth's surface, it produces identifiable spectral attenuation signals in these bands.

In passive remote sensing, instruments use sunlight as the radiation source and capture spectral variations using imaging spectrometers. Mainstream systems employ Fourier Transform Spectroscopy and Fabry-Pérot interferometers to enhance the ability to detect target bands and improve retrieval accuracy (He et al., 2023). To achieve reliable spatial coverage and quantitative monitoring, it is necessary to correct for observational geometry, atmospheric path length, and surface reflectance—ensuring the consistency and accuracy of output data.

Active remote sensing, by contrast, uses Differential Absorption Lidar (DIAL), which emits laser pulses at two closely spaced wavelengths and compares the difference in returned intensity to retrieve methane concentration. This technique does not rely on sunlight, offers high resistance to interference, and provides finer vertical profiling and spatial resolution, making it suitable for high-precision monitoring in critical regions. A representative initiative is the MERLIN satellite, jointly developed by Germany and France, which will carry the world's first space-based DIAL system to enhance methane detection capability, particularly in high-latitude regions.

3.2. Advances in Satellite Remote Sensing for Methane Monitoring

With continuous improvements in spectral resolution, retrieval algorithms, and platform design, satellite-based methane monitoring has made a significant leap forward. The field has evolved from early-stage global surveys to medium-scale regional monitoring, and now to the current phase where facility-level point-source detection and quantification are achievable. Today, the global methane satellite monitoring architecture has developed into a multi-tiered system combining “regional surveys + high-precision point-source detection”. Spatial resolution has

improved from kilometer-scale to meter-scale, spectral bands have expanded from single-channel to hundreds of continuous channels, detection sensitivity has increased from percentage level to parts per billion (ppb), and revisit cycles have shortened from weeks to daily monitoring. These advancements have greatly enhanced the capabilities for identifying, locating, and quantifying methane emissions, offering strong technical support for oil and gas sector mitigation, emergency response, and global climate governance.

Early methane remote sensing efforts focused on regional-scale surveys. A representative platform was the ENVISAT satellite launched in 2003, which carried the SCIAMACHY sensor—one of the first instruments to observe tropospheric methane from space (Guo et al., 2025). Although it had limited spatial resolution and degraded relatively quickly, it laid the foundation for later missions (Frankenberg et al., 2011). In 2009, Japan launched the GOSAT, which introduced the TANSO-FTS Fourier transform spectrometer, significantly improving data precision. Its successor, GOSAT-2, launched in 2018, further enhanced methane detection capabilities (Qin et al., 2023).

In 2017, the European Space Agency launched Sentinel-5P, a new-generation regional monitoring platform equipped with the TROPOMI sensor. This system improved spatial resolution to 7 km × 7 km, significantly enhancing the detection of medium-scale emission areas (Lorente et al., 2021). In 2023, the Environmental Defense Fund (EDF) launched MethaneSAT, pushing monitoring sensitivity to 3 ppb, with a 200 km swath and high spatiotemporal resolution. It is capable of automatically estimating methane emission rates (Hamburg et al., 2022).

In the field of point-source detection, technological advances have been even more dramatic. In 2016, the Canadian company GHGSat launched the first commercial satellite dedicated to methane monitoring, achieving point-source detection at 25-meter resolution—a milestone for high-precision commercial observation. Its follow-up GHGSat-C series continues to improve, with capabilities for daily revisit in specific regions (McLinden et al., 2024). China's GF-5B (Gaofen-5-02), launched in 2021, is equipped with an Advanced Hyperspectral Imager (AHSI) capable of high-sensitivity detection of methane absorption in the 2.3 μm band, covering 330 continuous spectral bands (Chen et al., 2021), establishing China's significant role in global high-resolution methane observation.

In recent years, commercial remote sensing systems have made significant breakthroughs in high-resolution point-source monitoring. The U.S. WorldView-3 satellite offers ultra-high, 3.7-meter spatial resolution (Cantrell et al., 2021), allowing the detection of even small-scale leak sources. The Tanager-1 satellite, launched in 2024, integrates over 400 hyperspectral bands spanning 400 - 2500 nm, with an improved 30-meter spatial resolution (Duren et al., 2024). China's Quehua-1 satellite has achieved a synchronized breakthrough of 25-meter spatial resolution and 0.1 nm spectral resolution, demonstrating the country's advanced capabilities in integrated remote sensing systems and high-end satellite manufacturing (Guo et al., 2025).

3.3. Global Methane Monitoring Networks and Data Sharing

As global attention to methane mitigation continues to grow, the construction of efficient, open, and collaborative data-sharing and monitoring systems has become an international consensus. Currently, through the joint efforts of the United Nations, research institutions, industry organizations, and commercial satellite companies, the global methane monitoring network is evolving into a broad-coverage, open-structure data infrastructure that supports evidence-based policy implementation.

The United Nations Environment Programme (UNEP) launched the International Methane Emissions Observatory (IMEO), which developed the Eye on Methane platform. This platform integrates self-reported industry data, national inventories, and independent measurement data to provide a unified data portal (United Nations Environment Programme, 2025a). IMEO also operates the Methane Alert and Response System (MARS), which leverages satellite remote sensing to quickly identify major methane emission events (United Nations Environment Programme, 2025b).

The Carbon Mapper project, co-initiated by the University of California and NASA, focuses on point sources such as oil and gas facilities and landfills. It is equipped with high-resolution sensors (3 - 8 meters), enabling the identification and tracking of “super-emitter” sources, with data openly accessible to the public (Duren et al., 2025). The Global Methane Hub acts as a neutral platform promoting cross-sector collaboration and data transparency across policymaking, research, and industry stakeholders.

The International Energy Agency (IEA) launched the Methane Tracker, which focuses on emissions from the energy sector and provides performance assessments of related policies. Meanwhile, the Copernicus Atmosphere Monitoring Service (CAMS) and the U.S. National Oceanic and Atmospheric Administration (NOAA) provide high-spatiotemporal-resolution observational and simulation data, reinforcing the consistency and comparability of global datasets.

Overall, the global methane monitoring framework is rapidly transitioning from fragmented observations to integrated and shared systems. Through platform interconnectivity, institutional cooperation, and technological advancements, these systems offer robust data support for scientific research, industrial governance, and international treaty compliance. They collectively form the foundation of a global MRV (Monitoring, Reporting, and Verification) system, with satellite remote sensing as a central pillar.

3.4. Satellite-Based Methane Monitoring Applications in the Oil and Gas Sector

At the regional scale, satellites such as TROPOMI (Sentinel-5P) and GOSAT have been widely used to assess methane emissions from oil and gas production areas. In 2018, researchers first used TROPOMI data to monitor a well blowout in Ohio, USA, estimating a leakage rate of 120 tons per hour and a total release of approx-

imately 60,000 tons of methane (Pandey et al., 2019). Multi-satellite retrievals have shown that methane column concentrations in areas like the Uinta Basin and the Permian Basin are significantly correlated with production levels, validating the effectiveness of satellite remote sensing in estimating regional emissions.

At the facility level, commercial satellite systems offer high-precision monitoring capabilities. The GHGSat satellite network from Canada achieves a spatial resolution of 25 meters. In 2019, it successfully identified methane emissions ranging from 10 - 43 tons per hour from a natural gas compressor station and detected surrounding associated emissions of 4 - 32 tons per hour, with annual leakage estimated at (142 ± 34) kilotons (Varon et al., 2019). Joint monitoring missions involving China's GF-5, ZY-1, and Italy's PRISMA satellites have covered a $150 \text{ km} \times 200 \text{ km}$ area in the Permian Basin. Using spectral analysis in the 2100 - 2450 nm band, they successfully identified 37 methane plumes, 29 of which had emission rates exceeding 1000 kg/h (Irakulis-Loitxate et al., 2021). The study revealed that newly built facilities emit methane 2.6 times more frequently and twice as intensely as older infrastructure. Compressor stations contributed 50% of total emissions, while flaring accounted for 21%, highlighting a strong correlation between facility operating status and emission characteristics (Chen et al., 2022).

In the context of offshore platform monitoring, technical breakthroughs are emerging. Due to interference from sea surface reflectance, traditional remote sensing methods face significant limitations. Currently, international oil companies are collaborating with GHGSat to develop a novel "glint mode" imaging technique (TotalEnergies, 2024), which adjusts the observation angle to target areas of strong sea surface reflection. This method effectively reduces sunlight interference and opens new possibilities for detecting methane emissions from offshore operations.

4. Methane Reduction Strategies and Industry Actions in Europe and the United States

4.1. Policy Dimensions

As major global energy consumers and carbon emitters, the European Union (EU) and the United States (US) have steadily strengthened their methane reduction policies in recent years. Through legislation, financial support, and international cooperation, both regions have built relatively comprehensive governance frameworks aimed at accelerating the transition of the energy sector toward low methane emissions. Currently, methane policy in Europe and the US is shifting from initiative-based approaches to legally binding frameworks and deep industrial integration, forming a governance pattern centered on institutions, technologies, and cooperation, which is profoundly shaping global methane mitigation efforts.

In the European Union, methane governance has become increasingly institutionalized. The EU Methane Strategy, launched in 2020, identified energy, agriculture, and waste management as the three priority sectors for emission reduction, promoting technological innovation and cross-border collaboration

(European Commission, 2020). In 2024, the EU formally adopted the Methane Regulation as part of the “Fit-for-55” climate legislation package. This became the world’s first law to mandate “Measurement, Reporting, and Verification” (MRV) obligations for the energy sector, imposing strict limits on avoidable venting and flaring. Importantly, it extends regulation to imported energy, requiring third-country suppliers to comply with the EU’s transparency standards on methane emissions (European Union, 2024). These measures not only accelerate the EU’s domestic low-carbon energy transition but also create supply chain spillover effects, pushing international partners—especially LNG-exporting countries—toward stricter methane controls. The EU also co-launched the Global Methane Pledge, which aims to cut global methane emissions by at least 30% from 2020 levels by 2030. As of early 2025, 159 countries and regions have joined the pledge (Global Methane Pledge, 2025).

The United States has pursued a multi-agency and multi-level approach, integrating federal, state, and local efforts. The 2021 U.S. Methane Emissions Reduction Action Plan proposed a mix of regulatory, technological, and incentive-based measures (U.S. Environmental Protection Agency, 2025). In 2022, the Inflation Reduction Act allocated \$1.36 billion to support methane detection technologies, emission accounting, and infrastructure upgrades. It introduced a combined “carrot-and-stick” approach that incorporates climate justice principles (U.S. Congress, 2022). In 2023, the Environmental Protection Agency (EPA) issued new methane regulations for the oil and gas industry, requiring both new and existing facilities to adopt advanced leak detection and repair technologies. These measures are expected to reduce 58 million tons of methane from 2024 to 2038 (U.S. Environmental Protection Agency, 2023). Additionally, the U.S. is expanding regulations beyond the energy sector, including proposed amendments to the Clean Air Act to strengthen methane control in landfills and other sources. Several states are also developing their own policies; for example, Pennsylvania is aligning federal regulations with localized approaches to improve flexibility and policy coverage.

At the global level, the EU and the US are actively promoting the implementation of the Global Methane Pledge. In 2022, they jointly launched the “Energy Pathway” with other countries, focusing on rapid emission cuts in the oil and gas sector. In 2023, the US reached a tripartite agreement with Canada and Mexico to reduce methane emissions from the waste sector by 15% by 2030 (Global Methane Pledge, 2024). Through the “Six Action Pathways”, the EU and the US are driving coordinated governance across energy, agriculture, and waste management. They are also leveraging platforms such as the Global Methane Hub to mobilize over \$200 million in funding for developing countries, supporting technology transfer and the implementation of methane reduction projects (United States Department of State, 2022).

4.2. Corporate Actions

Amid growing regulatory pressure and the momentum of the Global Methane Pledge, the five major international oil and gas companies—ExxonMobil, Shell,

Chevron, TotalEnergies, and BP—are increasingly placing methane reduction at the core of their climate strategies. These companies have established clear targets, deployed advanced technologies, and actively engaged in industry-wide collaborative platforms, advancing the shift from “voluntary commitments” to “regulatory compliance” in methane governance.

In terms of target-setting, all five companies have defined medium- and long-term goals for reducing methane emissions, either in terms of intensity or absolute volumes. For example, ExxonMobil has pledged to reduce its methane intensity by 70% - 80% by 2030 (ExxonMobil, 2022a, 2022b, 2025). TotalEnergies achieved its interim 50% reduction target for 2025 ahead of schedule in 2024, and aims for an 80% reduction from 2020 levels by 2030 (TotalEnergies, 2022). Shell and BP have committed to keeping their methane intensity below 0.05% and 0.2%, respectively, positioning themselves at the forefront of industry performance (International Energy Agency, 2023). In addition, all five companies actively participate in international initiatives such as OGMP 2.0 (Oil and Gas Methane Partnership) and the Methane Guiding Principles (MPG) (Global Methane Pledge, 2023), promoting transparency in emissions reporting and fostering cross-sector collaboration to enhance their roles in global methane governance (Oil and Gas Methane Partnership 2.0, 2023; Methane Guiding Principles, 2023).

On the technical front, these companies generally follow a strategy of “multi-tech monitoring—source-level control—integrated management” to enhance their capabilities in detecting, responding to, and mitigating methane emissions. ExxonMobil has established a centralized methane monitoring hub (COMET) and launched “Project Falcon” in the U.S., which combines ground sensors, drones, and satellite data for tiered monitoring (ExxonMobil, 2024). Shell has widely deployed infrared cameras and enhanced monitoring systems and is phasing out routine flaring in several operations. Chevron has embedded methane management into its corporate governance, introduced data dashboards, implemented employee incentive programs, and upgraded equipment across regions to reduce pneumatic emissions. TotalEnergies has developed and deployed the AUSEA system (Airborne Ultralight Spectrometer for Environmental Applications), which mounts dual gas sensors on drones to monitor both methane and CO₂ simultaneously across its global upstream assets, while also using IoT and predictive systems for real-time control (TotalEnergies, 2024). BP focuses on digitalization and AI, using intelligent algorithms to optimize valve control and leak response in projects across the U.S. and Middle East, yielding notable results in both emissions reduction and operational efficiency.

Importantly, both policy instruments and corporate actions are increasingly anchored in satellite-enabled MRV (Measurement, Reporting, and Verification) systems. The EU Methane Regulation explicitly mandates facility-level monitoring supported by remote sensing data, while the U.S. Inflation Reduction Act allocates funding for satellite detection technologies (European Commission, 2020; European Union, 2024; U.S. Congress, 2022). In parallel, oil and gas companies are

leveraging satellite platforms such as GHGSat, MethaneSAT, and Sentinel-5P to validate emissions reporting and fulfill compliance obligations. This convergence of governance and technology is driving the global methane mitigation regime toward greater accuracy, transparency, and enforceability (International Energy Agency, 2023).

5. Implications for China

5.1. Progress and Challenges in Methane Mitigation in China's Oil and Gas Sector

In recent years, China has made continuous progress in establishing a methane emissions mitigation system, with coordinated efforts from both policy and industry actors. A structured and institutionalized reduction framework is gradually taking shape. In November 2023, the Ministry of Ecology and Environment released the “China Methane Emissions Control Action Plan” (Ministry of Ecology and Environment, 2023), which, for the first time, laid out a comprehensive national-level strategy for methane reduction across key sectors such as energy, agriculture, and waste. The oil and gas sector is identified as a primary control target, with mandates to enhance gas recovery, reduce routine flaring, and promote leak detection and repair (LDAR) technologies. The plan also calls for the establishment of a standardized monitoring and repair system covering the entire industry chain. Furthermore, by 2030, China aims to fully establish a Measurement, Reporting, and Verification (MRV) system that integrates ground-based observations, drone surveillance, and satellite remote sensing, thereby providing a strong technical foundation for science-based governance.

Driven by both domestic policy incentives and international climate governance pressures, China's three major state-owned oil and gas enterprises—CNPC (China National Petroleum Corporation), Sinopec, and CNOOC (China National Offshore Oil Corporation)—are accelerating their methane reduction and green transition efforts in alignment with the country's “dual carbon” goals. All three companies are members of the China Oil and Gas Methane Alliance, launched in 2021, which has committed to keeping methane emission intensity below 0.25% during natural gas production by 2025 (China News Service, 2021). Specifically, CNPC aims to reduce methane intensity to 0.25% by 2025 and further to 0.20% by 2035, adopting strategies such as facility optimization, LDAR deployment, infrared imaging, and drone inspections. Sinopec targets a 20% reduction in methane intensity by 2028 compared to 2023 levels, establishing a diversified mitigation pathway. CNOOC is focusing on deploying low-carbon operational technologies in offshore oil and gas development, aiming to maintain methane intensity below 0.25% in gas production by 2025. The formation of the China Oil and Gas Methane Alliance marks the first collective consensus on methane management in China's oil and gas industry. With key members including CNPC, Sinopec, CNOOC, and China Oil & Gas Pipeline Network Corporation (PipeChina), the alliance aims to promote standard-setting, data sharing, technical cooperation,

and policy alignment, thereby strengthening industry-wide governance capabilities and enhancing China's role in global methane governance.

Despite steady progress in methane policy development and corporate action, China still faces several challenges. On the policy side, goals remain relatively general, lacking clear quantitative indicators, timelines, and enforceable implementation roadmaps, which weakens regulatory effectiveness. Compared to the specific reduction targets and regulatory mechanisms set by the EU and the U.S., China's framework still needs refinement and stronger enforcement systems. At the enterprise level, issues include limited data transparency, insufficient technical adaptability, and inadequate financial support. While advanced technologies such as LDAR and satellite monitoring are being promoted, small and medium-sized enterprises (SMEs) face significant barriers to adoption. Moreover, current reduction efforts mainly focus on Scope 1 and Scope 2 emissions, with little systemic attention paid to Scope 3 emissions, leaving a gap in achieving full life-cycle methane governance.

5.2. Insights and Recommendations

To effectively respond to the growing international competition and pressure brought by the rapid expansion of global methane remote sensing networks, China's oil and gas sector should systematically advance methane abatement and monitoring capacities across four key dimensions, aiming to build an autonomous, coordinated, and robust governance system.

First, China should set clear emission-reduction targets and enhance policy support to establish a coordinated domestic-international mechanism. This entails refining methane-reduction policies by setting absolute reduction goals for key milestones such as 2030 and 2050, and developing actionable, phased control plans that reflect regional differences and industry characteristics. At the same time, fiscal subsidies, tax incentives, and green finance tools should be used to encourage greater corporate investment in methane monitoring and abatement technologies. A methane carbon-footprint accounting and regulatory system should also be established to account for and manage embedded emissions in imported oil and gas products, thus promoting internationally aligned, internally driven emission-reduction mechanisms and enhancing the green competitiveness of the industry.

Second, China must enhance its remote sensing monitoring capacity and develop a multi-source coordinated system. Although initial progress has been made, there remains a need to improve spatial resolution, detection accuracy, and revisit frequency. It is recommended that China invest in hyperspectral imaging, low-concentration detection, and real-time data processing technologies and accelerate the deployment of satellite constellations centered on domestic platforms. Satellite orbit and observation strategies should be optimized to improve coverage over global oil and gas hotspots. The adoption of active sensing technologies such as LiDAR and radar remote sensing should also be promoted to enable all-

weather, three-dimensional monitoring. Furthermore, China should actively participate in international data-sharing and standard-setting efforts to integrate its methane remote sensing technologies into the global mainstream.

Third, it is critical to strengthen ground-based monitoring and technology integration to improve emissions inventory development. A robust methane monitoring system that combines “top-down” (remote sensing) and “bottom-up” (*in-situ*) approaches is essential for effective governance. Oil and gas companies should expand deployment of near-source monitoring technologies, such as UAV-based laser detection, ground infrared sensors, and portable spectrometers, to achieve high-frequency, high-precision field observations. Integration with satellite data should be accelerated to create high-resolution methane emissions inventory databases that support the development of corporate MRV (Measurement, Reporting, and Verification) systems. Drawing from international best practices, companies should build integrated platforms that combine leak detection, response mechanisms, and monitoring capabilities to enhance traceability and rapid response—thus providing strong data support for both policy implementation and international verification.

Lastly, China should deepen cooperation mechanisms and strengthen overall industry capabilities. This includes promoting both domestic and international collaboration in methane governance through platforms such as the China Oil and Gas Methane Alliance, which facilitates technical sharing and joint capacity building among enterprises. China should align more closely with international frameworks like OGMP 2.0, encouraging Chinese enterprises to participate in global rule-making and increasing their international influence. A dedicated support mechanism should also be established for small and medium-sized enterprises, providing access to technology transfer, training, and financial support to close capability gaps. Enterprises themselves should improve transparency, adopt advanced accounting methodologies, and implement robust disclosure practices to increase the international comparability and credibility of methane data—thereby enhancing overall emission-reduction effectiveness and global impact.

6. Conclusion

1) Methane is the second-most significant greenhouse gas contributing to global warming, after carbon dioxide. Due to its high emission intensity, concentrated leakage sources, and strong technical controllability, the oil and gas sector has become a key focus area for methane mitigation. Global methane emissions exhibit notable regional disparities, primarily driven by the distribution of natural resources and the strength of regulatory frameworks. Emission pressures are particularly pronounced in resource-rich regions such as North America, Eurasia, and the Middle East, where countries bear differentiated responsibilities for reduction efforts.

2) Establishing a scientifically sound and efficient methane monitoring system is a core prerequisite for promoting sustainable emission reductions in the oil and

gas sector and for enhancing international cooperation. In recent years, satellite remote sensing has gained prominence for its wide-area coverage, data consistency, and traceability. It is evolving from assessing regional average concentrations to identifying facility-level emissions, significantly improving the response speed to major leaks and the accuracy of point-source detection—thus advancing global monitoring toward greater standardization and coordination.

3) Western countries have continuously strengthened methane-reduction legislation and regulatory oversight, developing a systematic governance pathway that integrates target-setting, technology deployment, and data transparency. Under the “Global Methane Pledge” initiative, the five major international oil and gas companies have incorporated methane control into their core strategies. By setting emission-intensity caps and deploying satellite monitoring and LDAR (Leak Detection and Repair) technologies, the industry is shifting from “voluntary disclosure” to “enforceable mitigation”.

4) China is currently undergoing a critical transition from policy formulation to implementation in methane governance. While recent action plans mark important progress, they still lack specific quantitative targets and timelines. A more coordinated approach is needed across top-level policy design, data transparency, technology adoption, and regulatory enforcement. Drawing lessons from the experiences of Europe and the United States—particularly in legislative development, third-party verification, and regional pilot programs—can help China build a more scientific, transparent, and effective methane emission control system for the oil and gas sector.

5) Despite growing confidence in satellite-based methane monitoring, several limitations remain. Retrieval accuracy can be affected by cloud cover, surface reflectivity, and atmospheric interference, introducing uncertainties in emission quantification. Additionally, discrepancies often exist between satellite-derived estimates and national inventory reports, due to differences in methodologies, spatial resolutions, and reporting standards. These uncertainties underscore the need for continuous validation using ground-based measurements and for harmonizing cross-scale data to support policy and regulatory decision-making.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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