



ESCAP

Economic and Social Commission
for Asia and the Pacific

HANDBOOK

Methane Matters: A Handbook on Sources, Impacts and Mitigation Strategies

Environment and Development Division/Subregional Office for
East and North-East Asia



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Acronyms & Abbreviations

ASCOPE	ASEAN Council on Petroleum
ASEAN	Association of Southeast Asian Nations
AWD	Alternation of Wetting and Dry
CCAC	Climate and Clean Air Coalition
CCAFS	Climate Change, Agriculture and Food Security
CCUS	Carbon Capture, Utilisation, and Storage
CH₄	Methane
Cl	Chlorine
CLEAN	Coalition for LNG Emission Abatement toward Net-zero
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CMM	Coal Mine Methane
CMOP	Coalbed Mine Outreach Programme
CO₂	Carbon Dioxide
COP	Conference of Parties
EDF	Environmental Defense Fund
EPA	Environmental Protection Agency
ERP	Emissions Reduction Plan
ESA	European Space Agency
ESCAP	Economic and Social Commission for Asia and the Pacific
EU	European Union
FAO	Food and Agriculture Organization
FYP	Five-year Plans
GCP	Global Carbon Project
GHG	Greenhouse Gas
GMI	Global Methane Initiative
GMP	Global Methane Pledge
GWP	Global Warming Potential
IEA	International Energy Agency
IEF	International Energy Forum
IMEO	International Methane Emissions Observatory
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
JAXA	Japan Aerospace Exploration Agency
KOGAS	Korea Gas Corporation

LDAR	leak detection and repair
LNG	Liquefied Natural Gas
MARS	Methane Alert and Response System
MEAs	Multilateral Environmental Agreements
MLP	ASEAN Energy Sector Methane Leadership Program
MMRV	Methane Monitoring, Reporting, and Verification
MOEJ	Ministry of the Environment, Japan
M-RAP	Methane Roadmap Action Programme
MRV	Measurement, Reporting, and Verification
Mt	Million tons
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NIES	National Institute for Environmental Studies, Japan
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen Oxide
NSO	Netherlands Space Office
OECD	Organisation for Economic Co-operation and Development
OGDC	Oil & Gas Decarbonization Charter
OGMP	Oil and Gas Methane Partnership
OH	Hydroxyl Radical
ppb	Parts per billion
ppbv	Parts per billion by volume
REPP-SSN	ASEAN Regional Energy Policy and Planning Sub-Sector Network
SAF	Sustainable Aviation Fuel
SSP	Shared Socioeconomic Pathways
Tg	Teragram. Metric unit equivalent to 10 ⁶ tons
TMG	Tokyo Metropolitan Government
UAV	Unmanned Aerial Vehicle
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USGS	United States Geological Survey
VOCs	Volatile Organic Compounds
WHO	World Health Organization

Glossary

Climate Feedback	The processes that can either amplify (positive feedback) or reduce (negative feedback) the effects of climate forcings.
Conference of Parties (COP)	An international climate summit held annually as the decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC).
Fit for 55	A set of proposals to tighten European Union legislation with the aims of reducing greenhouse gas emissions by at least 55 per cent by 2030.
Food Security	Physical and economic access to sufficient safe and nutritious food to meet dietary needs.
Global Methane Budget	A detailed accounting of methane sources and sinks (where methane enters and leaves the atmosphere) to understand and quantify the role of methane in climate change.
Global Warming Potential (GWP)	A measure of the total energy that a gas absorbs over a particular period (usually 100 years), compared to carbon dioxide, which shows a GWP of 1 as a baseline.
Group of 20 (G20)	An intergovernmental forum between 19 countries, the African Union and the European Union, addressing major issues related to the global economy.
Light Detection and Ranging (LiDAR)	A remote sensing method that uses light in the form of a pulsed laser to measure distances by measuring time for the reflected light to return to the receiver.
Methanogenesis	A form of anaerobic respiration by certain microorganisms called methanogens that uses carbon as an electron acceptor and results in the production of methane.
Methanotrophs	Microorganisms that utilise methane as their source of carbon and energy.
Nationally Determined Contribution (NDC)	The climate action plan to reduce emissions and adapt to climate impacts, which each Party to the Paris Agreement submits to the UNFCCC secretariat every five years.
Pneumatic Controllers	The process control automation devices used widely in the natural gas industry to operate valves that control liquid level and pressure are classified as continuous bleed controllers and intermittent bleed controllers.
Relative Yield Loss (RYL)	The decrease in crop yields relative to the maximum possible yield under ideal conditions is used to evaluate the impact of various stress factors like pests, diseases, nutrient deficiency, or environmental conditions on crop performance.
Shared Socioeconomic	Five standard climate change scenarios that represent possible future global socioeconomic development are used in the IPCC 6th Report to

Pathways (SSP) Scenarios	Assess and quantify the challenges related to mitigation and adaptation in different socioeconomic contexts.
Unmanned Aerial Vehicles (UAVs)	An aircraft that carries no human pilot or passengers and flies autonomously or is piloted remotely.
Waste (Management) Hierarchy	An order of waste management options based on sustainability, prioritising options from the most preferable (prevention) to the least preferable (disposal).

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I. Introduction

Climate change is arguably the most significant challenge confronting humanity in the contemporary period, amounting to a planetary crisis. In 2024, the global mean temperature was 1.60 °C above the pre-industrial (1850-1900) average, marking the warmest year on record (Copernicus Climate Change Service, 2025). The effects of climate change are widespread, having detrimental impacts on human health, the environment, human settlements, and economic livelihoods, among others.

Rising anthropogenic greenhouse gas emissions (GHGs), primarily from the burning of fossil fuels since the Industrial Revolution, have largely contributed to climate change and global warming being experienced. By 2023, carbon dioxide levels had reached approximately 419.3 ppm, which is 150 per cent above the pre-industrial level (Lindsey, 2025). With these predicaments, scientists warn that current global warming risks crossing “tipping points”, leading to irreversible changes.

Recognising the extensive impacts of climate change, countries worldwide are actively collaborating to reduce GHGs and limit further temperature increases. The 2015 Paris Agreement aims to limit the global temperature rise to well below 2°C above pre-industrial levels, to keep it below 1.5°C. Realising this objective necessitates significant reductions in GHG emissions, including non-CO₂ gases.

Methane is the second most anthropogenically emitted GHG after carbon dioxide (GMI, 2023), accounting for about 16 per cent of global GHG emissions and over 30 per cent of current global warming (IEA, 2025; OECD, 2025). Despite comprising only 0.00019 per cent of the atmosphere, methane emissions have been steadily increasing, with 2021 seeing the most considerable annual rise of atmospheric methane concentration in four decades (NOAA, 2025).

According to the IPCC’s Sixth Assessment Report (2023), methane has a Global Warming Potential (GWP) between 27 and 29.8 times that of carbon dioxide over a 100-year time horizon, and a GWP of between 84 and 87 over a 20-year time horizon. Methane is also a Volatile Organic Compound (VOC) with an average atmospheric lifetime of 12 years, breaking down in the atmosphere in the presence of sunlight to produce tropospheric ozone and stratospheric water vapour, both of which are also greenhouse gases. Given the high GWP and short atmospheric lifetime of methane relative to other GHGs like carbon dioxide, coordinated global action to mitigate present-day methane emissions can yield significant and immediate benefits.

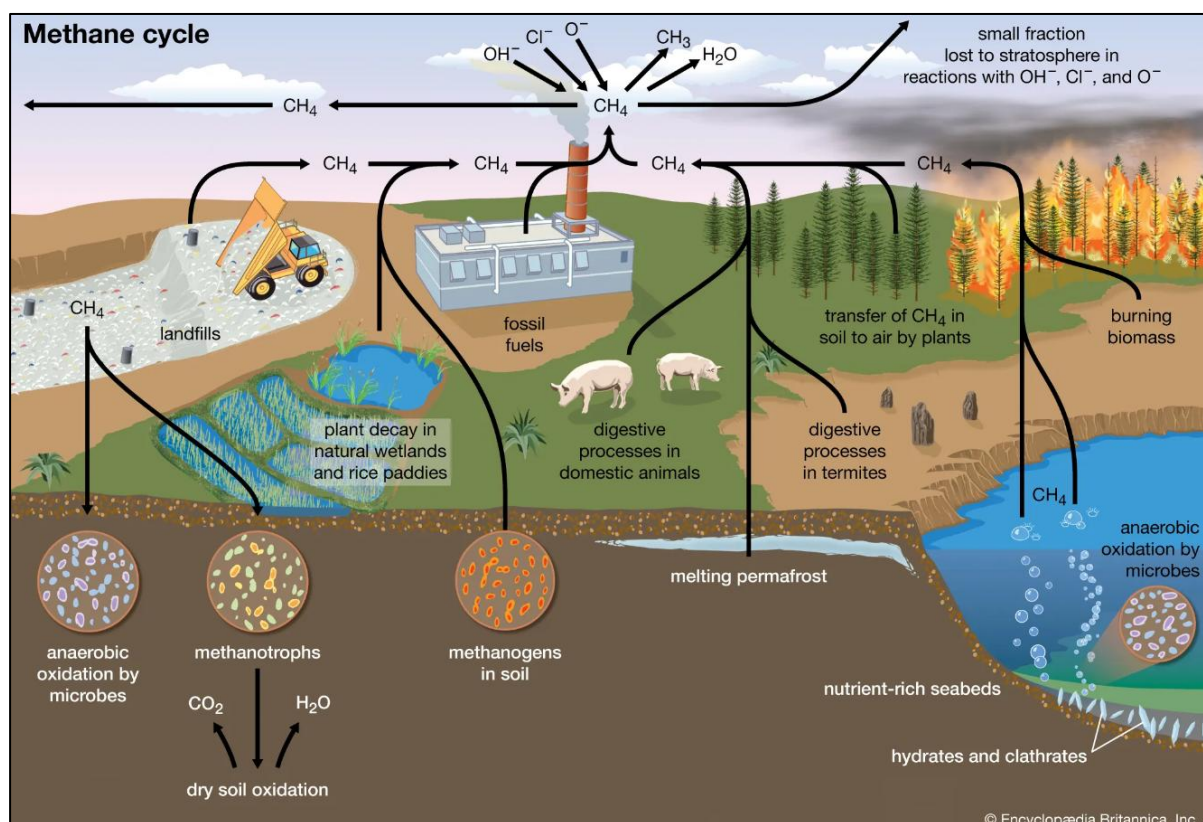
This handbook aims to emphasise the importance of methane mitigation by providing comprehensive knowledge on the subject, analysing its impacts, highlighting recent progress in global, regional, and national methane discussions, and raising awareness.

II. Sources of Methane: Where Does Methane Come From?

Overview of the Methane Cycle

The methane (CH_4) cycle involves production, emission, and removal of methane in the Earth's atmosphere. Methane is released from natural sources such as wetlands, oceans, and termites, as well as from human activities like livestock farming, rice cultivation, fossil fuel extraction, and landfills, shown in Figure 1. Methane emissions, arising from microbial processes in soil, waste disposal, and fossil fuel combustion, circulate within this cycle and eventually decompose through atmospheric and microbial oxidation. Once in the atmosphere, methane acts as a potent greenhouse gas, but has a relatively short atmospheric lifespan of about a decade. It is mainly removed through oxidation by hydroxyl radicals ($\text{OH}^\cdot$), transforming into carbon dioxide and water vapour (IPCC, 2007). This balance between sources and sinks determines the concentration of methane and its impact on climate change.

Figure 1: Overview of the Methane Cycle



Source: Methane Cycle from: Mann, M. E. (2025, October 29). Greenhouse Gas. Encyclopedia Britannica. <https://www.britannica.com/science/greenhouse-gas>

The Global Carbon Project (GCP) reported that methane emissions from natural sources between 2000 and 2017 accounted for 40 per cent, while 55 per cent originated from human activities. There is an imbalance with higher natural emissions contributing to an increase in atmospheric methane. GCP reported annual global methane emissions of 575 Tg CH₄ yr⁻¹ using the top-down approach and 669 Tg CH₄ yr⁻¹ using the bottom-up approach between 2010 and 2019. *Figure 3* illustrates methane emissions from the GCP data set, providing bottom-up estimates of sources and detailing sub-sectors of both natural and human origins. Inland water systems, including **freshwater bodies and wetlands, account for 38 per cent of total methane emissions, while agriculture (23 per cent) and fossil fuels (16 per cent) are the primary human-related sources.** Below are the main natural and human sources, along with their contributions to the global methane cycle.

Author's Note

This handbook relies heavily on methane emissions data from the [Global Carbon Project](#) (2025) because of its bottom-up approach, completeness, and consistency. However, methane emissions-related data is dynamic and gathered by various organisations, so readers should be cautious, as more recent data from sources such as the International Energy Agency (IEA) may provide updates that could impact the findings. It is advisable to consult the latest information for the most accurate understanding. The author will provide the most recent details whenever possible.

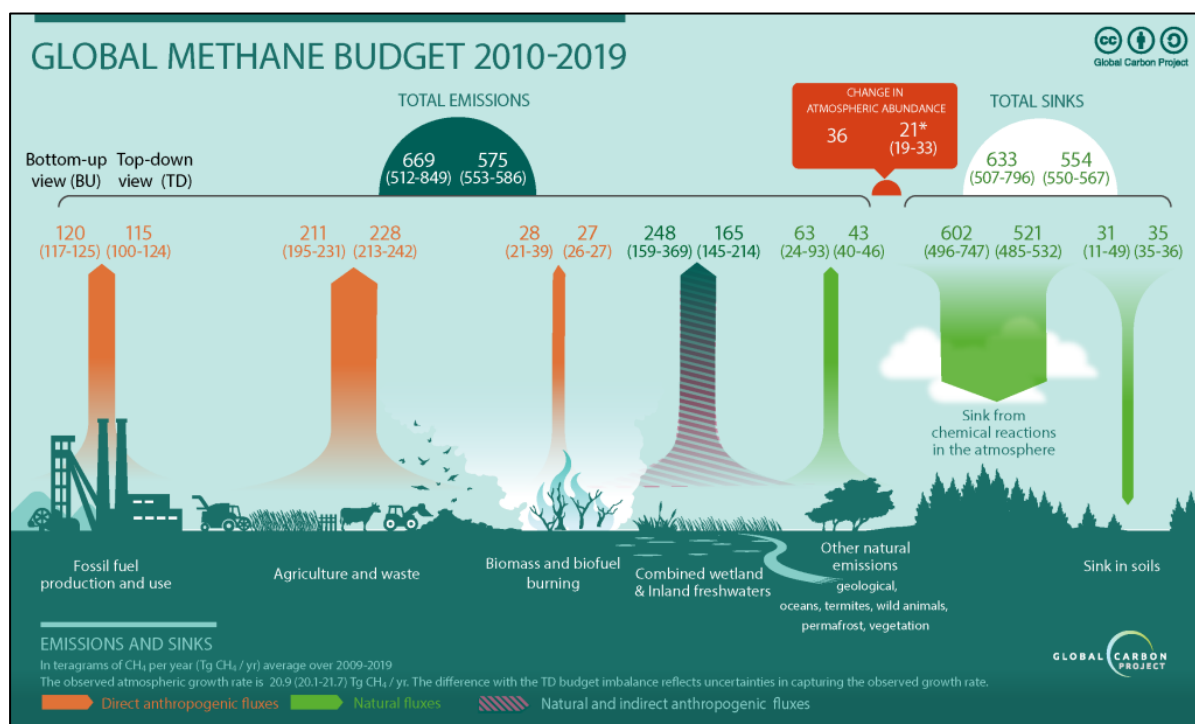
below illustrates the budget data from both approaches, showing a smaller gap for anthropogenic sources, but a larger discrepancy for some natural sources. Fortunately, advancements in monitoring equipment and analysis methods are accelerating the integration of the two approaches, reducing the gap and leveraging the strengths of both (GCP, 2020).

Other Sources of Information

- The 2021 report from the United Nations Environment Programme (UNEP) and the Climate and Clean Air Coalition (CCAC) states that more than half of methane emissions stem from human activities. The UNEP-CCAC estimate is slightly higher than GCP's.
- The International Energy Agency (IEA, 2025) reported that man-made methane emissions accounted for 60 per cent, while natural sources accounted for 40 per cent. This is primarily caused by increased human activities in the energy and agriculture sectors, along with higher waste production. IEA estimates for anthropogenic methane emissions are approximately 10 per cent higher than those of GCP and UNEP-CCAC.

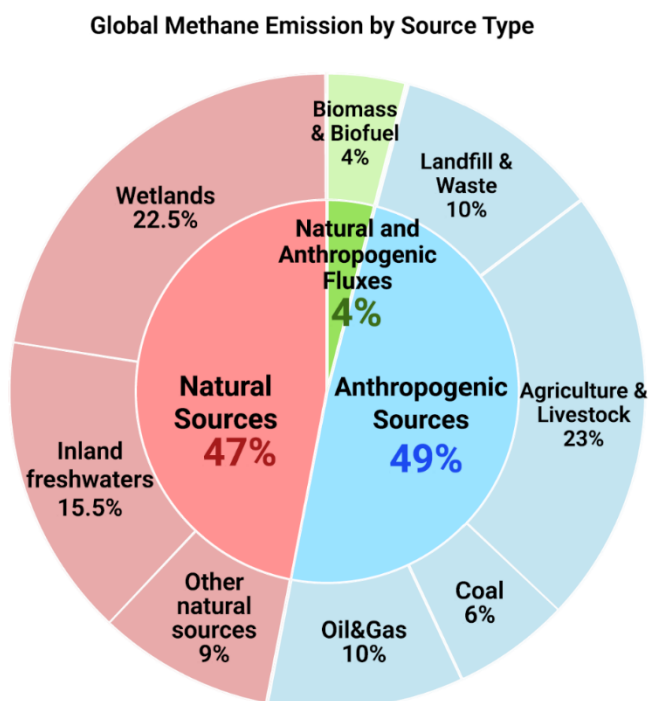
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Figure 2: Global Methane Budget 2010-2019



Source: Global Methane Budget 2010-2019 from Saunio, M. et al. (2025, May 09). Global Methane Budget 2000–2020. Earth System Science Data. <https://essd.copernicus.org/articles/17/1873/2025/>

Figure 3: Global Methane Emissions by Source Type



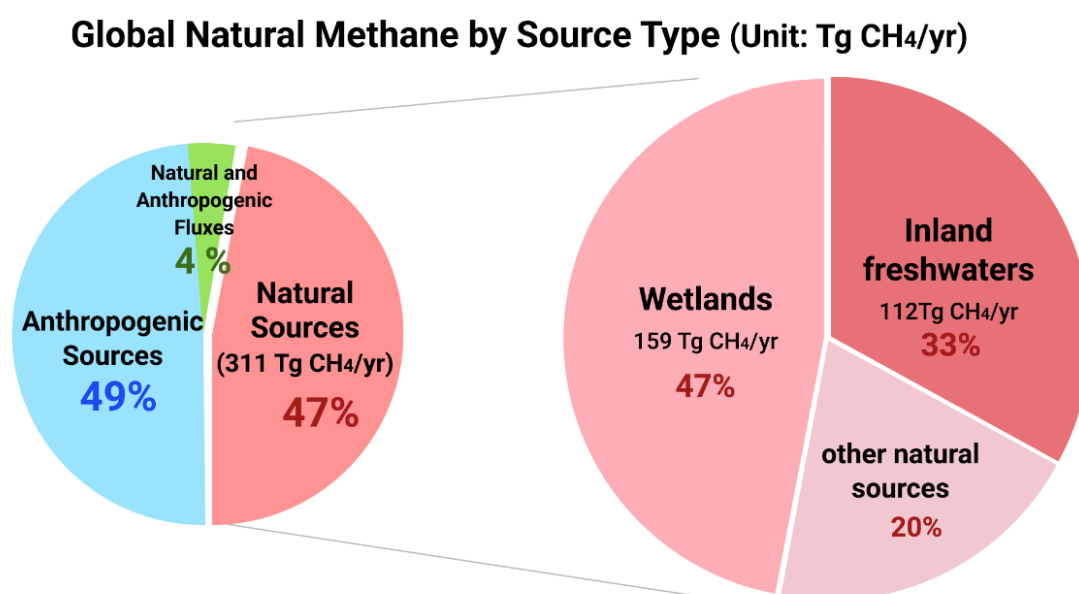
Source: Seohyun Hong, modified the data source from Global Carbon Project (GCP) (2025)

Note: This pie chart is based on data from The Global Methane Budget 2000-2020. The values shown represent the budget based on the bottom-up (BU) approach, which utilises inventories from the decade of 2010-2019.

Natural Sources

According to the Global Carbon Project, about half of global methane emissions originate from natural sources, including freshwater systems, geological sources, oceans, and non-livestock animal sources.

Figure 4: Global Natural Methane by Source Type



Source: Seohyun Hong, modified the data source from Global Carbon Project (GCP) (2024)

Freshwater Systems About one-third of natural methane emissions originate from freshwater systems such as lakes, ponds, and rivers, releasing approximately 112 Tg CH₄ annually. This methane is produced through microbial breakdown of organic carbon in anoxic sediments, a process known as methanogenesis. It enters the atmosphere via pathways including ebullition (bubble release), diffusion, storage, and plant emission. Ebullition, particularly in shallow waters, is a major route, facilitated by low water pressure and affected by organic input, production rates, ease of bubble release, and pressure variations from currents or waves.

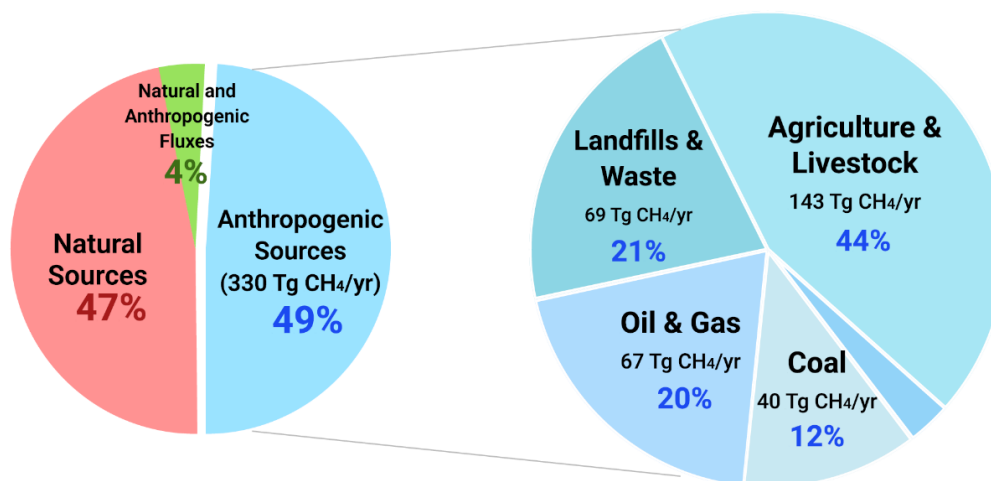
Wetlands Wetlands are the largest single natural source of methane, responsible for 47 per cent of natural emissions and about a quarter of global methane emissions, estimated at 159 Tg CH₄ annually. Waterlogged soil in wetlands create ideal conditions for the process of methanogenesis. Seasonal variations in emissions occur due to changes in the inundated soil area influenced by rainfall. Methane production in wetlands also depends on temperature and the amount of plant biomass.

Anthropogenic Sources

According to the Global Carbon Project, **anthropogenic activities account for about 49 per cent of global methane emissions**. Represented in *Figure 5*, agriculture alone contributes 44 per cent, energy 32 per cent, and waste management 21 per cent, making up 97 per cent of these emissions from 2010 to 2019.

Figure 5: Global Anthropogenic Methane by Source Type

Global Anthropogenic Methane by Source Type (Unit: Tg CH₄/yr)



Source: Seohyun Hong, modified the data source from Global Carbon Project (GCP) (2024)

Agriculture & Livestock According to the GCP, methane emissions from agriculture and livestock amount to approximately 143 Tg CH₄ annually, making up 44 per cent of anthropogenic emissions and about 20 per cent of total methane emissions. Growing consumer demand for meat and dairy—driven by population growth, rising incomes, and urbanisation—has resulted in higher livestock numbers today, especially in low- and middle-income countries. This increase in livestock has contributed to a rise in methane emissions, primarily through enteric fermentation, a digestive process in ruminant animals such as cattle and sheep. In 2017, there were approximately 1.5 billion cattle, 1.2 billion sheep, and nearly as many goats, with livestock emissions accounting for roughly one-third of global human-made emissions (FAO, 2017).

Rice Cultivation

Rice cultivation, which feeds a third of the global population, contributes 8–11 per cent of global anthropogenic methane emissions. Methane is produced through the anaerobic decay of organic material in flooded rice paddies and is released through diffusion, ebullition, and via rice plants.

Oil and Gas Industry According to the GCP, the oil and gas industry emits around 67 Tg CH₄ of methane each year through the entire process of extraction, production, transportation,

and distribution. Emissions originate from venting (68 per cent), fugitive methane emissions (22 per cent), and flaring (10 per cent).

The increase in methane emissions in Asia and the Pacific is driven by rapidly growing electricity demand, alongside both a substantial expansion of fossil fuel infrastructure and a rising share of renewable energy. While many countries in the region have scaled up the use of renewable energy, fossil fuels continue to dominate the energy mix, with Asia accounting for 82 per cent of global coal-fired power generation. Gas infrastructure is expanding at an unprecedented scale. Currently, 377 GW of gas-fired power plants are under development, along with 137 LNG terminals and 98,000 km of gas pipelines. Additionally, 40 gas extraction sites are being developed, with Southeast Asia considering over 20 billion cubic meters of new production capacity annually (Global Energy Monitor, 2025).

Methane can be emitted across the entire oil and gas value chain, which consists of three segments (IEA, 2025):

- **Upstream operations** (exploration and production): over 80 per cent of total oil and gas methane emissions.
- **Midstream operations** (processing and transportation): around 15 per cent.
- **Downstream operations** (refining and distribution): less than 5 per cent.

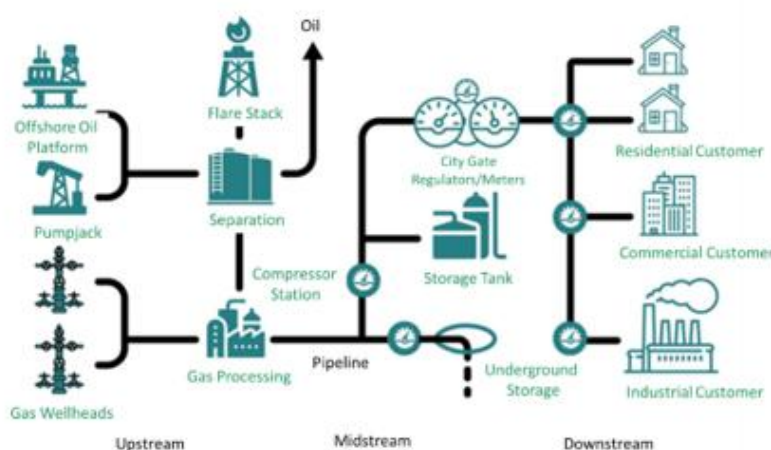
Most methane emissions from oil and gas operations fall into one of three categories:

- **Flaring** involves burning natural gas to relieve pressure, with most methane converting to carbon dioxide, but some remaining uncombusted.
- **Venting** involves the intentional release of unwanted gas, and occurs during extraction and operational practices.
- **Fugitive** emissions are accidental releases from infrastructure.

Other Sources of Information

- UNEP and CCAC (2021) state that methane emissions originate from agriculture (40 per cent), fossil fuels (35 per cent of human-caused emissions) and waste (20 per cent).
- IEA (2025) reported that man-made methane emissions by sector consist of 43 per cent from the agricultural sector, 36 per cent from the energy sector, and 21 per cent from the waste sector.

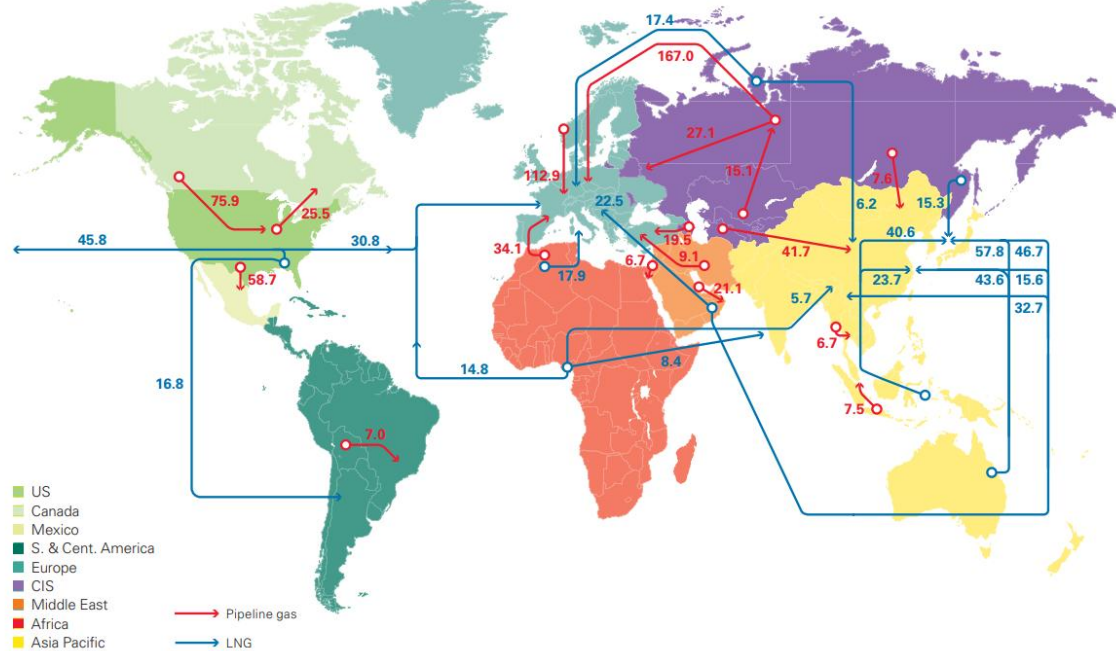
Figure 6: Supply Chain of the Oil and Gas Industry



Source: Methane Abatement for Oil & Gas: Handbook for Policymakers (2023).

Box 1: Natural Gas Trade Around the World

Major trade movements 2021
Trade flows worldwide (billion cubic metres)



Source: The British Petroleum Company (BP) (2022) (Unit: billion cubic metres, Gm³)

Methane leakages can occur anywhere along the natural gas supply chain, whether transmitted by pipeline or shipped in liquefied form. Leakages during the transmission and distribution process are significant, accounting for approximately 25 per cent of emissions throughout the entire oil and gas operation (U.S. EPA, 2022). The figure above illustrates the natural gas trade flow in 2021, highlighting the largest exporting countries: the Russian Federation (241.3 Gm³), the United States of America (U.S.) (179.3 Gm³), Qatar (127.9 Gm³), and Norway (113.1 Gm³), as well as the main importing regions, Europe (477.3 Gm³) and Northeast Asia (354.9 Gm³).

Box 2: Global Methane Tracker

The International Energy Agency (IEA) publishes the Global Methane Tracker annually, based on its methane database. The Methane Tracker concentrates on energy-related methane emissions, including those from oil, gas, and coal. The report assesses the abatement potential, recommends measures, and provides projections for policy implementation.

Full report of 2024 version, available at, <https://www.iea.org/reports/global-methane-tracker-2025> (Source: IEA, 2025)

Global Methane Tracker 2025



International Energy Agency

Landfills & Waste Management Methane emissions from waste management were estimated at 69 Tg CH₄ per year, accounting for 21 per cent of global anthropogenic emissions. Sources include both managed and unmanaged landfills, as well as wastewater treatment facilities. Under anaerobic conditions, methanogenic bacteria decompose waste and produce significant landfill gas. Landfill gas, a byproduct of organic decomposition, consists of approximately 50 per cent methane, 50 per cent carbon dioxide, and small amounts of other organic compounds. Food waste, due to its rapid decay rate, is a significant contributor to methane. Municipal wastewater treatment also emits methane through the anaerobic decomposition of organic material.

Coal Coal mining alone emits 40 Tg CH₄ per year, with potential new projects adding 13.5 Mt CH₄ yearly if developed. (Ryan, 2022). Methane emissions from coal mining arise from (1) ventilation systems, (2) drainage systems, (3) post-mining activities, and (4) outcrops and workings. Ventilation systems are the main source of methane at underground mines, while outcrops are the main source of methane at the surface, directly releasing methane into the atmosphere.

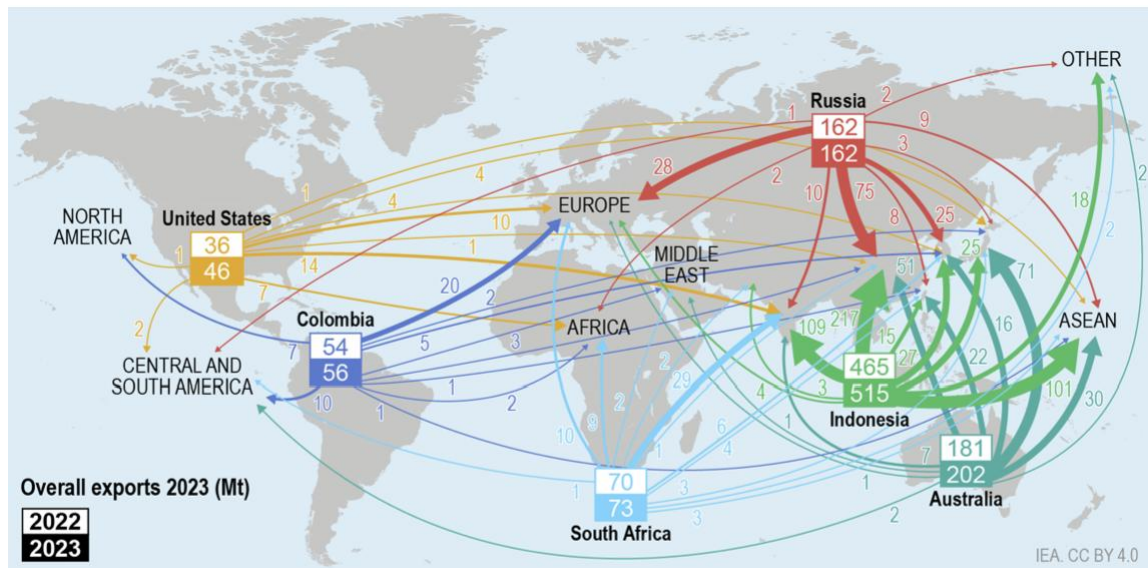
Table 1: Emissions Sources in Thermal and Coking Coal Mines

Type	Specific source	Underground	Surface
Vented	Ventilation systems	60 per cent	0 per cent
	Drainage systems	25 per cent	15 per cent
Incomplete combustion	Other losses	2 per cent	1 per cent
Fugitive	Other losses	5 per cent	1 per cent
	Post-mining	3 per cent	8 per cent
	Outcrops and workings	5 per cent	75 per cent
Total	Total	100 per cent	100 per cent

Source: IEA (2024)

Underground mines tend to emit more methane than surface mines due to deeper coal seams containing more methane. High-carbon coal types, such as steam coal (thermal coal) and coking coal (metallurgical coal), emit more methane when burned compared to lignite. More than 80 per cent of current coal production is steam coal, used primarily for heat and electricity generation, with 15 per cent being coking coal for steelmaking, and the remainder lignite (IEA, 2023).

Box 3: Coal Trade Around the World



Source: IEA (2024)

Despite its high carbon intensity, coal still supplies over a third of global electricity generation, and global carbon consumption is on the rise (IEA, 2022). The map above illustrates the global thermal coal trade in 2022 and 2023, showing most of the coal flowing from the top three exporters: Indonesia (515 Mt), Australia (202 Mt), and Russia (162 Mt), to the top four importers: China, India, Japan, and ASEAN. While coal is gradually being replaced for power generation in most countries, it continues to play a crucial role in iron and steel production until newer technologies become available.

Natural and Anthropogenic Fluxes

Biomass & Biofuel Burning Methane emissions from biomass and biofuel burning are included in both natural and human-made sources, amounting to an estimated 28 Tg CH₄ per year. This category encompasses methane released during the burning of forest biomass, agricultural residues, and biofuels in the residential sector. Methane escapes during incomplete combustion when there is insufficient oxygen for complete combustion, such as in charcoal production and smouldering fires.

While some biomass burning occurs naturally, most current burning is driven by human activities. Human-related fires are mainly found in the tropics and subtropics, where forests, savannahs, and grasslands are burned to clear land for agriculture or to maintain pastures. Most methane emissions from biofuels arise from domestic cooking and heating, particularly in open fires where wood, charcoal, agricultural residues, or animal manure are burned. It is estimated that over 2 billion people, primarily in developing countries, use solid biofuels for daily cooking and heating (Joseph O., 2024).

III. Methane and Its Impacts: What are the Consequences?

Understanding the impacts of methane emissions provides policymakers with crucial knowledge to develop more targeted, effective, and timely environmental policies. By recognising methane's short atmospheric lifespan and its disproportionately high global warming potential, they can:

- Prioritise strategies that deliver quick climate benefits – such as improving leak detection in oil and gas infrastructure, enhancing waste management practices, or supporting sustainable agriculture.
- Align national policies with international climate goals, such as those outlined in the Global Methane Pledge.
- Garner broader support for climate action and allocate resources more effectively.

Impacts on Climate

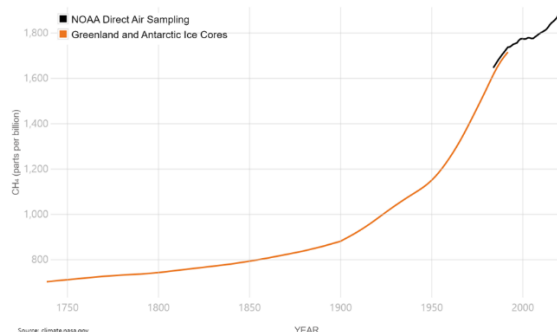
Methane's Global Warming Potential (GWP) is 80 times higher than that of carbon dioxide over a 20-year period, meaning it traps much more heat. Although methane stays in the atmosphere for a shorter time (around ten years) compared to other GHGs, this shorter duration creates faster opportunities for mitigation. Methane reacts with hydroxyl radicals to generate carbon dioxide and water vapor, both of which are also GHGs. Water vapor, though short-lived, enhances the warming effect of carbon dioxide through a positive climate feedback loop.

Atmospheric methane concentrations have been increasing, with 2021 marking the highest annual increase in four decades. As depicted in *Figure 7*, methane levels in the atmosphere have more than doubled in the last 200 years, surpassing 1900 ppb in 2022. The National Oceanic and Atmospheric Administration (NOAA) states that methane is responsible for approximately 30 per cent of the global temperature rise since the Industrial Revolution. However, it makes up only 0.00019 per cent of the atmosphere.

The rapid adoption of available methane mitigation strategies has the potential to substantially reduce the pace of global warming (Ocko et al., 2021). Specifically, such measures could slow the rate of warming over the next few decades by more than 25 per cent, avoiding 0.25°C of additional warming by 2050 and 0.5°C by 2100 relative to pathways without early methane reductions. These advantages are particularly significant in the short term because methane has a high warming potential and a brief atmospheric lifetime, making methane mitigation one of the most effective tools for immediate climate action.

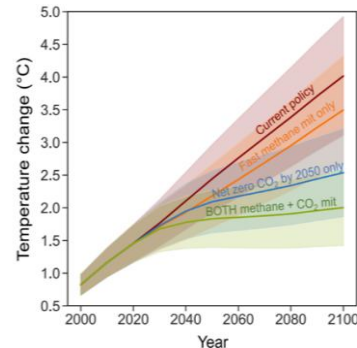
Figure 7: Atmospheric Methane Concentration and Global Mean Temperature Projection

Atmospheric Methane Concentration from 1010 to 2020 (Units: ppb)



Source: National Aeronautics and Space Administration of the United States (2023)

Global Mean Temperature Projections to 2100



Source : Tianyi Sun et al (2022)

Note: The projection is temperature change relative to pre-industrial level. The emission scenarios in the graph are (red) current policy, (orange) fast methane mitigation only, (blue) net zero CO₂ by 2050 only, and (green) net zero CO₂ and fast methane mitigation combined. Shading indicates one standard deviation of temperature projections.

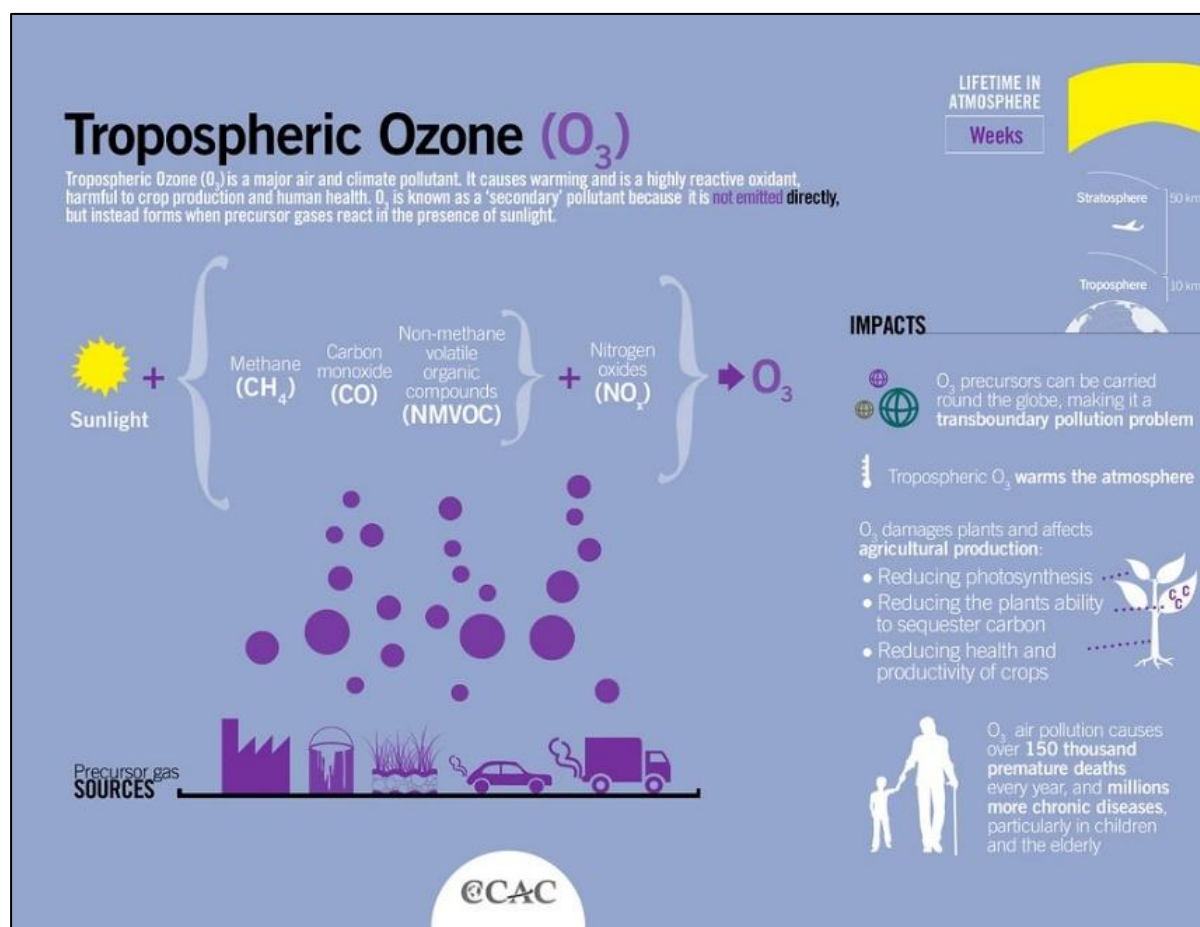
Reducing methane emissions is crucial for mitigating global warming. The IPCC projects that methane controls implemented between 2010 and 2030 could significantly reduce warming by 2040. The Climate and Clean Air Coalition (CCAC) emphasises the need to cut methane emissions by 30-60 per cent below 2020 levels by 2030 to meet the Paris Agreement's 1.5°C target. This reduction could prevent nearly 0.3°C of warming by 2045.

Impacts on Air Quality

Although not directly harmful to air quality, **methane plays a role in forming tropospheric ozone, a major air pollutant (**

Figure 8). Tropospheric ozone is produced through a chemical reaction involving sunlight, nitrogen oxides (NO_x), and volatile organic compounds (VOCs), which include methane. Exposure to ozone can lead to respiratory illnesses, causing an estimated one million premature deaths annually, especially among children, the elderly, and people with lung or heart conditions. Elevated ozone levels could cause up to a 20 per cent increase in crop damage in agricultural areas by 2050 compared to scenarios that ignore changes in ozone (CCAC, 2015).

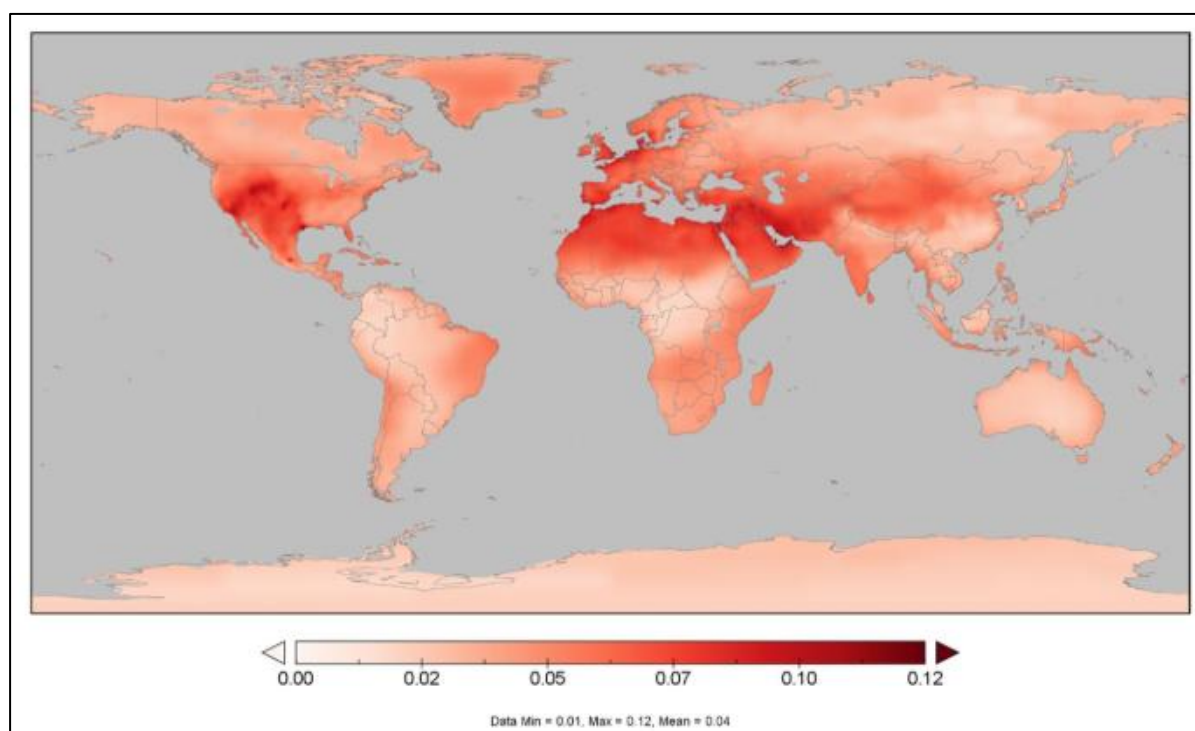
Figure 8: Tropospheric Ozone



Source: CCAC (2014)

Modelling shows high ozone levels in the Northern Hemisphere (**Error! Reference source not found.**), particularly in America, Africa, Europe, and Asia. According to the IPCC, methane emissions are responsible for half of the tropospheric ozone levels. Therefore, reducing methane emissions is crucial for maintaining air quality, promoting public health, supporting agriculture, and other socio-economic sectors. The CCAC emphasises that measures aimed at reducing methane emissions by 30 per cent from 2020 levels by 2030 could prevent 255,000 premature deaths due to high tropospheric ozone levels and avoid 26 million tonnes of crop losses annually.

Figure 9: Ozone Attributable to the Methane Emission (Units: ppbv)



Source: Sampedro (2023)

Note: The data represents a seasonal 3-monthly mean of 7-hour daytime ozone concentration during summertime (July). The modelling is based on the Shared Socioeconomic Pathways (SSP) scenarios of the IPCC. The scenario assumes a 10 per cent increase in projected U.S. methane emissions in 2020 under the SSP2-4.5 scenario, where climate change mitigation and socioeconomic development trends broadly follow historical patterns.

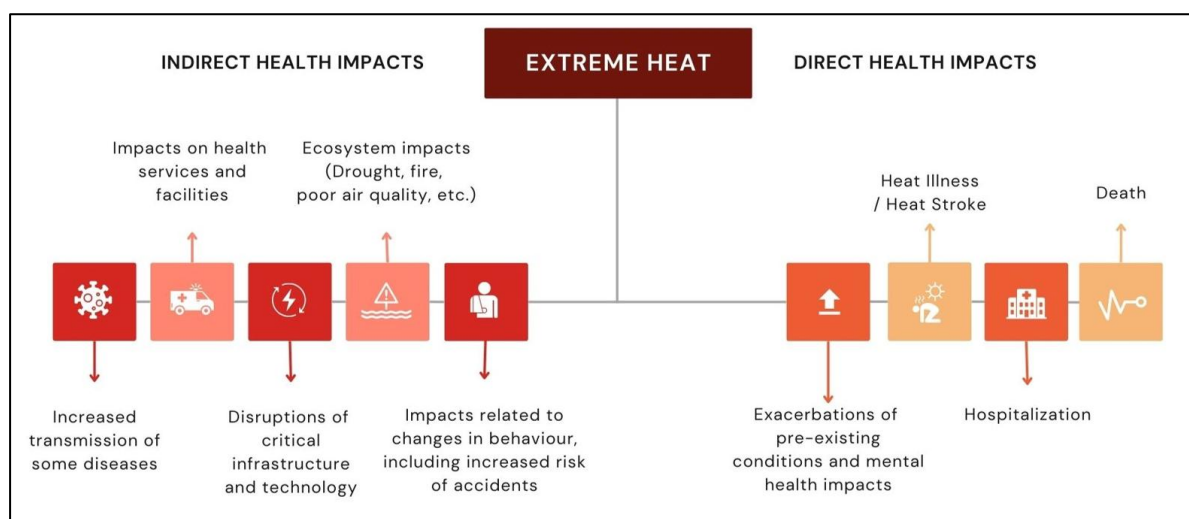
Impacts on Health

Methane contributes to global warming, which raises the risk of heat-related health problems.

Extreme heat can cause heat exhaustion, hyperthermia, and worsen chronic illnesses, leading to deaths related to high temperatures. The number of people exposed to extreme heat is increasing, with heat-related mortality for those over 65 rising 85 per cent between 2000 and 2004 and 2017 and 2021 (WHO, 2024). Reducing methane emissions by 30 per cent below 2020 levels by 2030 could prevent 775,000 asthma-related hospitalisations and save 73 billion hours of lost labour annually due to extreme heat (CCAC, 2021).

Tropospheric ozone, a secondary air pollutant, is also harmful to human health, causing respiratory and cardiovascular diseases. It worsens respiratory conditions and can cause permanent damage to lung tissue, especially in individuals with preexisting lung conditions like asthma. Long-term exposure to low-level ozone can also lead to serious health effects, including chronic respiratory illnesses.

Figure 10: Health Impacts of Heat



Source: WHO (2024)

Methane also presents an explosion hazard. It is extremely flammable and can ignite at concentrations between 5 per cent and 15 per cent. Safety precautions, like methane detectors in mining operations, are crucial to prevent explosions. In urban areas, frequent methane explosions in sewers have been reported, resulting in fatalities and damage to public infrastructure and buildings.

Impacts on Agriculture

Tropospheric ozone damages crop by entering leaf openings called stomata and oxidising plant tissue, which impairs growth and diminishes productivity. This affects various plant species, including key agricultural crops like rice, maize, and wheat. It also harms ecosystems dependent on plants, leading to soil erosion, flooding, and worsening food security.

Figure 11 shows the annual global relative crop yield losses due to ozone. Global estimates suggest that current relative yield losses (RYL) range from 7–12 per cent for wheat, 6–16 per cent for soybeans, 3–4 per cent for rice, and 3–5 per cent for maize (van Dingenen, 2009). In East Asia, China experiences the highest relative yield loss at 33 per cent for wheat, 23 per cent for rice, and 9 per cent for maize (Feng et al., 2020). The relative yield loss is considerably higher in hybrid rice compared to inbred varieties, approaching that for wheat. The total annual loss of crop production due to ozone is estimated at US\$63 billion.

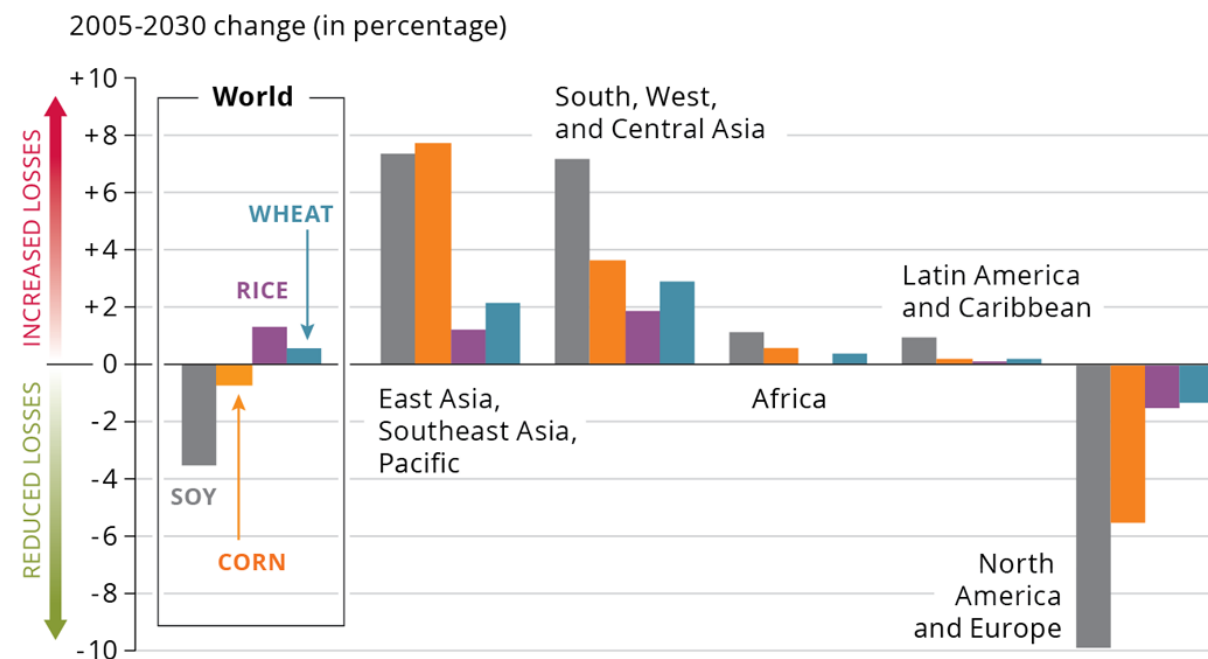
The significant impact of ozone (O₃) on crop production underscores the need for mitigation measures, including ozone emission controls and adaptive agricultural practices, to address the rising surface ozone levels across East Asia. According to UNEP and WHO, yield losses

Climate Change

Climate change, driven by increasing methane levels, disrupts weather patterns, leading to lower crop yields caused by more pests and diseases, as well as extreme weather events like droughts and floods. This endangers food security and puts additional strain on global food systems.

are expected to increase, particularly in Asia, if existing ozone-related legislation remains unchanged.

Figure 11: Relative Yield Losses for Major Crops Due to High Ozone Concentrations



Source: UNEP/WHO (2011)

IV. Tracking Methane: How is Methane Monitored?

Quantifying Methane: Top-down/Bottom-up Approach

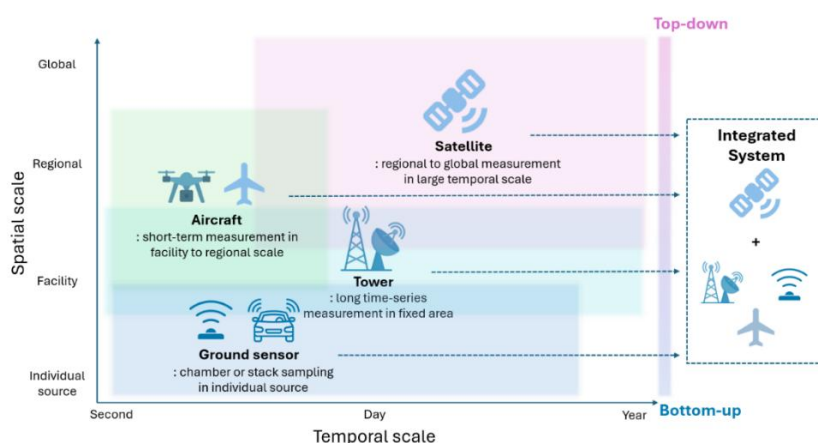
Governments compile national GHG emission inventories to track and report emissions, including methane, as part of the United Nations Framework Convention on Climate Change (UNFCCC) process. Monitoring methane emissions is critical for developing robust emission inventories, which are essential for establishing effective mitigation strategies. Methane measurement methods vary widely in both spatial and temporal scales, ranging from global assessments of annual emissions to localised measurements from individual sources over short times (*Figure 12*).

The two primary methods — top-down and bottom-up — each has its advantages and disadvantages:

- **The Top-Down Approach** A more holistic process, that focuses on the overall budget by optimally combining atmospheric observations and deriving the budget through inversion modelling. This approach provides an accurate snapshot of global GHG emissions with minimal relative uncertainty. However, it may struggle to attribute emissions to specific sources.
- **The Bottom-Up Approach** A more targeted process, estimates emissions by compiling inventories of individual sources. This method offers detailed information on the magnitude and intensity of emissions from specific subcategories. However, it might not account for all emission sources.

Therefore, to comprehend the overall global budget and develop suitable strategies for each sub-sector, the effective utilisation of both approaches is essential.

Figure 12: Methane Measurement Systems Across Spatial and Temporal Scales



Source: Seohyun Hong, modified data sources from NASEM (2018), Oberle et al (2019) and IEF (2021)

Ground-based Monitoring Ground-based monitoring directly measures emissions near their surface sources, covering individual point sources to small facilities. It uses fixed sensors, portable devices, or sensor-equipped vehicles to capture temporal trends, which are then calculated based on the flow rate and methane composition of the collected gas. While these methods provide accurate emissions data, they are limited spatially and temporally, as they cover only small areas and brief periods. This makes them less suitable for large-scale monitoring, as they may not capture all variability and cannot be conducted in remote or inaccessible areas, leading to increased uncertainty if emission patterns are inconsistent.

Airborne-based Monitoring Airborne-based monitoring overcomes the spatial and temporal limitations of ground-based methods by measuring vertical methane profiles regardless of geographical conditions. It includes aircraft, unmanned aerial vehicles (UAVs), and tower-based measurements, using sensors for passive sensing or Light Detection and Ranging (LiDAR) for active sensing. Aircraft fly in concentric paths at multiple altitudes around a source to measure methane concentrations, wind speed, and direction. UAVs, with the rapid commercial spread of drones, play a crucial role in providing high-resolution spatial methane data, enhancing methane insights. While aircraft measurements target specific emission regions and towers provide long-term data, both have limitations. Tower measurements have limited spatial coverage due to their fixed locations, and aircraft and UAV measurements are affected by weather conditions and uncertainties related to cloud layers and ground reflections. Distinguishing individual methane sources can also be challenging with tower-based measurements.

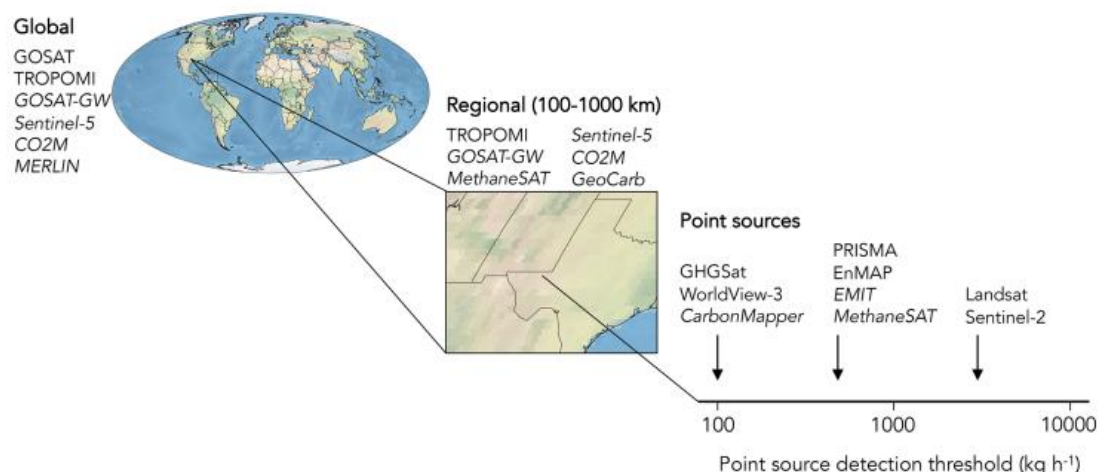
Space-based Monitoring Space-based methane monitoring uses satellites with advanced sensors to detect and measure atmospheric methane, providing near-real-time data on emission sources and patterns. Initially designed for global or regional total emissions, technological advancements now enable satellites to measure individual point sources with finer spatial resolution. Most satellite data is accessible through online platforms. The primary advantage of space-based monitoring is its ability to cover global and remote regions, making it possible to identify unknown emission sources, such as offshore oil and gas leaks and natural emissions, which ground-based methods cannot monitor. However, satellite monitoring is less accurate and precise than ground-based instruments due to weather conditions and aerosols, and incurs high development, launch and operation costs.

Importance of an Integrated Monitoring System

Each measurement technique has its strengths and weaknesses, emphasising the importance of an integrated approach. Airborne and space-based measurements offer extensive spatial coverage, including remote and inaccessible areas, but can find it challenging to identify specific emission sources. Conversely, ground-based monitoring provides highly accurate and precise data for known sources but may miss sources in unknown or inaccessible regions. Therefore, combining data from multiple methane measurement methods is crucial for reducing discrepancies and achieving a comprehensive understanding of methane emissions. By leveraging the unique advantages of each technique, integrated measurement systems can be developed. Global initiatives such as the International Methane Emission Observation (IMEO) are vital for this coordination effort. The International Measurement, Monitoring, Reporting, and Verification (MMRV) Framework aims to accurately quantify greenhouse gas emissions from the energy sector by establishing a consistent framework for measuring and

reporting emissions across different sectors. Additionally, advances in high-resolution instruments and their integration could help reconcile many top-down and bottom-up measurement approaches.

Figure 13: Methane Detecting Satellites



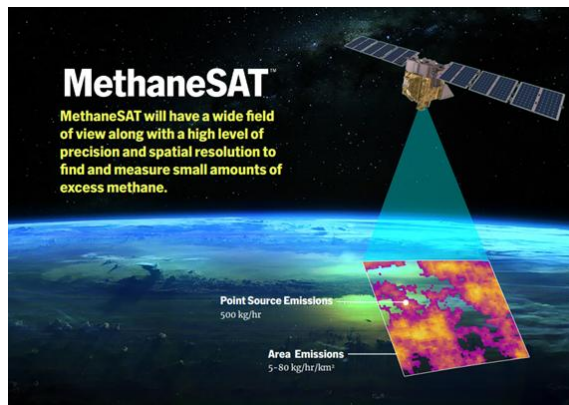
Source: Daniel et al (2022)

Table 2: Current and Planned Methane-Observing Satellites

Satellite	Organisation	Launch Date	Coverage
GOSAT/GOSAT 2	JAXA, MOEJ, NIES	2009- /2018-	global
Landsat-8, 9	USGS	2013- /2021-	global
WorldView-3	Digital Globe	2014-	targets
GHGSat	GHGSat, Inc.	2016-	targets
Sentinel-5p	ESA, NSO	2017-	global
EMIT	NASA	2022-	regional
MethaneSAT	EDF	2024-	global +targets
Carbon Mapper	Carbon Mapper and Planet	2024-	targets
GOSAT-GW	JAXA	2025-	global
Sentinel-5	ESA, EU	2025-	global
CO2M	ESA	planned in 2026	global

Box 4: MethaneSAT

Launched on 4 March 2024, MethaneSAT is a joint initiative by the Environmental Defense Fund (EDF) and the New Zealand Space Agency, designed to fill critical gaps in global methane monitoring. During its operational period, MethaneSAT provided unprecedented insights into methane emissions from oil and gas facilities worldwide, combining regional coverage with point-source detection.



Source: <https://www.methanesat.org/>

Key Achievements Before Transmission Loss

- **Global Coverage and Precision:** MethaneSAT effectively monitored regions accounting for over 80% of the world's oil and gas production, detecting methane levels as low as 3 parts per billion (ppb)—a level of accuracy unmatched by other satellites.
- **Identification of Super-Emitters:** Early data revealed clusters of high-emission facilities, enabling targeted mitigation strategies and affirming the importance of satellite-based methane monitoring.

- MethaneSAT detected methane emissions significantly higher than official estimates. It also revealed unexpected leaks from major oil and gas facilities, agricultural areas, and landfills—highlighting widespread underreported emissions. For example,
 - Permian Basin (Texas): Emissions up to approximately 5 times greater.
 - Caspian Sea region: Up to about 10 times greater than previous assessments.

Data Accessibility

Although transmission ceased in June 2025, MethaneSAT's collected data remains a valuable resource. EDF confirmed that historical measurements will be made publicly available through a cloud-based platform, integrated with Google Earth using AI-driven mapping for easy visualisation and analysis. MethaneSAT's operational phase demonstrated the feasibility of high-resolution methane monitoring at scale, reinforcing the urgency of global methane reduction efforts and setting a precedent for future satellite missions.

V. Methane Mitigation: What Actions Should Be Taken?

To effectively address methane emissions, prioritising the energy sector first is strategic due to its high potential for quick, cost-effective reductions.

- Methane leaks within the **energy sector** from oil and gas operations are often concentrated and easier to detect and repair using existing technologies, providing a high return on investment.
- The **waste sector**—particularly landfills and wastewater treatment—should be targeted, as it also offers clear opportunities for methane capture and utilisation, transforming emissions into energy.
- Although the **agriculture sector** is the largest source of methane worldwide, especially from enteric fermentation and rice paddies, mitigating it is more complex due to its diffuse nature and its links to food systems and livelihoods. Nonetheless, long-term innovation and behavioural change in agriculture are essential for sustained progress.

This prioritisation balances immediate impact with long-term transformation across sectors.

Energy Sector

Mitigating methane emissions from fossil fuels presents a significant opportunity to lessen their climate impact with low uncertainty. By integrating energy efficiency, clean renewable energy strategies, and sustainable energy management, we can play a crucial role in reducing methane emissions and supporting global efforts to mitigate climate change. The most significant potential for targeted mitigation is expected by 2030 (CCAC).

Oil & Gas

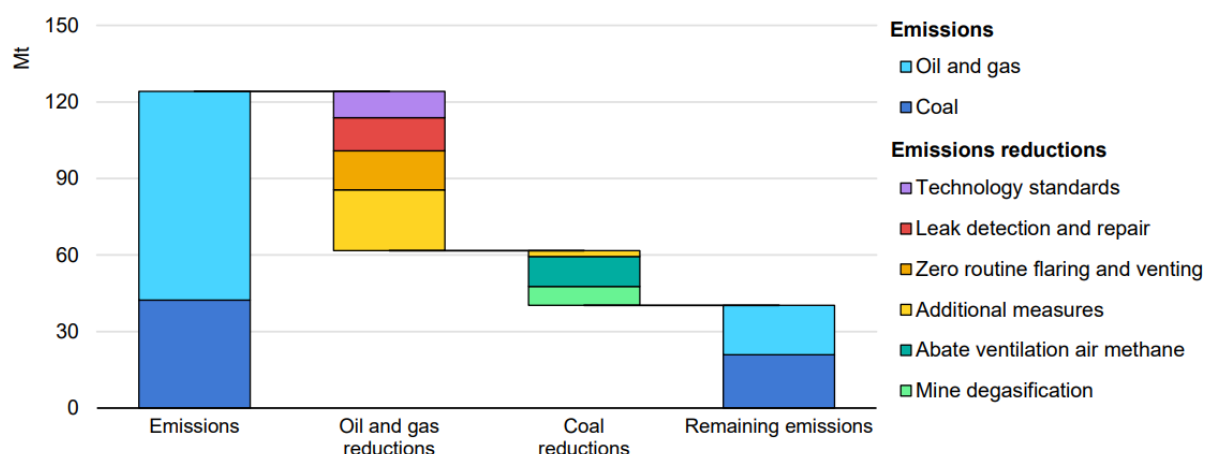
One of the most cost-effective mitigation options in the oil & gas industry is reducing leaks from long-distance gas transmission and distribution pipelines. Leak Detection and Repair (LDAR), involving inspection and repair, helps mitigate fugitive emissions. Equipment such as valves, pneumatic controllers, and pumps releases methane during operation. Replacing this equipment early with lower-emission versions can significantly reduce methane emissions. Additionally, installing new devices that capture and flare large sources of vented emissions is beneficial. **The IEA estimates that using the best available abatement technologies could reduce methane emissions from the oil and gas subsector by approximately 29-57 Mt annually, which is 72 per cent of its current emissions.**

Coal

Options for reducing Coal Mine Methane (CMM) include capturing methane during seam degasification in both underground and surface mines, as well as from outcrops and unsealed mine openings. In active underground mines, methane can be vented out through ventilation systems and then captured and concentrated for use as an energy source to heat mine facilities. The IEA report highlights that reducing CMM is a cost-effective strategy for addressing climate change while also improving mine safety and energy security. These abatement technologies are already deployed at numerous sites worldwide. The IEA estimates that approximately 70 per cent of CMM from underground mines and 20 per cent from surface mines could potentially be abated globally.

The IEA advises policymakers to follow a phased regulatory plan that involves initial baseline assessments, stakeholder engagement, legal framework creation, and strong monitoring, reporting, and verification (MRV) systems. Important policy steps include designing smart, tailored regulations, encouraging best practices in methane capture and usage, and promoting international collaboration for sharing data, technologies, and regulatory insights. These actions can quickly deliver climate benefits, enhance local air quality, and generate economic opportunities through methane recovery.

Figure 14: Potential of Abatement Options from Fossil Fuels in 2022



Source: IEA/CCAC (2023)

Box 5: Driving Down Coal Mine Methane Emissions: A Regulatory Roadmap and Toolkit

This report provides detailed guidance on designing and implementing new regulations to support the development of effective methane regulation. It discusses different regulatory approaches currently in use for methane, intending to provide a comprehensive toolkit for policymakers.

IEA suggests that policymakers should focus on phased, tailored regulations and international collaboration to maximise climate and economic benefits.

A full report is available at <https://www.iea.org/reports/driving-down-coal-mine-methane-emissions>



Source: IEA

Box 6: Coalbed Methane Outreach Programme (CMOP)

EPA's Coalbed Methane Outreach Program (CMOP) is a voluntary programme aimed at reducing methane emissions from coal mining activities to promote recovery, utilisation, and mitigation of coal mine methane (CMM). As of January 2023, CMOP is aware of 25 coal mine methane projects at 16 active mines and 35 abandoned mine methane projects at 66 abandoned (closed) mines in the US.

More information about CMOP,

<https://www.epa.gov/cmop>



Source: EPA

Waste Sector

The most significant potential lies in improving the treatment and disposal of solid waste. Up to 60 per cent of waste-sector target measures have either negative or low costs and could lower methane emissions from the waste sector by 29-36 Tg CH₄ annually by 2030 (UNEP & CCAC, 2021). Two methods can be used to control methane emissions from waste management systems:

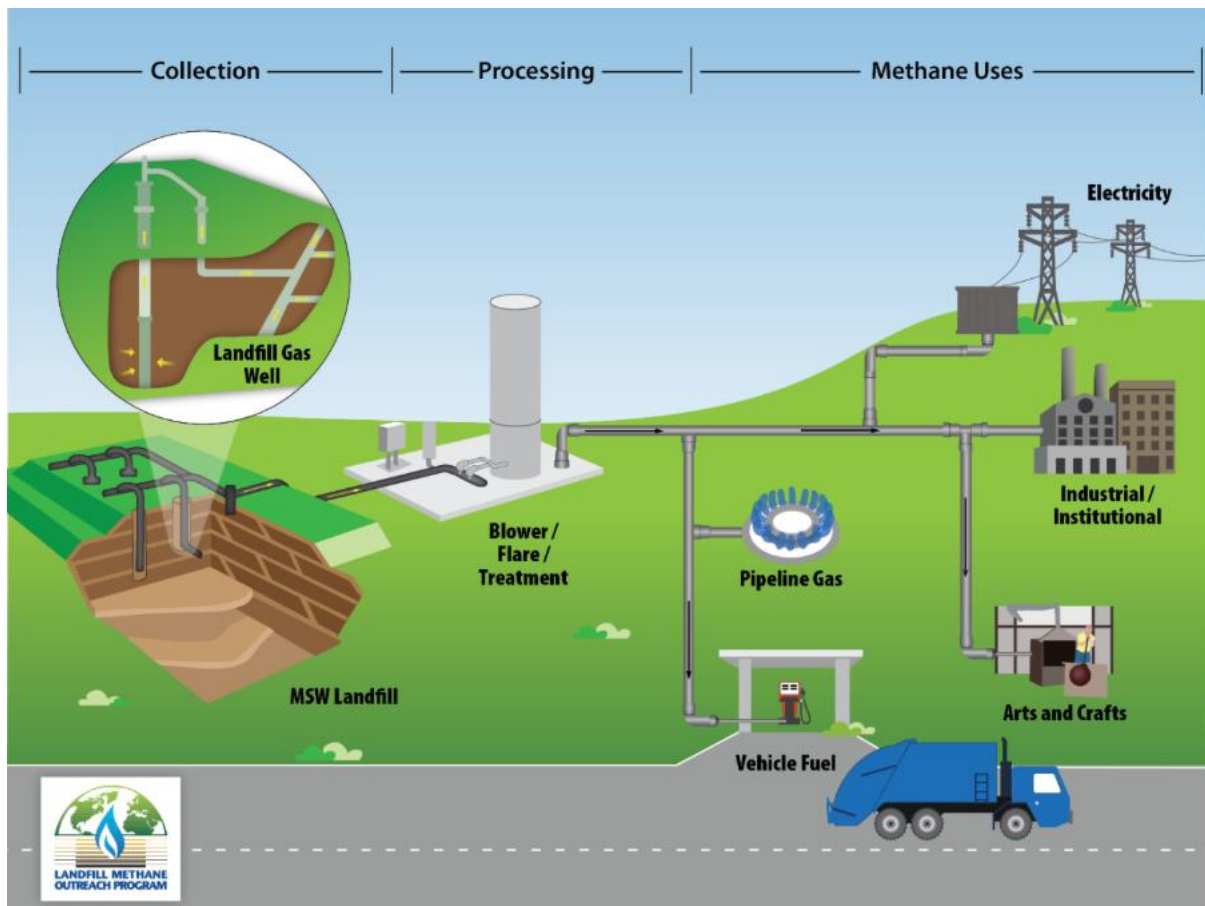
- The first method involves preventing methane emissions by separating and treating organic waste (e.g., food waste), which produces methane in landfills, from non-organic waste. Collected organic waste can be disposed of separately through anaerobic digestion or used as animal feed. Effective implementation requires the active involvement of national and local governments, aligning waste policies and actions with the waste management hierarchy: prevention, reuse/recycling, then disposal in landfills.
- The second method focuses on capturing biogas from waste treatment systems to stop methane from escaping into the air. Landfill gas can be collected using wells and a blower/flare system and then converted into renewable energy sources such as pipeline gas, electricity, boiler fuel, or vehicle fuel.

Box 7: Neste's sustainable aviation fuel (SAF) operations in Singapore

With advances in waste-to-energy technology, Neste has significantly expanded its presence in Singapore by opening the world's largest production facility for sustainable aviation fuel (SAF), which is produced from waste materials such as used cooking oil and animal fats. The expanded Tuas South refinery, part of a €1.6 billion project, can now produce up to one million tonnes of SAF annually - ten times more than before. Additionally, Neste has developed an integrated SAF supply chain to Changi Airport, supplying SAF to major international airports and fuel companies. This positions Neste as a leader in renewable aviation fuel, supporting decarbonisation in Singapore and the aviation industry.

Source: The Straits Times, Singapore (2023)

Figure 15 Controlling Methane Emissions from Waste: From Waste Separation to Biogas Recovery



Source: EPA

Agriculture Sector

In the agricultural sector, existing targeted measures could reduce methane emissions by around 30 million tonnes per year by 2030 (UNEP & CCAC, 2021). Reducing agricultural methane emissions can be achieved through the adoption of enhanced agricultural practices and improved farming systems. For enteric fermentation, strategies like using feed additives or vaccinations can enhance livestock growth and reduce methane emissions by altering biochemical processes in the rumen. Furthermore, selective breeding of low-emission livestock can cut these emissions by up to 20 per cent (CCAC). In terms of manure management, using biogas digesters or avoiding the storage of manure in uncovered anaerobic and wet systems can significantly reduce methane from livestock manure.

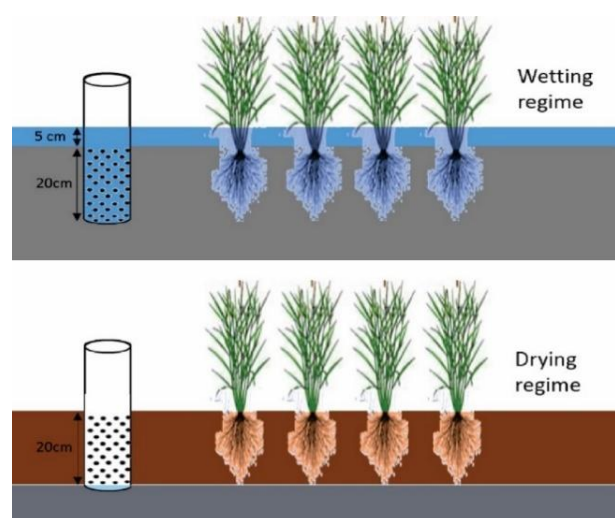


Figure 16: Alternative Wetting and Drying (AWD) Irrigation of Rice

The Alternate Wetting and Drying (AWD) method allows the top layer of soil to dry during the growing season, decreasing methane emissions by up to 50 per cent. Given the agricultural sector's diversity and varying environmental conditions across countries, tailored strategies are necessary; investments in biotechnology research are crucial for implementing effective mitigation strategies in agriculture.

Source: Riaz et al. (2018)

Box 8: Paddy Rice Production Project

Climate and Clean Air Coalition (CCAC), with the supports from International Rice Research Institute (IRRI) and Climate Change, Agriculture and Food Security (CCAFS), aims to promote Alternative Wetting and Drying (AWD) practices on a large scale, and is currently carrying out activities in Bangladesh, Colombia and Vietnam. AWD, the practice of allowing the water table to drop below the soil surface at points during a growing season, is an effective alternative to continuous flooding, proven to reduce methane emissions.

What are they doing?

- Supporting governments in implementing AWD policies and providing technical assistance.
- Developing a business case for AWD implementation in various countries.
- Mobilising action with the dissemination of AWD information.

What are the benefits?

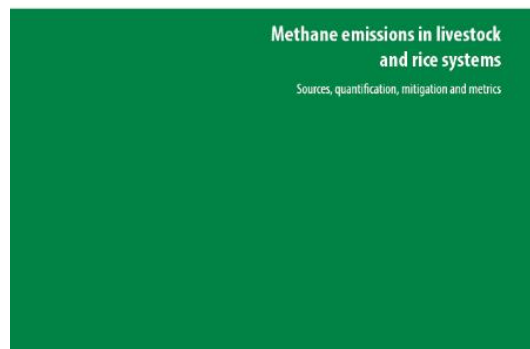
- Greenhouse gas mitigation potential: assumed to reduce methane emissions by an average of 48 per cent compared to continuous flooding.
- Reduce water use: can reduce water use by up to 30 per cent and help farmers cope with water scarcity.
- Increase net return for farmers

Box 9: Methane Emissions from Livestock and Rice: Sources, Quantification, Mitigation and Metrics

The publication published by the Food and Agriculture Organizations of the United Nations (FAO) offers quantified information on methane in agriculture and analyses the currently available methane mitigation strategies. It also highlights the role of improved livestock management, rice cultivation practices, and policy frameworks in achieving climate goals while maintaining food security.

Key policy recommendations include:

- Integrating methane mitigation into national climate strategies, such as Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs).
- Promoting innovation and investment in low-emission technologies and practices for livestock and rice systems.
- Enhancing data collection and monitoring systems to support evidence-based policymaking.
- Encouraging stakeholder collaboration, including farmers, researchers, and policymakers, to co-develop and implement context-specific solutions.
- Supporting capacity building and knowledge sharing to ensure effective implementation and scaling of mitigation strategies.



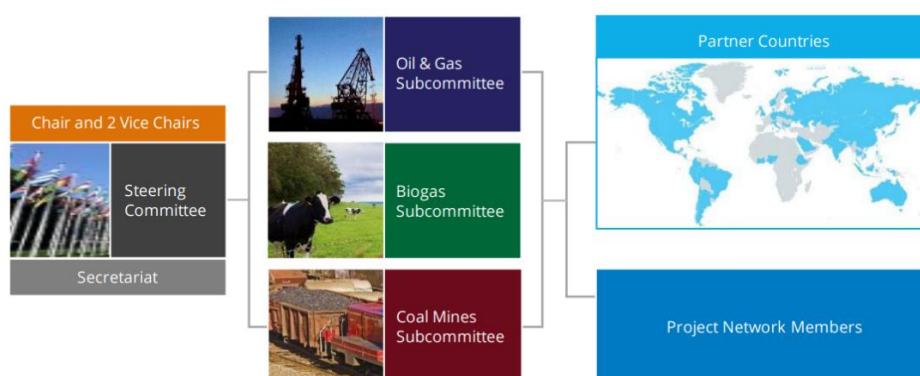
The full report is available at <https://www.fao.org/3/cc7607en/cc7607en.pdf>
Source: FAO (2023)

VI. Mitigating Methane: Efforts at Global, Regional and National Levels

Global Cooperation

With increased awareness of the impact of methane, global efforts to enhance collaboration on methane monitoring and mitigation across various sectors have intensified. The [*Global Methane Initiative \(GMI\)*](#), is an international public-private partnership focused on reducing emissions and utilising methane as a valuable energy source. GMI provides technical support in three key sectors: oil & gas, coal mines, and biogas, in collaboration with partner countries and organisations to launch methane recovery projects. As of 2024, GMI Partner Countries account for approximately 70 per cent of global anthropogenic methane emissions. These countries are encouraged to develop and submit action plans to the Secretariat hosted by the U.S. EPA, outlining key activities and priorities. GMI leverages these networks to share best practices, provide training, and share technical tools and resources in targeted sectors.

Figure 17: GMI Structure and Organisation to Address Methane in Three Key Sectors



Source : <https://www.globalmethane.org/>

[*The International Methane Emissions Observatory \(IMEO\)*](#) of UNEP, launched at the G20 (Group of 20) meeting in November 2021, addresses the lack of global methane measurement data in the oil and gas sector. IMEO provides publicly available and reliable emissions data focusing on the fossil fuel sector to help prioritise company actions and government policies. It collects and synthesises methane emission data from multiple sources and publishes integrated data for policymakers, companies and the public. Key elements of IMEO include [*the Oil and Gas Methane Partnership 2.0 \(OGMP 2.0\)*](#), UNEP's flagship oil and gas reporting and mitigation programme, and the [*Methane Alert and Response System \(MARS\)*](#), a global satellite detection and notification system focused on large methane emissions from the energy sector. IMEO also supports governments through capacity-building training to enhance policymaking and methane management.

Box 10: Oil and Gas Methane Partnership 2.0 (OGMP 2.0)

The Oil and Gas Methane Partnership (OGMP), initiated by the CCAC in 2014, was expanded in November 2020, evolving into OGMP 2.0. Launched by UNEP, CCAC, the European Commission, EDF, and 62 oil and gas companies, OGMP 2.0 introduced a comprehensive reporting framework that links reporting directly to strategic mitigation actions. By 2023, over 115 companies, representing nearly 40 per cent of global oil and gas production and 70 per cent of LNG flows, were part of OGMP 2.0. These companies commit to annual reporting on their methane emissions across all assets and to setting a methane reduction target by 2025, with progress reports. OGMP 2.0 fosters the exchange of experiences and capacity building through annual conferences and quarterly technical workshops.



Source: <https://ogmpartnership.com/>

Box 11: Methane Alert and Response System (MARS)

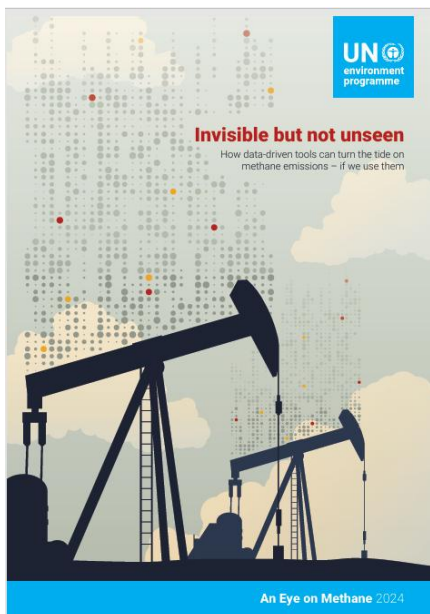


UNEP's IMEO launched the Methane Alert and Response System (MARS) is the first global satellite detection and notification system to provide actionable data on large methane emissions worldwide directly to governments and companies, enabling them to take action to address these emissions. In 2023, IMEO detected nearly 1,500 methane plumes globally from the energy sector. Of these, 600 plumes were identified using higher-resolution satellites, allowing MARS to notify relevant governments and companies. IMEO plans to expand MARS's monitoring capabilities to other sectors and detect smaller plumes.

Source: UNEP

Box 12: An Eye on Methane: IMEO's 2024 Annual Report

The IEA's 2024 report "Eye on Methane: Invisible but Not Unseen"—part of the Global Methane Tracker—highlights the persistent and critical challenge of methane emissions from the energy sector. Here are the key findings:



- Methane emissions from fossil fuels remained near record highs in 2023, with around 120 million tonnes (Mt) emitted, plus an additional 10 Mt from bioenergy.
- Despite growing commitments and improved monitoring, emissions have not declined significantly since 2019, indicating only a marginal drop in methane intensity.
- The top 10 countries emitting account for nearly 70 per cent of fossil fuel-related methane emissions. The U.S. leads in oil and gas emissions, while China dominates coal-related emissions.

The report emphasises the urgent need for stronger policies, enhanced data, and expedited action to meet global climate goals.

The full report is available at <https://wedocs.unep.org/handle/20.500.11822/46541>

Source: UNEP (2024)

Box 13: International MMRV Framework: Coordinating Global Methane Monitoring System

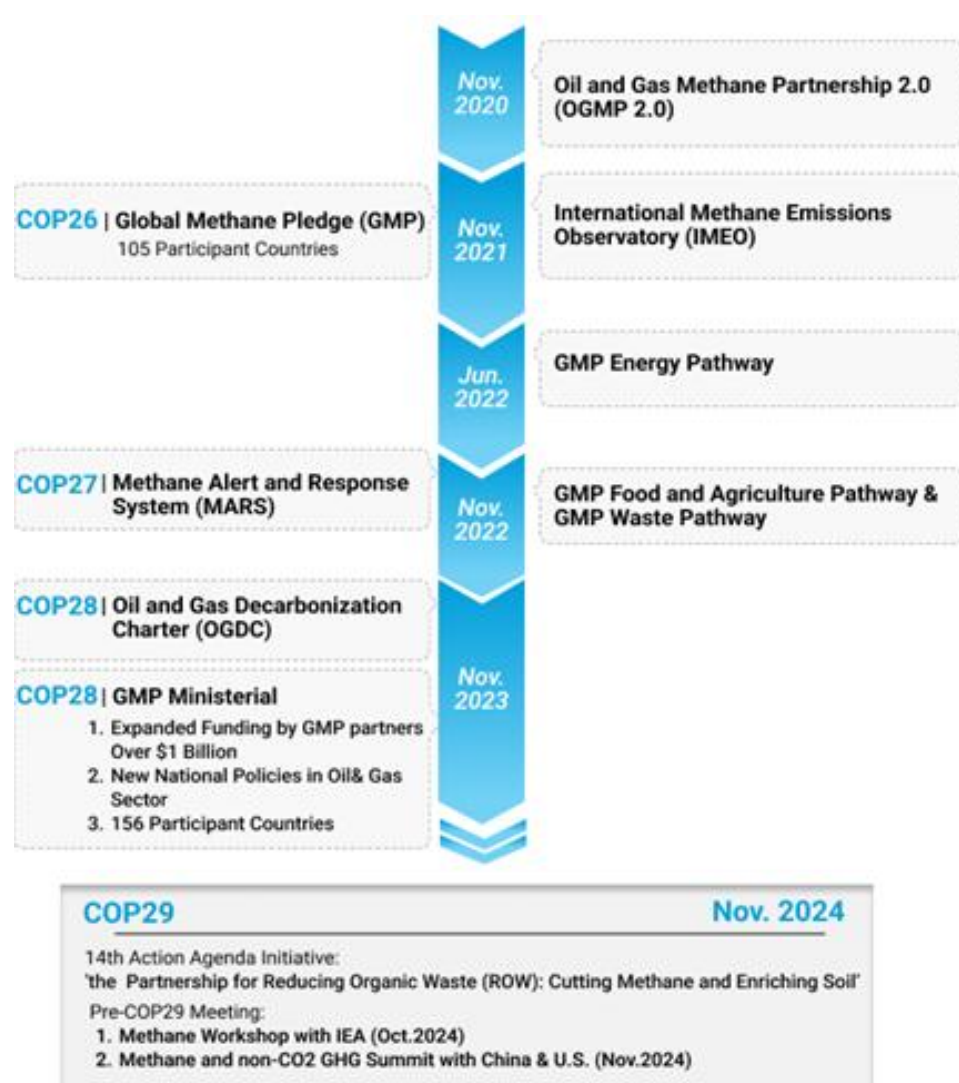
In November 2023, the International Working Group to Establish a Greenhouse Gas Supply Chain Emissions Measurement, Monitoring, Reporting, and Verification Framework was launched. This framework includes participation from the European Commission and 12 other countries, including the U.S., Australia, India, and Republic of Korea. Built on OGMP 2.0, the MMRV Working Group aims to provide natural gas market participants with comparable and reliable emissions data. They review existing standards and protocols to establish a consistent set of technical criteria for emissions reporting. Companies are encouraged to measure their emissions accurately and work towards effective reduction. Ultimately, these efforts will improve the accuracy and representativeness of the reported emissions data from the energy sector.

A significant milestone was achieved at COP26 in November 2021 with the launch of the first global-scale pledge on methane, the [Global Methane Pledge \(GMP\)](#). The GMP was initiated by EU and the U.S. with 103 participating countries. Countries joining the Pledge agree to take voluntary actions to reduce global methane emissions by at least 30 per cent from 2020 levels by 2030 globally. Participants commit to using the highest-tier IPCC good practice inventory methodologies and improving national GHGs inventory reporting under the UNFCCC and the

Paris Agreement. Canada, the Federated States of Micronesia, Germany, Japan, and Nigeria joined the EU and the U.S. as “Champions,” committing to support progress by other GMP countries and partners while advancing domestically. The Pledge also recognises the essential roles that the private sector, development banks, and financial institutions play in its implementation.

The GMP has since spurred further international collaborations, as illustrated in **Error! Reference source not found.** below. At COP28 in 2023, the Global Methane Pledge Ministerial announced over USD\$ 1 billion in new grant funding for methane action and new ambitious national commitments. By March 2024, the GMP had 158 participants representing over 50 per cent of global anthropogenic methane emissions. As an action agenda initiative of COP29 planned for November 2024, ‘the Partnership 4 reducing organic waste (ROW): cutting methane and enriching soil’ is selected. The partnership aims to reduce methane emissions from the waste sector with active partnerships and engagement, aligning with 1.5°C NDC commitments.

Figure 18 Timeline of Methane Discussions at COP Meetings



Source: Seohyun Hong (2025)

Box 14: The Oil and Gas Decarbonization Charter (ODGC)

At COP28 in November 2023, the Oil and Gas Decarbonization Charter (ODGC), an industry initiative focused on climate action across the oil and gas sector, was launched. A total of 52 companies, representing more than 40 per cent of global oil production, have signed the initiative. They agree to continue working towards industry's best practices in emission reduction, aiming to achieve the following three goals.

1. Achieve net-zero operations by 2050 at the latest
2. End routine flaring by 2030
3. Achieve near-zero upstream methane emissions by 2030

Regional Cooperation

Regional cooperation plays a vital role in reducing methane emissions, providing notable environmental and social advantages across borders. Recent instances include the EU's methane regulation and bilateral and sub-regional collaborations.

European Union (EU)

Since 1990, the EU has continuously reduced methane emissions, with future goals outlined in the [European Green Deal \(2020\)](#). The [European Climate Law \(2021\)](#) legislates these policy goals into legislation, aiming to cut GHG emissions by at least 55 per cent by 2030 compared to 1990 levels. The [EU methane strategy \(2020\)](#) outlines actions to reduce methane emissions across the energy, agriculture, and waste management sectors.

In June 2024, the EU Council approved the [EU Methane Regulation \(2024\)](#) (EU/2024/1787), part of the [Fit for 55](#) package, focusing on reducing methane emissions in the energy sector. This regulation mandates periodic emission reports, methane LDAR programs and bans venting and flaring. From 2027, new import contracts for oil, gas and coal must adhere to the same Measuring, Reporting, and Verification (MRV) standards as EU producers.

Figure 19 Timeline of EU's Methane Regulation



Source: Seohyun Hong (2025)

Association of Southeast Asian Nations (ASEAN)

ASEAN has committed to reducing methane emissions from the oil and gas sector as part of its broader decarbonisation efforts through the ASEAN Plan of Action for Energy Cooperation (APAEC) 2026–2030. The plan recognises the ‘ASEAN Energy Sector Methane Leadership Program (MLP)’ as a key initiative, serving as a regional platform for capacity building, knowledge sharing, and technical support to manage, report, and cut methane emissions. The initiative began with a 15-month MLP 1.0 in June 2023 to develop capacity for methane reduction aligned with the Global Methane Pledge. 18-month MLP 2.0 themed “Turning Capacity into Action,” focuses on practical implementation through three tracks: Methane Action (project support), Cross-Cutting & Knowledge Exchange (policy and technology alignment), and Capacity Building (advanced training), including the Southeast Asia Methane Emissions Technology Evaluation Centre (METEC). Looking ahead, the MLP Secretariat is designing the strategy and work plan for an 18-month MLP 3.0, starting in April 2026, to accelerate actions.” This effort aims to strengthen regional cooperation under the APAEC 2026–2030 and ASCOPE Charter, consolidating methane measurement, reporting, and mitigation efforts to reinforce ASEAN’s leadership in decarbonisation and methane reduction.

Central Asia

Central Asian countries have recently taken significant steps to address methane emissions through regional cooperation and policy development. In February 2025, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan launched the [*Central Asia Capacity Building for Methane Emission Reduction \(CA CBMER\)*](#) project. This initiative established a [*Regional Steering Committee*](#) to enhance national capacities in methane monitoring, reporting, and abatement, particularly in the energy and agriculture sectors (CAREC,2025). The project also encourages knowledge sharing and regional dialogue, with observers from Azerbaijan and Mongolia participating in discussions.

In parallel, these five countries endorsed [*the Regional Climate Change Adaptation Strategy for Central Asia*](#), developed with support from the Green Central Asia Initiative. The strategy emphasises the importance of reducing short-lived climate pollutants like methane as part of a broader regional climate response (UNECE & USAID, 2023). Further reinforcing this momentum, a UNEP-UNECE regional workshop held in June 2025 brought together government officials, legal experts, and civil society leaders from across Central Asia. The workshop focused on strengthening the implementation of multilateral environmental agreements (MEAs), including those targeting air pollution and hazardous emissions. Methane was highlighted as a key pollutant that warranted coordinated cross-border action.

China & U.S. Cooperation

In 2021, China and U.S. agreed on the [*China-U.S. Glasgow Declaration on Enhancing Climate Action in the 2020s*](#). In November 2023, they issued a comprehensive bilateral cooperation statement, [*the Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis*](#). Both countries committed to accelerating national methane action and developing policies to strengthen commitments under the Paris Agreement. A working group was established to cooperate on policy dialogue, technical exchanges, and capacity building. This cooperation is

significant as both countries contribute over 40 per cent of total annual emissions and have effective climate and renewable energy policies.

Japan & Republic of Korea Cooperation

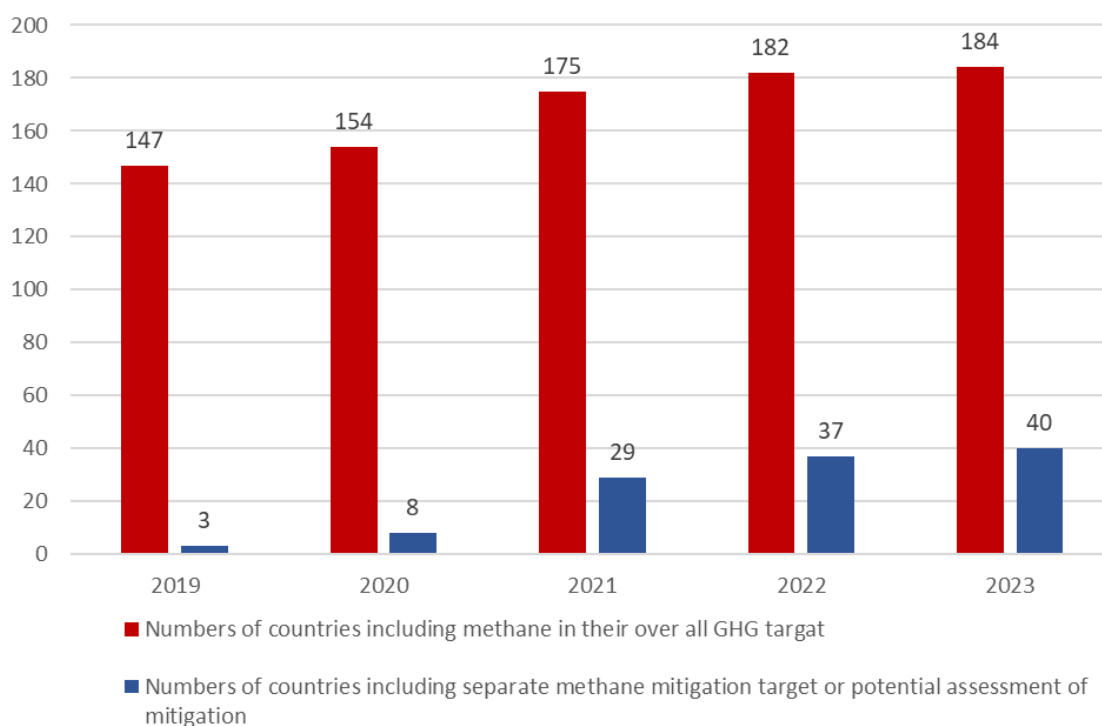
In 2023, JERA Co., Inc. (JERA) and Korea Gas Corporation (KOGAS) initiated the “*Coalition for LNG Emission Abatement toward Net-zero (CLEAN)*”. As major LNG buyers, Japan and the Republic of Korea aim to reduce GHG emissions in LNG value chain by enhancing visibility of methane emissions through collaboration.

National Policies and Regulations

Countries are establishing and implementing methane reduction measures customised to their emission characteristics. National planning involves submitting their Methane Action Plans or Roadmaps as part of the GMP commitment and integrating methane into their Nationally Determined Contributions (NDCs) as GHG mitigation targets. By the end of 2023, nearly 60 governments had completed or were in the process of finalising National Methane Action Plans.

Box 15: How Many Countries Include Methane in Their NDCs?

As of October 2023, it is estimated that over 90 per cent of NDCs include methane emissions within their target scope, while only 40 countries specify a separate methane target or assess methane mitigation potential. At COP28, a call was made to incorporate all GHG emissions from all sectors in revised 2035 NDC targets. It is anticipated that more countries will speed up efforts to establish specific methane targets in their NDCs.



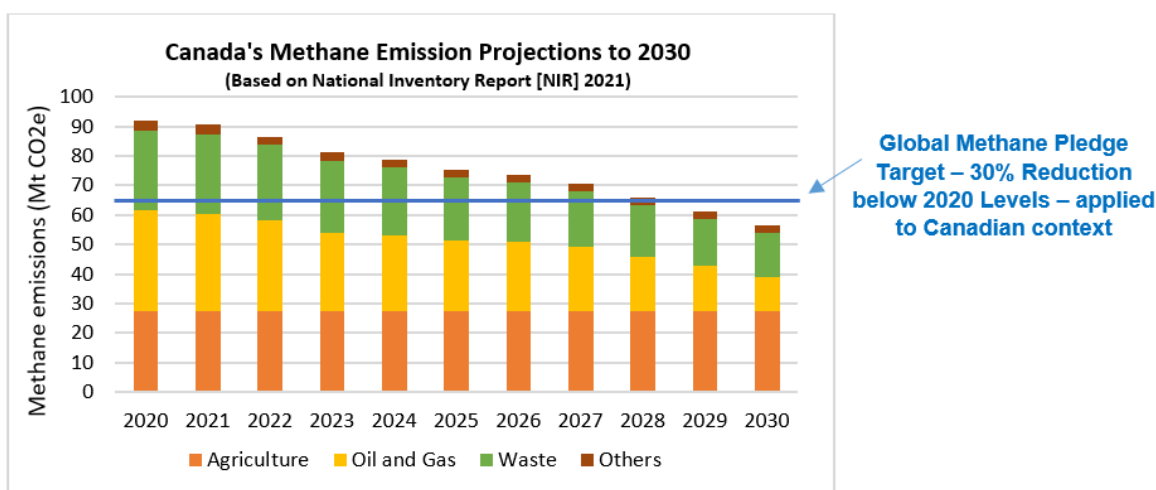
Source: Seohyun Hong, modified data sources from <https://www.globalmethanepledge.org/>

Canada

Canada is one of the earliest countries to regulate and track down methane emissions. The [Pan-Canadian Framework on Clean Growth and Climate Change \(2018\)](#) aims to reduce methane emissions from the oil and gas sector by 40-45 per cent by 2025. In 2021, Canada announced a goal to cut these emissions by at least 75 per cent below 2012 levels by 2030. The [2030 Emissions Reduction Plan \(ERP\)](#) and [Canada's Methane Strategy](#) outline reduction measures and supporting programmes for this target.

In December 2023, Canada announced draft methane regulations aimed at achieving a 75 per cent reduction by 2030, including more frequent leak inspections, strict limits on venting and flaring, and the phase-out of high-polluting devices. Additionally, CAD\$30 million was allocated for a Centre of Excellence to improve the understanding and reporting of methane emissions.

Figure 20: Canada's Methane Emission Projection in Emissions Reduction Plan (ERP)



Source: Government of Canada

Russian Federation

The Russian Federation is among the world's largest emitters of methane, mainly due to its extensive oil and gas infrastructure. Despite this, the country has not set specific national targets for methane reduction. While Russia has committed to achieving carbon neutrality by 2060, methane mitigation does not play a central role in its climate strategy (International Energy Agency (IEA, 2023). The country has also not joined the Global Methane Pledge, a voluntary initiative aimed at cutting global methane emissions by 30 per cent by 2030, which has been supported by over 150 countries (Global Methane Initiative, 2024).

The Russian Federation's energy policy focuses on reducing energy intensity and enhancing efficiency, which may indirectly lower methane emissions; however, it lacks direct regulatory mechanisms or incentives targeting methane leaks and venting (IEA, 2023). International organisations, including the IEA and the United Nations Environment Programme (UNEP), have urged Russia to adopt stronger methane monitoring and abatement measures, especially considering the cost-effectiveness of many available technologies.

China

Coal production is the main source of methane emissions in China, responsible for around 40 per cent of annual emissions. China has issued coalbed methane-specific Five-Year Plans (FYP) since the 11th FYP (2006-2010). In 2016, the 13th FYP provided a framework for policy options supporting coal mine methane utilisation. Following the China-U.S. Joint Declaration at COP26, China released the [Methane Emissions Control Action Plan](#) in November 2023, which contains 20 key tasks for methane action in the energy, agriculture, and waste sectors.

Beijing Gas distinguishes itself with its bold methane reduction plan, aiming for a methane emission intensity below 0.12 per cent by 2025 and striving for climate neutrality by 2030. This target is more aggressive than those set by China's three major oil firms—CNPC, Sinopec, and CNOOC—which have each pledged to cut methane intensity to under 0.25 per cent by 2025. These companies are heavily investing in technologies such as carbon capture, utilisation, and storage (CCUS), along with leak detection and repair systems to achieve their objectives. All four organisations are members of the China Oil & Gas Methane Alliance, formed to coordinate efforts across the sector and collectively reduce methane emissions in natural gas production to below 0.25 per cent by 2025 (UNEP, 2019; OGCI 2025, Sinopec, 2024).

Table 3: Methane Reduction Strategies – Major Chinese Energy Companies

Company	Methane Intensity Target	Key Initiatives	Alliance Memberships	Climate Goals
Beijing Gas	<0.12% by 2025	Investments in clean energy (solar, waste treatment), ecological restoration, and climate-neutral operations by 2030	China Oil & Gas Methane Alliance	Climate-neutral by 2030
CNPC	<0.25% by 2025	Leak detection and repair (LDAR), carbon capture and storage (CCUS), coal-to-gas switching, and methane monitoring systems	China Oil & Gas Methane Alliance, OGCI	Net-zero by 2050
Sinopec	<0.25% by 2025	Advanced methane monitoring, green hydrogen development, LDAR, renewable energy integration	China Oil & Gas Methane Alliance	Net-zero by 2050
CNOOC	<0.25% by 2025	Offshore methane control technologies, CCUS deployment, integration of renewables in offshore platforms	China Oil & Gas Methane Alliance	

Sources: UNEP (2019), OGCI (2025), Sinopec (2024)

Japan

As participants of the GMP, Japan has included methane reduction goals in its [updated NDC](#), aiming to reduce methane emissions to 26.7 Mt-CO₂ by 2030 compared to 30.0 Mt-CO₂ in 2013. Since about 80 per cent of methane emissions in Japan are from the agriculture sector, the Ministry of Forestry, Agriculture, and Fisheries introduced the [MIDORI strategy](#) in 2021. As one of the “GMP Champions” countries, Japan is committed to playing a leading role in international methane efforts and strengthening domestic methane mitigation efforts.

At the city level, Tokyo’s advanced waste management system is internationally recognised for its efficiency, cleanliness, and environmental sustainability. Key features of Tokyo’s waste management system (The Government of Japan, 2015 and 2022)

Reduce, Reuse, Recycle

- Tokyo highlights the hierarchy of waste management: generation control, reuse, recycling, heat recovery, and proper disposal.
- Public education campaigns and school programmes raise awareness of the 3Rs, with over 70,000 students visiting waste facilities each year.

High-Tech Waste Incineration

- Tokyo operates 19 advanced incineration plants that process around 8,000 tonnes of waste daily.
- Waste is incinerated at over 800°C, reducing volume by 95 per cent and minimising dioxin emissions.
- Emissions are strictly regulated, and chimneys emit harmless vapour, not smoke.

Energy Recovery and Circular Economy

- Heat from incineration is utilised to:
- Operate the waste facilities.
- Supply electricity to the grid (earning approximately ¥9.8 billion annually).
- Supply hot water to local swimming pools and greenhouses.

Community Integration

- Waste facilities are built with modern architecture and are often situated in urban areas.
- Residents are encouraged to visit the plants, promoting transparency and trust.

Strict Waste Sorting and Collection

- Citizens must sort waste into categories such as burnable, non-burnable, plastics, and recyclables.
- Collection operates with high efficiency, collecting 100 per cent of household waste daily.

Legal and Policy Framework

- Tokyo adheres to national laws such as the Basic Law for Establishing a Recycling-Based Society and the Waste Disposal and Public Cleansing Law.
- The Tokyo Metropolitan Government (TMG) implements a five-year waste management plan to continually improve systems.

Republic of Korea

The Korean government formulated the '[2030 Methane Emissions Reduction Roadmap](#)' in 2023, aiming to cut methane emissions by 30 per cent by 2030 compared to 2020 levels. The targets include sector-specific reduction goals: the agriculture and livestock sector (11.9 to 9.9 Mt CH₄), the waste sector (8.8 to 4.5 Mt CH₄), the energy sector (5.9 to 4.6 Mt CH₄), and others (0.8 to 0.1 Mt CH₄). The roadmap outlines 14 policy tasks across agriculture and livestock, waste, energy, and cross-sector implementation. As the world's third-largest importer of LNG, Republic of Korea plans to enhance emission measurement accuracy by investing in MRV technologies and periodically formulating the 'Fugitive Emissions Management Plan' to address fugitive methane gas from the energy sector.

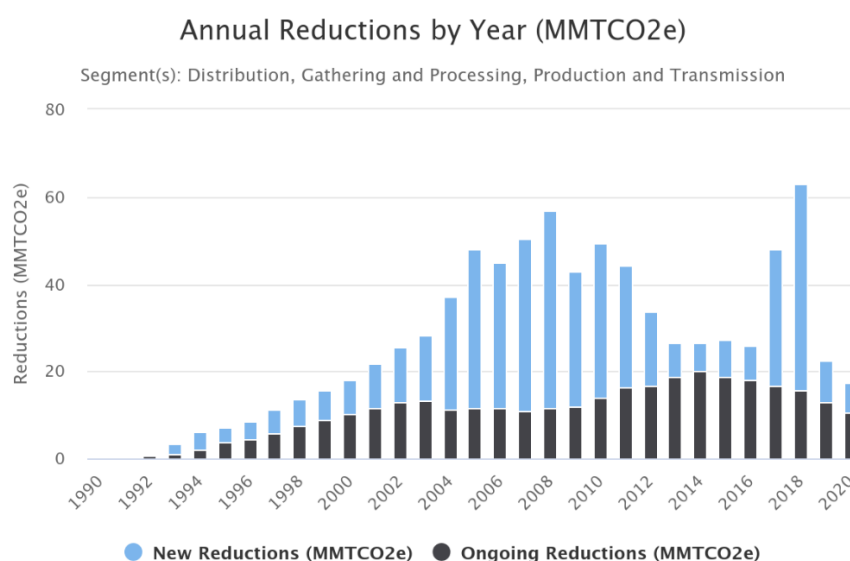
The Republic of Korea has tackled urban waste challenges in Seoul by implementing the 'Pay-As-You-Throw' (PAYT) system in 1995 to reduce landfill issues. It shifted from flat rates to charges based on waste volume or weight, using standardised bags. The system now features RFID-enabled smart bins, prepaid chips, and specialised waste bags for precise measurement and billing, encouraging waste reduction. Collected food waste is transformed into animal feed, compost, and biogas, supporting a circular economy. The PAYT system has enhanced recycling rates and transformed waste management culture, with public education and policies achieving over 95 per cent recycling. Ongoing upgrades aim to boost further environmental sustainability. Key results and impacts are:

- Food waste landfilling was banned in 2005; now only 3–5 per cent ends up in landfills
- Waste generation dropped from 1.3 kg/person/day in 1994 to ~1.0 kg since 2012
- Recycling rate increased from 24 per cent in 1995 to over 60 per cent by 2017
- RFID bins led to a 40 per cent reduction in food waste in pilot areas

United States of America

The U.S. EPA launched the [Natural Gas STAR partnership](#) in 1993 to encourage oil and gas operators to share innovative actions for reducing methane emissions. By 2021, this partnership had reduced 1.68 trillion cubic feet of methane emissions through the implementation of 153 cost-effective technologies and practices. These practices include LDAR, capturing vented gas, and rerouting captured gas during transmission. In 2016, the EPA established the [Methane Challenge Partnership](#) to further encourage methane abatement.

Figure 21: Methane Reduction Reported by Natural Gas STAR Partners



Source: EPA | Note: Units: CO₂ equivalent to a million metric tons

In November 2021, the U.S. government announced an updated [U.S. Methane Emissions Reduction Action Plan](#) to reduce methane emissions by 30 per cent below 2020 levels by 2030. The Inflation Reduction Act (IRA) of 2022 included the [Methane Emissions Reduction Programme](#), which provides financial and technical assistance and introduces a charge on methane emissions exceeding applicable waste emission thresholds. In 2023, the EPA announced [a final rule](#) under GHG reporting programme to prevent an estimated 58 million tons of methane emissions from 2024 to 2038.

Box 16: Methane Roadmap Action Programme (M-RAP)

In 2022, CCAC launched the Methane Roadmap Action Programme (M-RAP) to support the development and implementation of transparent and consistent national methane action plans and roadmaps. This programme assists countries in identifying, analysing, and building upon existing commitments, plans, and activities using a transparent and standardised methodology. In doing so, it aims to facilitate coordinated and accelerated progress in identifying and developing targeted methane reduction measures, particularly within the framework of revised NDCs. CCAC funding support for developing national methane roadmaps or action plans is available to GMP countries. By the end of 2023, 31 countries have completed or are in the process of completing their national methane plans with support from the CCAC.

List of References

Chapter 1: Introduction

1. Copernicus Climate Change Service. (2025, January 10). 2024 is the first year to exceed 1.5°C above pre-industrial level. <https://climate.copernicus.eu/copernicus-2024-first-year-exceed-15degc-above-pre-industrial-level>
2. Global Methane Initiative. (2023). *Importance of methane*. U.S. Environmental Protection Agency. <https://www.epa.gov/gmi/importance-methane>
3. Global Methane Pledge. (n.d.). *Global Methane Pledge*. <https://www.globalmethanepledge.org/>
4. Intergovernmental Panel on Climate Change. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee & J. Romero (Eds.)]. IPCC. <https://doi.org/10.59327/IPCC/AR6-9789291691647>
5. Intergovernmental Panel on Climate Change. (2018). *Summary for policymakers*. In V. Masson-Delmotte et al. (Eds.), *Global warming of 1.5°C: An IPCC special report* (pp. 3–24). Cambridge University Press. <https://doi.org/10.1017/9781009157940.001>
6. International Energy Agency (IEA). (2025). *Global Methane Tracker 2025*. IEA. <https://www.iea.org/reports/global-methane-tracker-2025>
7. Lindsey, R. (2025, May 21). *Climate change: Atmospheric carbon dioxide*. NOAA Climate.gov. <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>
8. NOAA Global Monitoring Laboratory. (2025, July 14). *Trends in CH₄*. NOAA Earth System Research Laboratories. https://gml.noaa.gov/ccgg/trends_ch4/
9. Organisation for Economic Co-operation and Development. (2025). *Targeting methane emissions to mitigate the risk of climate overshoot*. OECD Publishing. https://www.oecd.org/en/publications/targeting-methane-emissions-to-mitigate-the-risk-of-climate-overshoot_5fa37719-en.html
10. Ritchie, H., Rosado, P., & Roser, M. (2020). *Greenhouse gas emissions*. Our World in Data. <https://ourworldindata.org/greenhouse-gas-emissions>
11. Rohde, R. (2024). *Global temperature report for 2023*. Berkeley Earth. <https://berkeleyearth.org/global-temperature-report-for-2023/>
12. United Nations Development Programme, & University of Oxford. (2024). *People's Climate Vote 2024*. <https://peoplesclimate.vote/download>
13. United Nations Environment Programme. (n.d.). *Facts about methane*. <https://www.unep.org/explore-topics/energy/facts-about-methane>
14. UNFCCC. (n.d.). *History of the convention*. United Nations Framework Convention on Climate Change. <https://unfccc.int/process/the-convention/history-of-the-convention#Essential-background>
15. U.S. Environmental Protection Agency. (n.d.). *Greenhouse gases*. <https://www.epa.gov/climate-indicators/greenhouse-gases>

16. World Meteorological Organization (WMO). (2022). *WMO greenhouse gas bulletin – No. 19: The state of greenhouse gases in the atmosphere based on global observations through 2022*. Geneva.
17. World Meteorological Organization (WMO). (2024). *State of the global climate 2023* (WMO-No. 1347). Geneva.

Chapter 2: Sources of Methane: Where Does Methane Come From?

1. André, J.-C., Boucher, O., Bousquet, P., Chanin, M.-L., Chappellaz, J., & Tardieu, B. (2014). Le méthane: d'où vient-il et quel est son impact sur le climat. *EDP Sciences, Académie des Sciences et Technologies*.
2. Bastviken, D., Tranvik, L. J., Downing, J. A., Crill, P. M., & Enrich-Prast, A. (2011). *Freshwater methane emissions offset the continental carbon sink*. *Science*, 331(6013), 50. <https://doi.org/10.1126/science.1196808>
3. CarbonBrief. (2023). *Mapped: The global coal trade*. <https://www.carbonbrief.org/mapped-the-global-coal-trade/>
4. Chen, Y., Wu, N., Liu, C., Mi, T., Li, J., He, X., Li, S., Sun, Z., & Zhen, Y. (2022). *Methanogenesis pathways of methanogens and their responses to substrates and temperature in sediments from the South Yellow Sea*. *Science of the Total Environment*, 815, 152645. <https://doi.org/10.1016/j.scitotenv.2021.152645>
5. Commercial Law Development Program (CLDP). (2023). *Methane abatement for oil and gas: Handbook for policymakers*. U.S. Department of Commerce, in coordination with the U.S. Department of State, Bureau of Energy Resources. <https://cldp.doc.gov/sites/default/files/2024-05/Chapter%20%20-%20Methane%20Handbook.pdf>
6. DelSontro, T., Kunz, M. J., Kempter, T., Wüest, A., Wehrli, B., & Senn, D. B. (2011). *Spatial heterogeneity of methane ebullition in a large tropical reservoir*. *Environmental Science & Technology*, 45(23), 9866–9873. <https://doi.org/10.1021/es2005545>
7. Dirisu, J. O., Salawu, E. Y., Ekpe, I. C., Udoye, N. E., Falodun, O. E., Oyedepo, S. O., Ajayi, O. O., & Kale, S. A. (2024). *Promoting the use of bioenergy in developing nations: A CDM route to sustainable development*. *Frontiers in Energy Research*, 11. <https://doi.org/10.3389/fenrg.2023.1184348>
8. Dlugokencky, E., & Houweling, S. (2015). *Chemistry of the atmosphere: Methane*. In *Encyclopedia of Atmospheric Sciences* (2nd ed.). Academic Press.
9. Encyclopedia Britannica, Inc. (n.d.). *Methane cycle*. <https://www.britannica.com/science/methane>
10. Evans, C., & Gauci, V. (2023). *Wetlands and methane: Technical paper*. Wetlands International.
11. Food and Agriculture Organization of the United Nations (FAO). (2023). *Methane emissions in livestock and rice systems – Sources, quantification, mitigation and metrics*. Rome. <https://doi.org/10.4060/cc7607>
12. Global Energy Monitor. (2025). *Asia Gas Tracker*. <https://globalenergymonitor.org/projects/asia-gas-tracker/r>
13. International Energy Agency (IEA). (2024). *Global Methane Tracker 2024*. IEA.

14. Intergovernmental Panel on Climate Change. (2007). *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Chapter 7.4.1). Cambridge University Press. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-4-1.html
15. Neue, H. (1993). *Methane emission from rice fields: Wetland rice fields may make a major contribution to global warming*. *BioScience*, 43(7), 466–473.
16. Peng, S. (2023). *Challenges and opportunities in the global methane cycle*. *iScience*, 26(6), 106878. <https://doi.org/10.1016/j.isci.2023.106878>
17. Peng, S., Lin, X., Thompson, R. L., et al. (2022). *Wetland emissions and atmospheric sink changes explain methane growth in 2020*. *Nature*, 612, 477–482. <https://doi.org/10.1038/s41586-022-05447-w>
18. Ryan Driskell Tate. *Coal Mine Methane 2022: sizing up coal mine methane*. Global Energy Monitor, 2022.
19. Sanches, L. F., Guenet, B., Marinho, C. C., et al. (2019). *Global regulation of methane emission from natural lakes*. *Scientific Reports*, 9, 255. <https://doi.org/10.1038/s41598-018-36519-5>
20. Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., Raymond, P. A., Dlugokencky, E. J., Houweling, S., Patra, P. K., Ciais, P., Arora, V. K., Bastviken, D., Bergamaschi, P., Blake, D. R., Brailsford, G., Bruhwiler, L., Carlson, K. M., Carrol, M., Castaldi, S., Chandra, N., Crevoisier, C., Crill, P. M., Covey, K., Curry, C. L., Etiope, G., Frankenberg, C., Gedney, N., Hegglin, M. I., Höglund-Isaksson, L., Hugelius, G., Ishizawa, M., Ito, A., Janssens-Maenhout, G., Jensen, K. M., Joos, F., Kleinen, T., Krummel, P. B., Langenfelds, R. L., Laruelle, G. G., Liu, L., Machida, T., Maksyutov, S., McDonald, K. C., McNorton, J., Miller, P. A., Melton, J. R., Morino, I., Müller, J., Murguía-Flores, F., Naik, V., Niwa, Y., Noce, S., O'Doherty, S., Parker, R. J., Peng, C., Peng, S., Peters, G. P., Prigent, C., Prinn, R., Ramonet, M., Regnier, P., Riley, W. J., Rosentreter, J. A., Segers, A., Simpson, I. J., Shi, H., Smith, S. J., Steele, L. P., Thornton, B. F., Tian, H., Tohjima, Y., Tubiello, F. N., Tsuruta, A., Viovy, N., Voulgarakis, A., Weber, T. S., van Weele, M., van der Werf, G. R., Weiss, R. F., Worthy, D., Wunch, D., Yin, Y., Yoshida, Y., Zhang, W., Zhang, Z., Zhao, Y., Zheng, B., Zhu, Q., Zhu, Q., and Zhuang, Q.: *The Global Methane Budget 2000–2017*, *Earth Syst. Sci. Data*, 12, 1561–1623, <https://doi.org/10.5194/essd-12-1561-2020>, 2020.
21. Saunois, M., Martinez, A., Poulter, B., Zhang, Z., Raymond, P. A., Regnier, P., Canadell, J. G., Jackson, R. B., Patra, P. K., Bousquet, P., Ciais, P., Dlugokencky, E. J., Lan, X., Allen, G. H., Bastviken, D., Beerling, D. J., Belikov, D. A., Blake, D. R., Castaldi, S., Crippa, M., Deemer, B. R., Dennison, F., Etiope, G., Gedney, N., Höglund-Isaksson, L., Holgersson, M. A., Hopcroft, P. O., Hugelius, G., Ito, A., Jain, A. K., Janardanan, R., Johnson, M. S., Kleinen, T., Krummel, P. B., Lauerwald, R., Li, T., Liu, X., McDonald, K. C., Melton, J. R., Mühle, J., Müller, J., Murguía-Flores, F., Niwa, Y., Noce, S., Pan, S., Parker, R. J., Peng, C., Ramonet, M., Riley, W. J., Rocher-Ros, G., Rosentreter, J. A., Sasakawa, M., Segers, A., Smith, S. J., Stanley, E. H., Thanwerdas, J., Tian, H., Tsuruta, A., Tubiello, F. N., Weber, T. S., van der Werf, G. R., Worthy, D. E. J., Xi, Y., Yoshida, Y., Zhang, W., Zheng, B., Zhu, Q., Zhu, Q., and Zhuang, Q.: *Global Methane Budget 2000–2020*, *Earth Syst. Sci. Data*, 17, 1873–1958, <https://doi.org/10.5194/essd-17-1873-2025>, 2025.
22. United Nations Environment Programme. (2022). *An Eye on Methane: International*

23. United Nations Environment Programme. (2023). *An Eye on Methane – The road to radical transparency: International Methane Emissions Observatory 2023.*
24. United Nations Environment Programme. (n.d.). Facts about methane. <https://www.unep.org/explore-topics/energy/facts-about-methane>
25. U.S. Environmental Protection Agency (USEPA). (2010). Greenhouse gas emissions estimation methodologies for biogenic emissions from selected source categories: Solid waste disposal, wastewater treatment, ethanol fermentation. Measurement Policy Group.
26. U.S. Environmental Protection Agency (EPA). (n.d.). Coalbed Methane Outreach Program (CMOP). <https://www.epa.gov/cmop>
27. World Bank. (n.d.). *Global Flaring and Methane Reduction Partnership (GFMR).* <https://www.worldbank.org/en/programs/gasflaringreduction>

Chapter 3: Methane and Its Impacts: What Are the Consequences?

1. Archer, D., Eby, M., Brovkin, V., Ridgwell, A., Cao, L., Mikolajewicz, U., Caldeira, K., Matsumoto, K., Munhoven, G., Montenegro, A., & Tokos, K. (2009). *Atmospheric lifetime of fossil fuel carbon dioxide. Annual Review of Earth and Planetary Sciences*, 37, 117–134. <https://doi.org/10.1146/annurev.earth.031208.100206>
2. Chuwah, C., van Noije, T., van Vuuren, D. P., Stehfest, E., & Hazeleger, W. (2015). *Global impacts of surface ozone changes on crop yields and land use.* *Atmospheric Environment*, 106, 11–23.
3. Climate and Clean Air Coalition (CCAC) (2014). Time to Act to Reduce Short-Lived Climate Pollutants. <https://www.ccacoalition.org/sites/default/files/resources/Time%20To%20Act%20to%20Reduce%20Short-Lived%20Climate%20Pollutants.pdf>
4. De Vita, A., Belmusto, A., Di Perna, F., Tremamunno, S., De Matteis, G., Franceschi, F., & Covino, M. (2024). *The impact of climate change and extreme weather conditions on cardiovascular health and acute cardiovascular diseases.* *Journal of Clinical Medicine*, 13(3), 759. <https://doi.org/10.3390/jcm13030759>
5. Food and Agriculture Organization of the United Nations (FAO). (2023). Methane emissions in livestock and rice systems – Sources, quantification, mitigation and metrics. Rome. <https://doi.org/10.4060/cc7607en>
6. Feng, Z., Xu, Y., Kobayashi, K., et al. (2022). *Ozone pollution threatens the production of major staple crops in East Asia.* *Nature Food*, 3, 47–56. <https://doi.org/10.1038/s43016-021-00422-6>
7. Hollaway, M. J., Arnold, S. R., Challinor, A. J., & Emberson, L. D. (2012). *Intercontinental trans-boundary contributions to ozone-induced crop yield losses in the Northern Hemisphere.* *Biogeosciences*, 9, 271–292. <https://doi.org/10.5194/bg-9-271-2012>
8. International Energy Agency (IEA). (2022). Global methane tracker 2022. <https://www.iea.org/reports/global-methane-tracker-2022>
9. Jackson, R. B., Saunio, M., Bousquet, P., Canadell, J. G., Poulter, B., & Stavert, A. R. (2020). *Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel*

- sources. *Environmental Research Letters*, 15(7), 071002. <https://doi.org/10.1088/1748-9326/ab9ed2>
10. Jon Sampedro, Stephanie Waldhoff, Marcus Sarofim, Rita Van Dingenen (2023). *Marginal Damage of Methane Emissions: Ozone Impacts on Agriculture*. *Environmental and Resource Economics* (2023) 84:1095–1126, <https://doi.org/10.1007/s10640-022-00750-6>
 11. Kumar, N., & Gupta, H. (2021). *Methane: Risk assessment, environmental, and health hazard*. In *Hazardous Gases* (pp. 225–238). Academic Press. <https://doi.org/10.1016/B978-0-323-89857-7.00009-8>
 12. McDonald, B. C., Yates, E. L., & Luecken, D. J. (2023). *Evaluation of model performance for the simulation of surface ozone in the United States*. National Oceanic and Atmospheric Administration (NOAA). <https://csl.noaa.gov/pubs/EM202309McDonald.pdf>
 13. McDuffie, E. E., Sarofim, M. C., Raich, W., Jackson, M., Roman, H., Seltzer, K., et al. (2023). *The social cost of ozone-related mortality impacts from methane emissions*. *Earth's Future*, 11, e2023EF003853. <https://doi.org/10.1029/2023EF003853>
 14. Tianyi Sun, Ilissa B Ocko and Steven P Hamburg (2021). *The value of early methane mitigation in preserving Arctic summer sea ice*. *Environmental Research Letters* 17. <https://iopscience.iop.org/article/10.1088/1748-9326/ac4f10/pdf>
 15. United Nations Environment Programme (UNEP_ and World Meteorological Organization (WMO) (2011). *Integrated Assessment of Black Carbon and Tropospheric Ozone*. https://www.ccacoalition.org/sites/default/files/resources/2011_integrated-assessment-FULL_UNEP-WMO.pdf?utm_source=chatgpt.com
 16. United Nations Environment Programme/Climate and Clean Air Coalition. (2022). *Global methane assessment: 2030 baseline report*. Nairobi.
 17. West, J. J., & Fiore, A. M. (2005). *Management of tropospheric ozone by reducing methane emissions*. *Environmental Science & Technology*, 39, 4685–4691.
 18. World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM_{2.5} and PM₁₀), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. Geneva: World Health Organization.
 19. World Meteorological Organization. (2024). *State of the global climate 2023* (WMO-No. 1347). Geneva: World Meteorological Organization.
 20. van Dingenen, R., Dentener, F. J., Raes, F., Krol, M. C., Emberson, L., & Cofala, J. (2009). *The global impact of ozone on agricultural crop yields under current and future air quality legislation*. *Atmospheric Environment*, 43(3), 604–618.

Chapter 4: Tracking Methane: How Is Methane Monitored?

1. Archer, D., Eby, M., Brovkin, V., Ridgwell, A., Cao, L., Mikolajewicz, U., Caldeira, K., Matsumoto, K., Munhoven, G., Montenegro, A., & Tokos, K. (2009). *Atmospheric lifetime of fossil fuel carbon dioxide*. *Annual Review of Earth and Planetary Sciences*, 37, 117–134. <https://doi.org/10.1146/annurev.earth.031208.100206>
2. Ayasse, A. K., Thorpe, A. K., Cusworth, D. H., Kort, E. A., Negron, A. G., Heckler, J., Asner, G., & Duren, R. M. (2022). *Methane remote sensing and emission quantification of offshore shallow water oil and gas platforms in the Gulf of Mexico*. *Environmental Research Letters*,

- 17(8), Article 084039. <https://doi.org/10.1088/1748-9326/ac8566>
3. Choosing the Right Technology: A Guide to Quantifying Methane Emissions on Offshore Platforms. (n.d.). <https://www.industrialdecarbonizationnetwork.com/emissions-management/articles/choosing-the-right-technology-a-guide-to-quantifying-methane-emissions-on-offshore-platforms>
 4. Daniel J. Jacob, Daniel J. Varon, Daniel H. Cusworth, Philip E. Dennison, Christian Frankenberg, Ritesh Gautam, Luis Guanter, John Kelley, Jason McKeever, Lesley E. Ott, Benjamin Poulter, Zhen Qu, Andrew K. Thorpe, John R. Worden, and Riley M. Duren (2022). *Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane*. Atmospheric Chemistry and Physics, Vol 22, Issue 14. <https://doi.org/10.5194/acp-22-9617-2022>
 5. International Energy Agency (IEA). (2023). Global Methane Tracker 2023. <https://www.iea.org/reports/global-methane-tracker-2023>
 6. International Energy Forum (IEF). (2021). Methane mitigation in the energy sector: New methodology and opportunities. https://www.ief.org/_resources/files/pages/methane-initiative/ief-methane-report.pdf
 7. Jacob, D. J., Varon, D. J., Cusworth, D. H., Dennison, P. E., Frankenberg, C., Gautam, R., Guanter, L., Kelley, J., McKeever, J., Ott, L. E., Poulter, B., Qu, Z., Thorpe, A. K., Worden, J. R., & Duren, R. M. (2022). *Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane*. Atmospheric Chemistry and Physics, 22, 9617–9646. <https://doi.org/10.5194/acp-22-9617-2022>
 8. McDonald, B. C., Yates, E. L., & Luecken, D. J. (2023). *Evaluation of model performance for the simulation of surface ozone in the United States*. National Oceanic and Atmospheric Administration (NOAA). <https://csl.noaa.gov/pubs/EM202309McDonald.pdf>
 9. Measurement of Methane Emissions from Abandoned Wells & Mines. (n.d.). <https://carboncontainmentlab.org/publications/methane-measurement-techniques>
 10. National Academies of Sciences, Engineering, and Medicine. (2018). *Improving characterization of anthropogenic methane emissions in the United States*. The National Academies Press. <https://doi.org/10.17226/24987>
 11. Oberle, F. K. J., Gibbs, A. E., Richmond, B. M., & others. (2019). *Towards determining spatial methane distribution on Arctic permafrost bluffs with an unmanned aerial system*. SN Applied Sciences, 1, 236. <https://doi.org/10.1007/s42452-019-0242-9>
 12. Sun, S., Ma, L., & Li, Z. (2021). *Methane emission estimation of oil and gas sector: A review of measurement technologies, data analysis methods and uncertainty estimation*. Sustainability, 13(24), 13895. <https://doi.org/10.3390/su132413895>
 13. Sánchez-García, E., Gorroño, J., Irakulis-Loitxate, I., Varon, D. J., & Guanter, L. (2022). *Mapping methane plumes at very high spatial resolution with the WorldView-3 satellite*. Atmospheric Measurement Techniques, 15, 1657–1674. <https://doi.org/10.5194/amt-15-1657-2022>

Chapter 5: Key Actions for Mitigation: What Actions Are Required?

1. Allen, J. M., & Sander, B. O. (2019). *The diverse benefits of alternate wetting and drying (AWD)*. Los Baños, Philippines: International Rice Research Institute. Available online at:

2. Climate and Clean Air Coalition (CCAC). (2016). Alternate wetting & drying infographic. <https://www.ccacoalition.org/sites/default/files/resources//AWDper cent20Infographic.pdf>
3. Climate and Clean Air Coalition (CCAC). (2022). Factsheet: Methane emission mitigation in the agriculture sector. <https://www.ccacoalition.org/sites/default/files/resources//Methaneper cent20Mitigationper cent20inper cent20theper cent20Agricultureper cent20Sectorper cent20-per cent20Factsheet.pdf>
4. Chang, J., Peng, S., Yin, Y., Ciais, P., Havlik, P., & Herrero, M. (2021). *The key role of production efficiency changes in livestock methane emission mitigation*. AGU Advances, 2, e2021AV000391. <https://doi.org/10.1029/2021AV000391>
5. Commercial Law Development Program (CLDP). (2023). *Methane abatement for oil and gas: Handbook for policymakers*. U.S. Department of Commerce, in coordination with the U.S. Department of State, Bureau of Energy Resources. <https://cldp.doc.gov/sites/default/files/2024-05/Chapter%20%20-%20Methane%20Handbook.pdf>
6. Food and Agriculture Organization of the United Nations (FAO). (2023). Methane emissions in livestock and rice systems – Sources, quantification, mitigation and metrics. Rome. <https://doi.org/10.4060/cc7607en>
7. Food and Agriculture Organization of the United Nations (FAO). (2023). *Methane emissions in livestock and rice systems: Sources, quantification, mitigation and metrics*. FAO. <https://openknowledge.fao.org/handle/20.500.14283/cc7607en>
8. Global Alliance for Incinerator Alternatives (GAIA). (2022). A key to rapid methane reductions: Keeping organic waste from landfills. https://www.no-burn.org/wp-content/uploads/2022/11/GAIA_White_Paper_A_Key_to_Rapid_Methane_Reductions_FINAL.pdf
9. Gabriel Vegh-Gaynor, Rowland, A., Quintana, A., & Nguyen, L. (2023). *Mitigating methane from food and agriculture: A global health strategy*. The Global Climate and Health Alliance (GCHA). <https://climateandhealthalliance.org/wp-content/uploads/2023/08/MethaneReport-Ag-FINAL.pdf>
10. International Energy Agency (IEA) & Climate and Clean Air Coalition (CCAC). (2023). The imperative of cutting methane from fossil fuels: An assessment of the benefits for the climate and health. <https://www.ccacoalition.org/sites/default/files/resources/files/Theper cent20imperativeper cent20ofper cent20cuttingper cent20methaneper cent20fromper cent20fossilper cent20fuels.pdf>
11. International Energy Agency (IEA). (2023). Global methane tracker 2023. <https://www.iea.org/reports/global-methane-tracker-2023>
12. International Energy Agency (IEA). (2024). Global methane tracker. https://iea.blob.core.windows.net/assets/d42fc095-f706-422a-9008-6b9e4e1ee616/GlobalMethaneTracker_Documentation.pdf
13. International Energy Agency (IEA). (2023). *Driving down coal mine methane emissions: A regulatory roadmap and toolkit*. IEA. <https://www.iea.org/reports/driving-down-coal-mine->

methane-emissions

14. Kok, Y. (2023, May 17). *S'pore home to world's largest production facility for jet fuel made from waste materials*. The Straits Times. <https://www.straitstimes.com/singapore/s-pore-home-to-world-s-largest-production-facility-for-jet-fuel-made-from-waste-materials>
15. Króliczewska, B., Pecka-Kiełb, E., & Bujok, J. (2023). *Strategies used to reduce methane emissions from ruminants: Controversies and issues*. Agriculture, 13, 602. <https://doi.org/10.3390/agriculture13030602>
16. National Institute of Green Technology (NIGT). (2023). *Strategies for implementing the Global Methane Pledge in the agriculture sector*. NIGT FOCUS, 1(4).
17. Ocko, I., Sun, T., Shindell, D., Oppenheimer, M., Hristov, A., Pacala, S., Mauzerall, D., Xu, Y., & Hamburg, S. (2021). *Acting rapidly to deploy readily available methane mitigation measures by sector can immediately slow global warming*. Environmental Research Letters, 16. <https://doi.org/10.1088/1748-9326/abf9c8>
18. Riaz, A.; Khaliq, A.; Fiaz, S.; Noor, M.A.; Nawaz, M.M.; Mahboob, W.; Ullah, S. Weed Management in Direct Seeded Rice Grown under Varying Tillage Systems and Alternate Water Regimes. Planta Daninha 2018, 36, 59.
19. The FARM Environmental Stewardship Continuous Improvement Reference Manual, Chapter 5. (2017). National Dairy Farm Program.
20. U.S. Environmental Protection Agency (EPA). (n.d.). AgSTAR: Biogas recovery in the agriculture sector, practices to reduce methane emissions from livestock manure management. <https://www.epa.gov/agstar/practices-reduce-methane-emissions-livestock-manure-management>
21. U.S. Environmental Protection Agency (EPA). (n.d.). Coalbed methane outreach program (CMOP). <https://www.epa.gov/cmop>
22. de Haas, Y., Veerkamp, R. F., de Jong, G., & Aldridge, M. N. (2021). *Selective breeding as a mitigation tool for methane emissions from dairy cattle*. Animal: An International Journal of Animal Bioscience, 15(Suppl 1), 100294. <https://doi.org/10.1016/j.animal.2021.100294>

Chapter 6: Mitigating Methane: Efforts at Global, Regional and National Levels

1. ASEAN Centre for Energy & Methane Leadership Program (MLP). (2024). *ASEAN energy sector methane leadership program (MLP)*. Retrieved from <https://aseanenergy.org/post/asean-energy-sector-methane-leadership-program-mlp/>
2. Central Asia Climate Portal. (2025, July 10). *Central Asian countries launch Regional Steering Committee to accelerate methane reduction efforts*. <https://centralasiacclimateportal.org/central-asian-countries-launch-regional-steering-committee-to-accelerate-methane-reduction-efforts/>
3. Climate and Clean Air Coalition (CCAC). (2022). *European Union methane action plan*. Retrieved July 17, 2025, from <https://www.ccacoalition.org/sites/default/files/resources//European%20Union%20Methane%20Action%20Plan.pdf>

4. European Union. (2024). *Regulation on methane emissions in the energy sector* [EU Regulation L 2024/1787]. Retrieved July 16, 2025, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202401787
5. Global Methane Initiative (GMI). (2024). *GMI fact sheet*. Retrieved from <https://globalmethane.org/downloads/GMI%20Fact%20Sheet.pdf>
6. Global Methane Initiative (GMI). (2024). *Russia – Partner Country*. <https://www.globalmethane.org/partners/detail.aspx?c=russia>
7. Government of Japan. (2015). *Advanced waste disposal technology makes Tokyo the cleanest city*. JapanGov. https://www.japan.go.jp/tomodachi/2015/winter2015/advanced_waste_disposal_technology.html
8. Institute for Governance & Sustainable Development (IGSD). (2023). *China methane emissions control action plan*. Retrieved from <https://www.igsd.org/wp-content/uploads/2023/11/2023-CHINA-METHANE-EMISSIONS-CONTROL-ACTION-PLAN.pdf>
9. Institute for Governance & Sustainable Development (IGSD) & Asia Pacific Clean Energy Leadership (APCEL). (2024). *China's ongoing efforts to address methane emissions and opportunities to further raise China's methane mitigation ambition*. Retrieved July 23, 2025, from <https://law.nus.edu.sg/apcel/wp-content/uploads/sites/3/2024/03/China-Methane-Briefing-APCEL-Mar-2024.pdf>
10. International Energy Agency (IEA). (2023). *Methane tracker 2023: Interactive country and regional estimates*. IEA. <https://www.iea.org/reports/methane-tracker-2020/interactive-country-and-regional-estimates>
11. International Energy Agency (IEA). (n.d.). *China national methane action plan*. Retrieved from <https://www.iea.org/policies/16940-national-methane-action-plan>
12. Oil and Gas Climate Initiative (OGCI). (2025, July 2). *Learn about reducing methane emissions*. OGCI. <https://www.ogci.com/methane-emissions/methane-intensity-target/>
13. Olczak, M. (2024). *Analysing the EU methane regulation: What is changing, for whom and by when?* Oxford Institute for Energy Studies. <https://www.oxfordenergy.org/publications/analysing-the-eu-methane-regulation-what-is-changing-for-whom-and-by-when/>
14. Regional Environmental Centre for Central Asia (CAREC). (2025). *Central Asia Capacity Building for Methane Emission Reduction (CA CBMER)*. https://carececo.org/en/main/activity/projects/ca_cbmer/
15. Seoul Metropolitan Government. (2018). *Recycling (Smart Waste Management in Seoul)*. Seoul Solution. <https://seoulsolution.kr/en/content/2691>
16. Sinopec. (2024, August 1). *Sinopec announces the launch of Carbon Footprint Alliance to drive green development in energy and chemicals*. <http://www.sinopec.com/listco/en/000/000/064/64601.shtml>
17. Sinopec Economic & Technological Research Institute. (2024). *China Energy Outlook 2060 (2024 edition)*. http://edri.sinopec.com/edri/news/com_news/20240109/news_20240109_325732006670.shtml

18. Tokyo Metropolitan Government. (2022). *Tokyo Environmental Master Plan (Digest Version)*. <https://www.kankyo.metro.tokyo.lg.jp/documents/d/kankyo/masterplandigestversion>
19. United Nations Economic Commission for Europe (UNECE) & U.S. Agency for International Development (USAID). (2023, November 6). *Methane emissions abatement as an enabler for regional economic development* [Workshop presentation]. Almaty Energy Forum. <https://unece.org/sites/default/files/2023-11/4.%20Meyer%20-%20USAID%20Slides%20for%20Workshop%20on%20Methane%20Management%20at%20the%20Almaty%20Energy%20Forum%2C%20November%206%2C%202023%20rev.pdf>
20. United Nations Environment Programme (UNEP). (2003, March 7). *Korea Environmental Policy Bulletin: Volume-Based Waste Fee System*. <https://www.unep.org/resources/report/korea-environmental-policy-bulletin-volume-based-waste-fee-system>
21. United Nations Environment Programme (UNEP). (2019, March 9). *Beijing air improvements provide model for other cities*. UNEP. <https://www.unep.org/news-and-stories/press-release/beijing-air-improvements-provide-model-other-cities>
22. United Nations Environment Programme (UNEP). (2022). *An eye on methane: International Methane Emissions Observatory 2022*. Nairobi. <https://www.unep.org/methane>
23. United Nations Environment Programme (UNEP). (2023). *An eye on methane – The road to radical transparency: International Methane Emissions Observatory 2023*. Nairobi. <https://www.unep.org/methane>
24. United Nations Environment Programme (UNEP). (2024). *An eye on methane 2024: Invisible but not unseen – How data-driven tools can turn the tide on methane emissions – if we use them*. UNEP. <https://wedocs.unep.org/handle/20.500.11822/46541>
25. United Nations Framework Convention on Climate Change (UNFCCC). (2022). *Japan's Nationally Determined Contribution*. Retrieved July 31, 2024, from https://unfccc.int/sites/default/files/NDC/2022-06/JAPAN_FIRST%20NDC%20%28UPDATED%20SUBMISSION%29.pdf
26. U.S. Agency for International Development (USAID). (2024). *MLP 2.0 design document*. Developed by USAID Southeast Asia Smart Power Program in collaboration with MLP members.
27. U.S. Environmental Protection Agency (EPA). (1993–2022). *Natural Gas STAR Partnership*. Retrieved from <https://www.epa.gov/natural-gas-star-program/natural-gas-star-partnership-1993-2022>
28. U.S. Environmental Protection Agency (EPA). (2016–2024). *Methane Challenge Partnership*. Retrieved from <https://www.epa.gov/natural-gas-star-program/methane-challenge-partnership-2016-2024>
29. Yu, K.-Y. (2018). *Pay-as-you-throw system of Seoul*. Seoul Solution. <https://seoulsolution.kr/en/content/6326>

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