UN environment programme

GLOBAL METHANE STATUS REPORT

2025

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

ISBN: 978-92-807-4240-4
Job number: DTI/2722/PA
DOI: https://doi.org/10.59117/20.500.11822/48921

Cover Photo credit
Clean Air Task Force.

Suggested citation
United Nations Environment Programme (2025). *Global Methane Status Report*. Paris

Production: Paris
URL: https://www.unep.org/resources/report/global-methane-status-report-2025

Acknowledgements

The Climate and Clean Air Coalition (CCAC), a United Nations Environment Programme (UNEP) convened initiative would like to thank the report's Steering Committee; the UNEP International Methane Emissions Observatory (IMEO); the coordinating lead, and other contributing authors; the expert reviewers and the project coordination team for their contribution to the development of this report.

The individuals mentioned below contributed to the production of the report. Steering Committee members, authors and expert reviewers contributed in their individual capacities and their affiliations are only mentioned for identification purposes.

Steering Committee

Tomás de Oliveira Bredariol (International Energy Agency), Manfredi Caltagirone (IMEO, UNEP), Steven Hamburg (Environmental Defense Fund), Andrea Hinwood (UNEP), Lena Höglund-Isaksson (International Institute for Applied Systems Analysis), Johan C.I. Kuylenstierna (Stockholm Environment Institute York, University of York), Marcelo Mena (Global Methane Hub), Mushtaq Ahmed Memon (UNEP), Martina Otto (CCAC Secretariat, UNEP), Aditi Ramola (Waste and Resources Consultant), Drew Shindell (Duke University), Aimable Uwizeye (Food and Agriculture Organization of the United Nations)

Authors

Stefania Abakerli (World Bank), Tarek Abichou (IMEO, UNEP), Jonathan Banks (Clean Air Task Force)*, Marci R. Baranski (IMEO, UNEP), Nathan Oliveira Barros (Federal University of Juiz de Fora), Martial Bernoux (Food and Agriculture Organization of the United Nations)*, Sophie Bonnard (CCAC Secretariat, UNEP), Nathan Borgford-Parnell (CCAC Secretariat, UNEP), Andreea Calcan (IMEO, UNEP), Krystal Crumpler (Food and Agriculture Organization of the United Nations)*, Benjamin Heras Cruz (Carbon Limits AS), Meghan Demeter (IMEO, UNEP), Gabrielle Dreyfus (Institute for Governance & Sustainable Development), Giulia Ferrini (UNEP), Robert A. Field, Carlos Silva Filho (S2F Partners / iPNRS)*, James Lawrence France (Environmental Defense Fund & Royal Holloway University of London), Giulia Maria Galbiati (Food and Agriculture Organization of the United Nations), Adriana Gomez-Sanabria (International Institute for Applied Systems Analysis), Steven Hamburg (Environmental Defense Fund / IMEO, UNEP)*, Lena Höglund-Isaksson (International Institute for Applied Systems Analysis)*, Itziar Irakulis-Loitxate (IMEO, UNEP), Irina Isakova (Carbon Limits)*, Dr. S.M. Mofijul Islam (Soil Science Division, Bangladesh Rice Research Institute), Daniel J. Jacob (Harvard University), Mary Kang (McGill University), Kavya Koonampilli (World Biogas Association), Mark Lunt (Environmental Defense Fund), Chris Malley (Stockholm Environment Institute York, Univeristy of York)*, Sandra M. Mazo-Nix (Independent Consultant), Malika Menoud (IMEO, UNEP), Baysa Naran (Climate Policy Initiative), Euan G. Nisbet (Royal Holloway, University of London, the United Kingdom of Great Britain and Northern Ireland), Linh Nguyen (Clean Air Task Force), Paolo Prosperi (Food and Agriculture Organization of the United Nations), Scarlett Quinn-Savory (CCAC Secretariat, UNEP)*, Arne Michael Ragossnig (RM Umweltkonsulenten ZT GmbH), Aditi Ramola (Waste and Resources Consultant)*, Saskia Reppin (Food and Agriculture Organization of the United Nations), Thomas Röckmann (Institute for Marine and Atmospheric Research Utrecht, Utrecht University, Utrecht, Netherlands), Felicia Ruiz (Director, Coal Mine Methane and Strategic

Partnerships), Mirella Salvatore (Food and Agriculture Organization of the United Nations), Laure-Sophie Schiettecatte (Food and Agriculture Organization of the United Nations), Stefan Schwietzke (IMEO, UNEP), Drew Shindell (Duke University)*, Lauren Sidner (Massachusetts Institute of Technology)*, Kushal Tibrewal (IMEO, UNEP), Aimable Uwizeye (Food and Agriculture Organization of the United Nations), Jingyi Ye (CCAC Secretariat, UNEP), Daniel Zavala-Araiza (Environmental Defense Fund), Shaohui Zhang (International Institute for Applied Systems Analysis)
* Coordinating Lead Authors

Expert Reviewers
Ilse Aben (Space Research Organisation Netherlands), Olga Brovkina (Global Change Research Institute of the Czech Academy of Sciences), James Garvie (CCAC Secretariat, UNEP), Chiara Giamberardini (United Nations Economic Commission for Europe), Claire Henly (Super Pollutant Action Alliance), Kenzie Huffman (Carbon Mapper), Bryce Kelly (University of New South Wales Australia), Chris Konek (Global Methane Hub), Malika Menoud (IMEO, UNEP), John Olivier Mikala (Independent Consultant – Climate & Environment, the Republic of the Congo), Eleanor Milne (Colorado State University), Zura Nukusheva (CCAC Secretariat, UNEP), Kaj Ouellet (Canada government), Genevieve Plant (University of Michigan), Jude Samuelson (Stakeholder Democracy Network), Donovan Storey (CCAC Secretariat, UNEP), Sophie Szopa (Laboratoire des Sciences du Climat et de l'Environnement), Yuri Schmitke Almeida Belchior Tisi (LATAM Global WtERT Council), Kushal Tibrewal (IMEO, UNEP), Felix Vogel (Environmental and Climate Change Canada), Durwood Zaelke (Institute for Governance & Sustainable Development)

Project Coordination
Sophie Bonnard (CCAC Secretariat, UNEP), Nathan Borgford-Parnell (CCAC Secretariat, UNEP), Jingyi Ye (CCAC Secretariat, UNEP)

Editing and Communications
Bart Ullstein (Banson), Ava Bahrami (CCAC Secretariat, UNEP), Vincent Hughes (CCAC Secretariat, UNEP)

Design and Layout
Biyoke Madavisid

Special Thanks
The Steering Committee and authors are grateful for the support of the UNECE Group of Experts on Coal Mine Methane and Just Transition Secretariat. They also extend a special thanks to Nancy J. Aburto (Food and Agriculture Organization of the United Nations), Rebekah Ash (CSIRO & UTAS), Mario Bloise (Food and Agriculture Organization of the United Nations), Flora Brocza (International Institute for Applied Systems Analysis), Beau Damen (Food and Agriculture Organization of the United Nations), Deepshikha (Indian Institute of Technology, Delhi), Alessandro Francesco Ferrara (Food and Agriculture Organization of the United Nations), Jose Manuel Ramirez Garcia (Food and Agriculture Organization of the United Nations), Hugo Denier van der Gon (Department of Air Quality and Emissions Research, Netherlands Organisation for Applied Scientific Research, TNO, Utrecht, the Kingdom of the Netherlands), Rosati Ilaria (Food and Agriculture Organization of the United Nations), Beatriz Sanchez Jimenez (Food and Agriculture Organization of the United Nations), Lovisa Kuhnle-Nelson (International Institute for Applied Systems Analysis), Eleanor Milne (Colorado State University), Victoria Padula de Quadros (Food and Agriculture Organization of the United Nations), Fernanda Garcia Sampaio (Brazilian Agricultural Research Corporation - Embrapa Environment), and Roubin Wu (Food and Agriculture Organization of the United Nations).

List of Abbreviations

ABC+	Low Carbon Emission in Agriculture Plan (Brazil)
ADB	Asian Development Bank
AFOLU	Agriculture, Forestry, and Land Use
AgriPDB	Agricultural Public Development Bank
AMM	Abandoned-mine methane
ASEA	Agency for Safety, Energy and the Environment (Agencia de Seguridad, Energia y Ambiente, Mexico)
ASMOC	Caucaia West Metropolitan Sanitary Landfill (Brazil)
AWD	alternative wetting and drying
BAU	business as usual
bcm	billion cubic meters
BSF	black soldier fly
BTR	Biennial Transparency Reports
BU	bottom up
C	centigrade
ºC	degrees centigrade
CAN US$	Canadian dollar
CATF	Clean Air Task Force
CCAC	Climate and Clean Air Coalition
CCAP	Center for Clean Air Policy
CDM	Clean Development Mechanism
CEDS	Community Emissions Data System
CH_4	methane
CH4D	Global Methane Reduction Platform for Development
CLE	current legislation emissions (scenario)
CLTRAP	Convention on Long-Range Transboundary Air Pollution
CMM	coal-mine methane
CNPE	National Energy Policy Council (Brazil)
COP	Conference of the Parties
CO	carbon monoxide
CO_2	carbon dioxide
CO_2eq	carbon dioxide equivalent
CPI	Climate Policy Initiative
DaIMA	Dairy Interventions for Mitigation and Adaptation
DFI	development finance institution
EDGAR	Emissions Database for Global Atmospheric Research
e.g.	exempli gratia (for example)
ESMAP	Energy Sector Management Assistance Program
et al.	et alia (and others)
FAO	Food and Agriculture Organization of the United Nations
FFRP	Fossil Fuel Regulatory Programme

G20+	G20 plus group of countries (includes the 19 sovereign countries of the G20, i.e., Argentina, Australia, Brazil, Canada, China, France, Germany, Italy, India, Indonesia, Japan, Mexico, the Russian Federation, Saudi Arabia, South Africa, the Republic of Korea, Türkiye, the United Kingdom of Great Britain and Northern Ireland, and the United States of America, plus remaining 24 European Union countries, 3 Western European countries Norway, Switzerland and Iceland, and New Zealand.) All countries not included in the G20+ are categorized as belonging to the non-G20+ regions.
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GCF	Green Climate Fund
GDP	gross domestic product
GMA	Global Methane Assessment
GMP	Global Methane Pledge
GWP	Global warming potential
IADB	Inter-American Development Bank
i.e.	id est (that is)
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IIASA	International Institute for Applied Systems Analysis
ILRI	International Livestock Research Institute
IMEO	International Methane Emissions Observatory
IPCC	Intergovernmental Panel on Climate Change
IPCC AR6	IPCC's Sixth Assessment Report
km	kilometer (1,000 meters)
km^2	square kilometer
LD4D	Livestock Data for Decisions
LDAR	leak detection and repair
LFG	landfill gas
LGCC	General Law of Climate Change (Ley General de Cambio Climático, Mexico)
LNG	liquified natural gas
LOW-Methane	Lowering Organic Waste Initiative
LSU	livestock unit
m	meter
m^2	square meter
m^3	cubic meter
MAP	Methane Action Plan
MARS	Methane Alert and Response System
MDB	multilateral development bank
METEC	Methane Emissions Technology Evaluation Centre
MRV	monitoring, reporting and verification
MSW	municipal solid waste
M-RAP	Methane Roadmap Action Programme
Mt	million tonnes
MTFR	maximum technically feasible reduction
NC	National Communication
NDC	Nationally Determined Contribution
NGER	National Greenhouse and Energy Reporting (Australia)
NGO	non-governmental organization
NIR	National Inventory Report
NMVOC	non-methane volatile organic compound

N_2O	nitrous oxide
NOC	national oil company
NO_x	nitrous oxides
NOC	national oil company
O_3	ozone
O&M	operations and maintenance
ODA	official development assistance
OECD	Organisation for Economic Co-operation and Development
OGDC	Oil and Gas Decarbonization Charter
OGMP	Oil and Gas Methane Partnership
OH	hydroxide (or hydroxyl)
PE	polyethylene
PEMEX	Petróleos Mexicanos
PforR	Program-for-Results Financing
PM	particulate matter
$PM_{2.5}$	fine particulate matter with a diameter of 2.5 micrometers or less
ppb	parts per billion (109)
PPP	public-private partnership
PVC	polyvinyl chloride
R&D	research and development
REME	Reducing Enteric Methane Emissions from Beef Cattle Protocol (Canada)
RFS	Renewable Fuel Standard
ROW	Reducing Methane from Organic Waste Declaration
RTO	Regenerative Thermal Oxidizer
SATAT	Sustainable Alternative Towards Affordable Transportation (India)
SLCP	short-lived climate pollutant
SMEs	small and medium-sized enterprises
SRF	solid recovered fuel
SSP	Shared Socioeconomic Pathway
t	tonne
TD	top down
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VAM	ventilation air methane
vs	versus
3-NOP	3-Nitrooxypropanol

Table of Contents

List of Tables

List of Figures

Technical Annex can be found in:
https://www.ccacoalition.org/resources/global-methane-status-report-technical-annex

Implementation of current NDC and MAP commitments could result in:

8% REDUCTION IN ANTHROPOGENIC CH_4 EMISSIONS BY 2030 BELOW 2020 LEVELS

THE LARGEST AND MOST SUSTAINED PROJECTED DECLINE IN METHANE EMISSIONS IN RECORDED HISTORY

Increasing ambition with full implementation of existing technically feasible reductions could result in:

32% REDUCTION IN ANTHROPOGENIC CH_4 EMISSIONS BY 2030 BELOW 2020 LEVELS

0.2°C OF WARMING AVOIDED BY 2050

180,000 PREMATURE DEATHS PREVENTED ANNUALLY BY 2030

---

19 MILLION TONNES OF CROP LOSSES AVOIDED ANNUALLY BY 2030

DELIVER **US$ 330** BILLION BENEFITS ANNUALLY BY 2030

OVER **80%** OF REDUCTIONS AT LOW-ANNUAL COST

Photo: Eean Chen/Unsplash

Foreword

Cristina Lobillo Borrero and Tibor Stelbaczky

Respectively Director for International Relations and Energy Security, European Commission, and European Union Principal Adviser on Energy Diplomacy - Global Methane Pledge Champions

Since the launch of the Global Methane Pledge, we have seen an unprecedented increase in the availability and quality of data and knowledge, and the ambition for methane abatement. This is proof of what collective action can achieve. The report shows that the next five years will be critical. Now we must focus on implementing and scaling proven solutions—cutting methane together to deliver rapid climate and health benefits.

As co-convener of the Global Methane Pledge, Canada has seen the progress we can achieve together but this report underscores that implementation of higher ambition policies is needed to meet the GMP target. Methane mitigation is cost effective and consistent with sustainable economic growth. We must continue to work together through the GMP and by domestic action to reduce methane emissions to ensure cleaner air, stronger economies, and a more resilient planet.

Michael Bonser

Associate Assistant Deputy Minister, Strategic Policy and International Affairs Branch, Canada - Global Methane Pledge Champion

Tackling methane emissions is one of the fastest ways we can slow global warming this decade, while delivering immediate health, food security, and clean air benefits.
As this report shows, the urgency to act has never been greater. Through the galvanising force of the Global Methane Pledge, the United Kingdom of Great Britain and Northern Ireland will continue to step up and champion global action in this space, protecting current and future generations from the climate crisis.

Katie White

Parliamentary Under-Secretary of State (Minister for Climate), the United Kingdom of Great Britain and Northern Ireland - Co-Chair of the Climate and Clean Air Coalition and Global Methane Pledge Champion

The Global Methane Status Report demonstrates that over three-quarters of the methane cuts we need can be made with proven, low-cost measures that deliver cleaner air, healthier people, higher crop yields, and stronger economies. In this decisive decade, our collective leadership will determine whether we win the race for a safer, healthier planet.

Adalberto Maluf

National Secretary of Urban Environment, Water Resources and Environmental Quality, Ministry of Environment and Climate Change, Brazil - Co-Chair of the Climate and Clean Air Coalition

Cutting methane is the fastest way to slow warming, improve air quality, protect lives, and strengthen economies. Now is the time to pull this climate emergency brake, and that means every leak must be fixed, every waste site improved, and every farm protected from disasters, opening up new business and investment opportunities. UNEP stands ready to support countries in turning the recommendations and solutions presented in this report into reality.

Sheila Aggarwal-Khan

Director, Industry and Economy Division, United Nations Environment Programme

Photo: 24Novembers/Adobe Stock

Executive Summary

Methane (CH_4) mitigation is one of the most powerful and cost-effective strategies to slow near-term warming and deliver major benefits for air quality, public health and food security. Despite rising global emissions, momentum for action has been strong, driven by increasing political will, available and cost-effective technological solutions, and economic incentives.

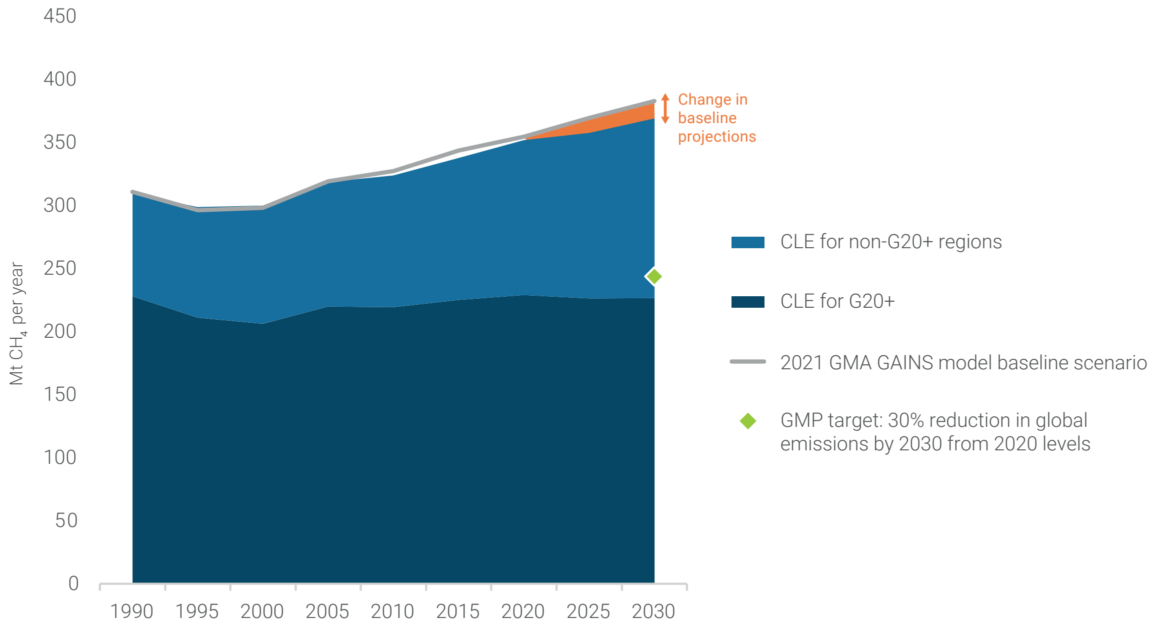
The Global Methane Pledge (GMP), launched in 2021, has catalysed ambitious action. New initiatives and policy plans have laid the foundations for accelerated implementation of methane abatement in the years ahead. Reaching the GMP target of reducing global anthropogenic emissions by at least 30 per cent below 2020 levels by 2030 is technically still possible in case of full implementation of proven technical methane abatement measures. Most of these solutions are low-cost and offer climate, air-pollution and development benefits that far exceed their costs. The energy sector has the largest reduction opportunity, with measures that prevent production losses and come at particularly low or even negative cost. Success will, however, depend on robust emissions monitoring, stronger policies and a significant scale-up in finance flows. Rapid methane reductions must be integrated with broader transformations in energy and food systems and resource efficiency towards circular economy to stay aligned with internationally agreed climate goals. The next five years will be decisive in turning down the heat and reducing risks of reaching climate tipping points. Immediate action on methane can deliver fast, multiple wins for the climate and clean air.

Progress Since the Launch of the Global Methane Pledge

Methane's atmospheric concentrations have more than doubled since pre-industrial times. According to new modelling for this report, global anthropogenic emissions of methane reached approximately 352 million tonnes (Mt) per year in 2020 and, under current legislation, are projected to continue rising, reaching 369 Mt per year in 2030, 5 per cent above 2020. These rising global emissions would contribute to almost 24,000 additional premature deaths and 2.5 Mt of crop losses annually by 2030, relative to 2020, and would commit the world to an additional 0.025°C of warming by 2050. The economic damage of these impacts could reach US$43 billion per year in 2030. The largest increases are forecast for the agricultural and waste sectors, driven by projected larger livestock herds and higher waste generation due to expanding populations and economic growth.

This projected growth is, however, slower compared to previous assessments. At the time the GMP was negotiated, emissions were expected to continue increasing steadily, reaching 383 Mt per year by 2030. Since then, new waste management regulations in Europe and North America, and slow growth in natural gas markets have translated into a lower-than-expected increase in anthropogenic methane emissions. As a result, the new current legislation (CLE) scenario projects that emissions in 2030 will be 14 Mt lower than previously estimated, equivalent to more than 10 per cent of current annual methane emissions from the energy sector globally.

Figure ES 1: **Change in global anthropogenic methane emissions from 1990 to 2030 in the Current Legislation Emissions (CLE) scenario used for this report, in comparison to the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model baseline scenario used in the 2021 Climate and Clean Air Coalition Global Methane Assessment (GMA), million tonnes per year, and annual global benefits associated with this revised baseline in year 2030, except for avoided warming by 2050 (averaged over 2040–2070).**



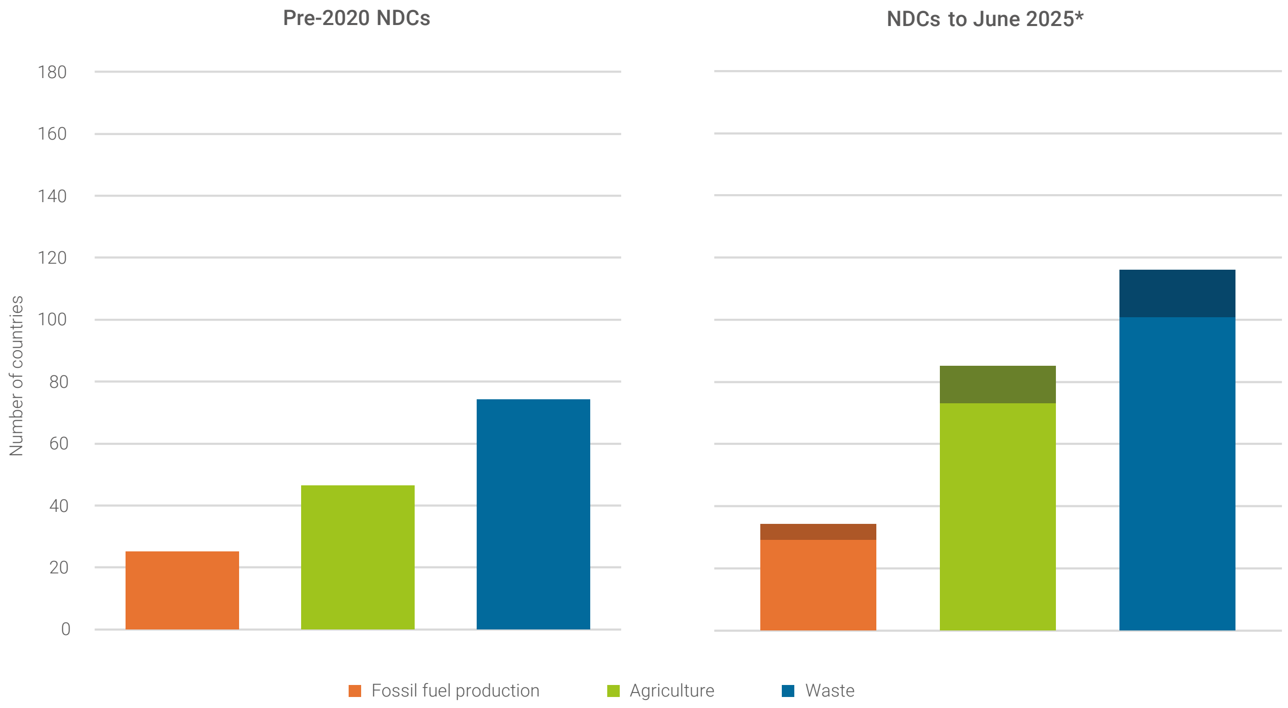
	Avoided warming by 2050	Avoided premature deaths (per year)	Avoided crop loss (per year)	Value of benefits (per year)
Benefits from revised baseline	0.021 °C	20,000	2 million tonnes	US$ 36 billion

Note: Throughout this report, G20 plus group of countries (G20+) includes the 19 sovereign countries of the G20, i.e., Argentina, Australia, Brazil, Canada, China, France, Germany, Italy, India, Indonesia, Japan, Mexico, the Russian Federation, Saudi Arabia, South Africa, the Republic of Korea, Türkiye, the United Kingdom of Great Britain and Northern Ireland, and United States of America, plus remaining 24 European Union countries, 3 Western European countries Norway, Switzerland and Iceland, and New Zealand. All countries not included in the G20+ are categorized as belonging to the non-G20+ regions.

The primary challenge for GMP participating countries was to arrest and reverse the trend of rapidly increasing emissions, as a first step towards reducing emissions by 30 per cent below 2020 levels. The last five years have seen unparalleled global attention and action to address methane which should reverse the rise in emissions by 2030. Even though a number of significant methane emitters, including three of the top five, are yet to committed to the GMP, an increasing number of policies and plans have been adopted and are starting to be implemented. Countries' political commitments to reduce methane emissions have grown substantially in both number and specificity, reflecting a broader global ownership of national methane mitigation planning, as shown in the latest Nationally Determined Contributions (NDCs) and Methane Action Plans (MAPs). As of June 2025, 127 countries, 65 per cent of countries who are Parties to the Paris Agreement, include policies and measures targeting major methane sources in their latest NDCs, representing an approximate 38 per cent increase compared with pre-2020 NDCs (92 countries), with particularly notable increases among United Nations Framework Convention on Climate Change (UNFCCC) Non-Annex I countries[1]. 115 countries, 59 per cent, include measures addressing methane from waste, 85, 44 per cent, include agricultural methane measures and 35, 18 per cent, include measures targeting emissions from fossil fuels. Compared with pre-2020 NDCs, this reflects increases of 58 per cent, 89 per cent and 52 per cent, respectively.

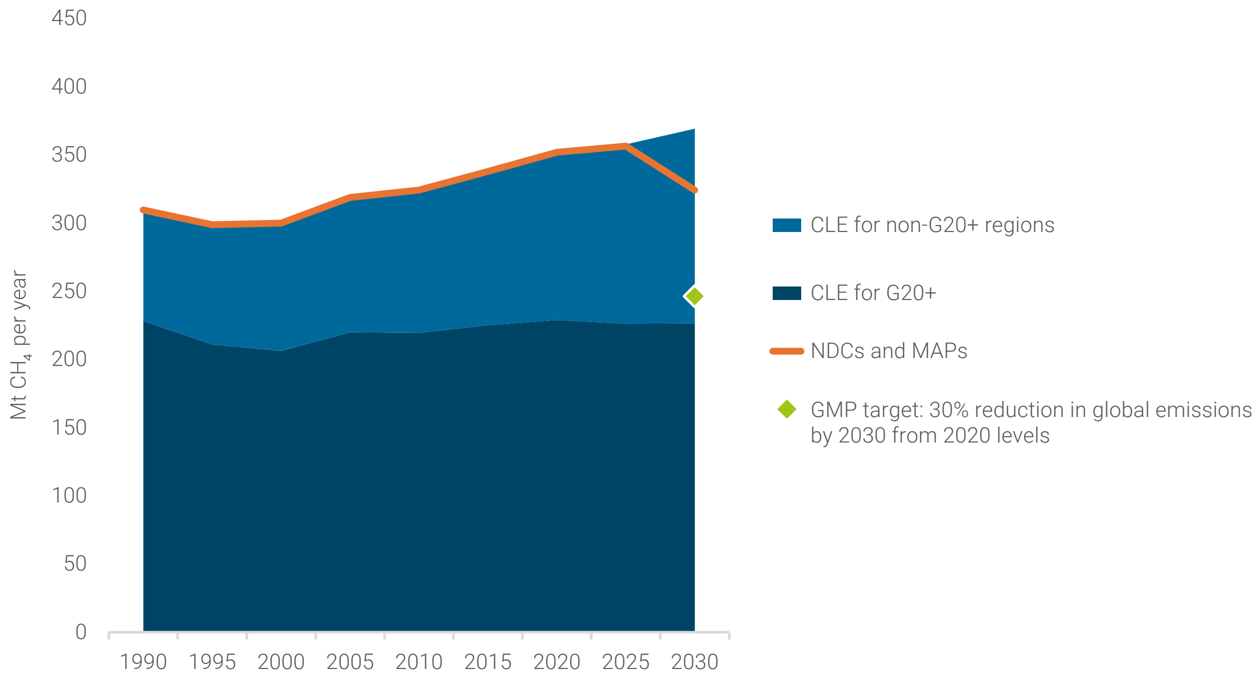
1 See list at: https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states?field_national_communications_target_id%5B515%5D=51

Figure ES 2: **Number of countries including methane mitigation measures in Nationally Determined Contributions (NDCs) by sector, pre-2020 and to June 2025. NDC3.0 are indicated by darker shade. *Submitted as of 01 June 2025.**



The NDC and MAP commitments, if fully implemented, would translate into a reduction of annual global anthropogenic methane emissions by up to 42 Mt by 2030 compared with the current legislation (CLE) for 2030, equivalent to 8 per cent below 2020 levels. This is insufficient to meet the GMP target by 2030, but would still deliver major climate and development benefits, avoiding up to 60,000 premature deaths and 6.1 Mt of crop losses annually by 2030, and up to 0.06°C of warming by 2050, relative to the CLE scenario. The value of these benefits is up to US$107 billion per year by 2030, far outweighing the cost of implementing the measures. This reduction would also represent the largest and most sustained decline in anthropogenic methane emissions with available records.

Figure ES 3: **Comparison of global anthropogenic methane emissions under the Current Legislation Emissions (CLE) and the Current Nationally Determined Contributions and Methane Action Plans (NDCs and MAPs) scenarios from the GAINS model, 1990–2030, million tonnes per year, and annual global benefits associated with implementation of the NDCs and MAPs scenario in year 2030, except for avoided warming by 2050 (averaged over 2040–2070).**

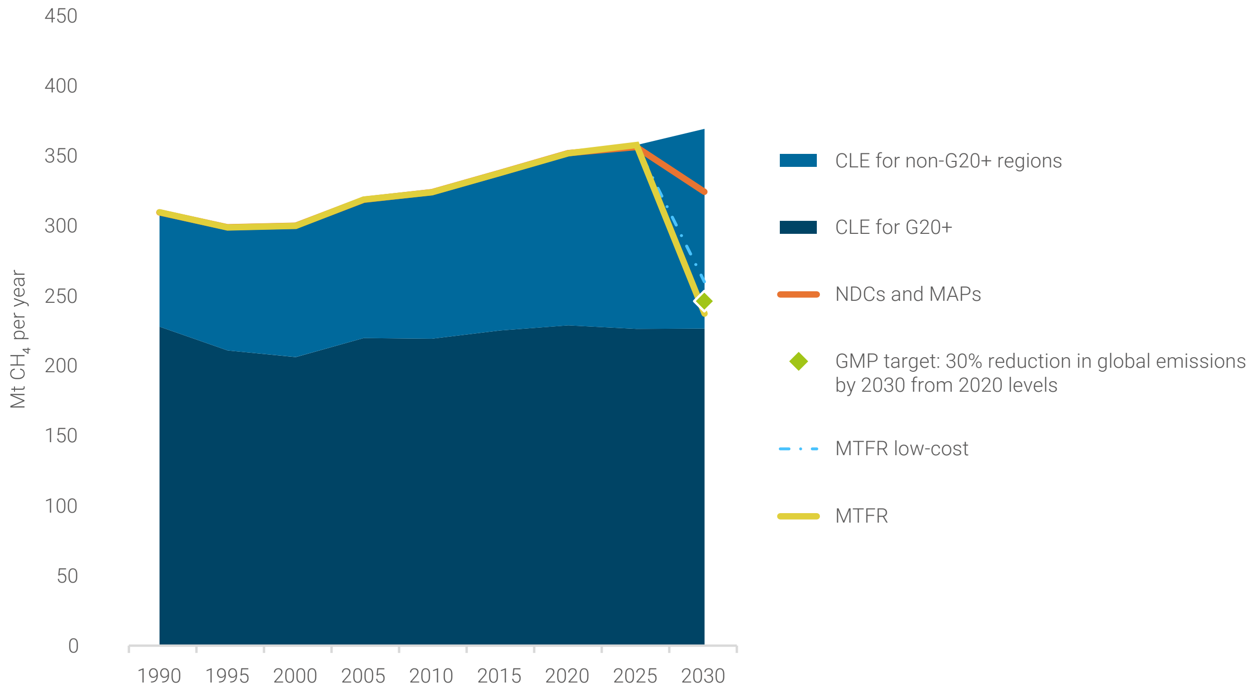


	Avoided warming by 2050	Avoided premature deaths (per year)	Avoided crop loss (per year)	Value of benefits (per year)
NDCs and MAPs	0.06 °C	60,000	6.1 million tonnes	US$ 107 billion

Ramping up Toward 2030

Meeting the 2030 GMP target will require further raising of ambition to the full implementation of the maximum technically feasible reductions (MTFR) globally, with mitigation potential varying between countries and across the three main emitting sectors: energy, agriculture, and waste by 2030 – a short timeframe. With full implementation of all technical measures globally, annual methane emissions in 2030 could be reduced by 131 Mt below CLE 2030 levels, representing a 32 per cent reduction compared with 2020 emissions levels. This level of action would deliver substantial benefits, including avoiding 0.2°C of warming by 2050 (averaged over 2040–2070). It would also avoid over 180,000 premature deaths, and nearly 19 Mt of avoided crop losses annually by 2030. The value of these benefits is estimated to exceed US$330 billion annually by 2030. When factoring in the broader social cost of methane, the benefit would be even greater.

Figure ES 4: **Comparison of global anthropogenic methane emissions under CLE, NDCs and MAPs, Maximum Technically Feasible Reductions (MTFR) and MTFR low-cost scenarios from the GAINS model, 1990–2030, million tonnes per year, and benefits associated with implementation of the NDCs and MAPs and MTFR scenarios in year 2030, except for avoided warming by 2050 (averaged over 2040–2070). MTFR low-cost consists of existing methane control technologies available at an average abatement cost below US$1,000 per tonne of methane or US$36 per tonne CO_2eq.**



	Avoided warming by 2050	Avoided premature deaths (per year)	Avoided crop loss (per year)	Value of benefits (per year)
NDCs and MAPs	0.06 °C	60,000	6.1 million tonnes	US$ 107 billion
MTFR	0.2 °C	180,000	19 million tonnes	US$ 330 billion

Looking Beyond 2030

Following current legislation, emissions are expected to continue increasing to 427 Mt per year by 2050, 21 per cent above 2020 levels. In 1.5°C and 2°C-consistent scenarios developed for the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6), global methane emissions should decrease steadily through mid-century, falling more than 50 per cent below 2020 levels by 2050.

After 2030, targeted technical mitigation options alone will not be sufficient to reduce methane emissions to levels consistent with climate and development goals. Additional maximum technically feasible reductions could reach 220 Mt per year by 2050, a 37 per cent reduction below 2020 levels. Similarly, focusing on broader decarbonisation action in the energy and transport sectors alone will not be enough to meet the GMP by 2030 or stay on a 1.5°C or 2°C trajectory through 2050.

The pathway to 2050 consistent with agreed climate goals requires a combination of full implementation of targeted technical methane control measures with parallel efforts to decarbonize global energy and transportation systems, along with shifts in demand-side behaviour including the adoption of healthier diets and reducing food waste. This combined pathway could reduce annual emissions to 164 Mt per year in 2050, 53 per cent reduction below 2020 levels. Continued research and development of new and emerging methane abatement technologies, particularly in the agricultural sector, could increase this mitigation potential.

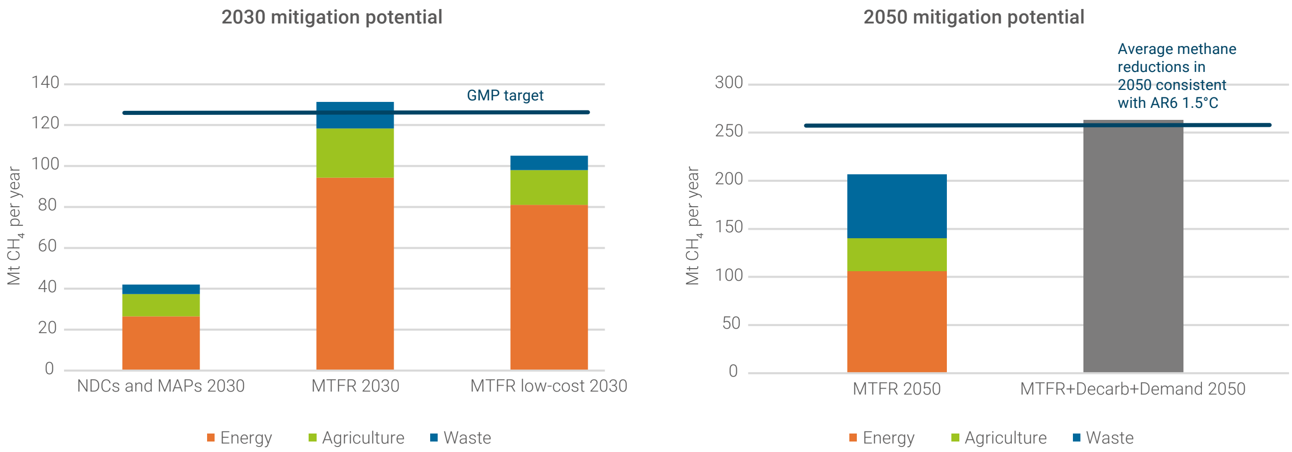
The Opportunity

Most global anthropogenic methane emissions come from three sectors: about 42 per cent from the agricultural sector, 38 per cent from the energy sector and 20 per cent from the waste sector. Two-thirds, 65 per cent, of total emissions originate from the G20 plus group of countries (G20+) which includes the 19 sovereign countries of the G20, plus the remaining 24 European Union countries, 3 Western European countries, Norway, Switzerland and Iceland, and New Zealand.

Full implementation of all available technical measures globally in all three sectors is required in all countries – not just GMP participating ones – to meet the 2030 GMP target. Mitigation potential in these sectors vary from one country to another. 72 per cent of the global methane mitigation potential by 2030 from 2020 emission levels, lies with the G20+ countries where emissions could be reduced by 36 per cent between 2020 and 2030.

The total annual cost of achieving the full MTFR in 2030 is estimated at US$127 billion. More than 80 per cent of the MTFR, 109 Mt per year could be implemented for a low-annual cost[2].

Figure ES 5: (left) Projected 2030 annual methane mitigation potential below CLE 2030 levels, by sector, under NDCs and MAPs, MTFR, and MTFR low-cost scenarios, million tonnes per year. The GMP target line represents annual reductions needed to achieve the Global Methane Pledge in 2030; (right) Projected 2050 annual methane mitigation potential below CLE 2050 levels, by sector, under MTFR and combined MTFR, Decarbonization (Decarb) and Demand-side measures (Demand) scenarios, million tonnes per year. The line represents annual reductions needed in line with 1.5°C-consistent scenarios from the Intergovernmental Panel on Climate Change Sixth Assessment Report (AR6).



2 Low-cost is defined as an average cost of less than US$1000 per tonne of methane or US$36 per tonne CO_2eq.

Table ES 1: Methane mitigation potential under different scenarios and associated implementation costs, by sector, in million tonnes and billion United States dollars.

Sector	2030 emissions under current legislation	Technical methane mitigation potential by sector in 2030			Implementation Costs		Methane mitigation measures
		NDCs and MAPs	MTFR	MTFR low-cost	MTFR	MTFR low-cost	
	Mt / yr	Mt / yr	Mt / yr	Mt / yr	bUS$/yr	bUS$/yr	
ENERGY							
Oil and gas sector upstream emissions	64	18	56	55	6.6	3.4	Extended recovery and utilization of vented gas: capture of associated gas from oil wells; blowdown capture; recovery and utilization of vented gas with vapor recovery units and well plungers. Addressing unintended leaks from equipment through leak detection and repair programs (LDAR): regular inspections (and repair); replace pressurized gas pumps and controllers with electric or air systems; replace gas-powered pneumatic devices and gasoline or diesel engines with electric motors; early replacement of devices with lower-release versions; replace compressor seals or rods; cap unused wells. Plug abandoned oil and gas wells.
Oil and gas sector downstream emissions	17	0.1	11	0.9	80.2	0.2	Oil refineries: leakage control through LDAR programs; extended flaring. Consumer gas distribution networks: leakage control through LDAR programs; upgrade to PE or PVC networks. Long-distance gas transmission pipelines and storage: leakage control through LDAR programs; equipping all new pipelines with compact (non-leak) flanges; refurbishment or replacement of existing pipelines.
Coal mining	43	8.3	27	25	10.8	6	Oxidation of ventilation air methane through use of Regenerative Thermal Oxidizers, RTOs. Pre-mining degasification. Abandoned coal mines: flooding of mines.
ENERGY TOTAL	**124[1]**	**26**	**94**	**81**	**98**	**10**	
AGRICULTURE							
Rice cultivation	31	8.1	9.8	9.2	2	0.5	Water management measures e.g., intermittent aeration and dry direct seeding; alternative rice hybrids; soil amendments e.g., sulphate-containing substrates and biochar.
Agricultural waste burning	4.7	0.7	4.7	4.7	0	0	Ban or enforcement of existing bans.
Livestock manure emissions	9.7	1.4	2.6	1.5	1.9	-4.2	Pigs on farms > 100 Livestock units[4] with liquid manure systems: Anaerobic digesters with biogas recovery.

Sector	2030 emissions under current legislation	Technical methane mitigation potential by sector in 2030			Implementation Costs		Methane mitigation measures
		NDCs and MAPs	MTFR	MTFR low-cost	MTFR	MTFR low-cost	
	Mt / yr	Mt / yr	Mt / yr	Mt / yr	bUS$/yr	bUS$/yr	
Livestock enteric fermentation emissions	112	0.7 (7.7)[2]	7 (16)[2]	1.2 (3)[2]	34	0.2	Smallholder & pastoralist systems in Africa: climate resilience measures i.e., human and animal vaccination against zoonotic diseases, emergency feed storage, and female empowerment. Dairy and non-dairy cattle on farms > 50 Livestock units and at least partly housed: Breeding for multiple traits to enhance productivity and animal longevity and fertility; enhanced feed efficiency; use of feed additives (3-NOP or red seaweed). Dairy and non-dairy cattle on farms >50 Livestock units in pasture-based systems in Americas, Australia & New Zealand: Breeding for multiple traits to enhance productivity and animal longevity and fertility; inter-seeding with grass legumes to improve quality of feed. Sheep and goats on farms > 50 Livestock units: Breeding for multiple traits to enhance productivity and mal longevity and fertility.
AGR TOTAL	**157**	**11**	**24**	**17**	**38**	**-3.5**	
WASTE							
Municipal solid waste	37	4.3 (7.7)[3]	5.9 (15)[3]	5.7 (14)[3]	-6.5	-7.2	Upgrade to managed landfills with gas recovery & utilization; source separation and treatment of organic waste in biogas digesters, composts or through recycling.
Industrial solid waste	14	0.1 (0.7)[3]	1.8 (5.9)[3]	1.2 (5.6)[3]	0.4	-0.8	Upgrade to managed landfills with gas recovery & utilization; anaerobic digestion with biogas recovery; composting; energy recovery.
Domestic wastewater	18	0.1	0.5	0	4	0	Two-stage anaerobic treatment with biogas recovery followed by aerobic treatment; upgrade of existing capacity at end of plant lifetime.
Industrial wastewater	12	0.2	4.8	4.8	-6.5	-6.5	Two-stage anaerobic treatment with biogas recovery followed by aerobic treatment; upgrade of existing capacity at end of plant lifetime.
WASTE TOTAL	**81**	**5 (8)**	**13 (21)**	**12 (20)**	**-9**	**-14.5**	
TOTAL	**369**	**42**	**131**	**109**	**127**	**-8**	

1 Other fuel combustion sources are projected to contribute 7.4 Mt/yr in 2030, but are not included in this table due to limited identified mitigation options.

2 Emissions reduction potential from enteric fermentation measures in 2040 including full effect of breeding measures implemented pre-2030. Effects on methane emissions reductions from breeding through selection of traits that target enteric methane both at individual and stock levels are only assumed to be realized from 10 years after the start of the breeding scheme.

3 Emissions reduction potential in 2040 from the waste sector measures implemented pre-2030. Full effect on methane emissions are realized with a time-lag of 10–20 years due to continued decomposition of organic waste deposited in landfills.

4 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)

The Energy Sector

The energy sector offers the largest share of ready-to-implement, cost-effective methane mitigation options. Under current legislation, annual methane emissions from the energy sector are projected to decline slightly in this decade but will then increase by 8 per cent by 2050, compared with 2020 levels. Achieving energy sector mitigation commitments in NDCs and MAPs could reduce emissions by up to 26 Mt by 2030. This, however, remains far below the potential of full deployment of MTFRs, which could reduce emissions from the energy sector by 94 Mt per year by 2030 compared with CLE 2030, in line with the GMP target. The combined total annual cost for MTFR measures in the energy sector is US$98 billion, which is equivalent to just 2–4 per cent of the sector's income in 2023 – and this estimate does not include environmental benefits.

To achieve this additional mitigation potential, urgent and coordinated action is needed to scale up proven solutions and fully harness notable recent progress in methane policy, particularly in oil and gas, as well as kickstarting action in the coal sector, which lags significantly behind. Despite readily available low-cost mitigation options in the coal sector, such as Regenerative Thermal Oxidizers (RTOs), pre-mine degasification, abandoned-mine methane control, and improved mine closure, technical and economic challenges, along with a lack of global voluntary initiatives for companies, have hindered action. Nonetheless, some jurisdictions, including such major coal producers as Australia and China, have recently taken steps to regulate coal methane emissions.

Since the launch of the GMP in 2021, oil and gas regulations have expanded and become more innovative. Comprehensive frameworks now cover many major producing regions. The European Union has introduced the world's first methane import standard, while countries including Brazil, Canada and Kazakhstan are strengthening national regulations. Voluntary initiatives by the industry have also grown rapidly, programmes such as the Oil and Gas Methane Partnership (OGMP) 2.0 and the Oil and Gas Decarbonization Charter (OGDC) now cover 40–45 per cent of global oil and gas output, more than doubling their reach in recent years.

Critical implementation barriers, however, persist: fragmented regulation, weak enforcement, lack of emissions monitoring capacity, limited access to finance in the case of national oil companies (NOCs) in least developed countries, and inconsistent data transparency. Addressing these barriers through targeted policy, finance, and capacity and technical assistance is needed to realize the technical potential. While there are many efforts underway, there needs to be a shift to move from fragmented voluntary efforts to more coherent and enforceable action.

The Waste Sector

Without additional action, methane emissions from waste are projected to increase by 13 per cent by 2030 and 56 per cent by 2050, compared with 2020 levels. This rise is driven by population and economic growth, along with expanded waste and wastewater collection, which provides significant health and environmental benefits but also increases methane emissions unless targeted mitigation measures are implemented in parallel. Even with current pledges in the latest NDCs and MAPs, annual emissions from the sector are expected to grow by 3 Mt in 2030 compared with 2020.

Full deployment of methane targeted measures in the sector could reduce annual emissions by 13 Mt per year by 2030, compared to CLE 2030. But the mitigation benefits of these pre-

2030 investments in landfill and waste management systems are projected to grow to 21 Mt per year by 2040, as methane emissions from legacy waste can persist for decades.

These mitigation opportunities could deliver significant cost savings, US$9 billion annually primarily due to energy savings through methane capture. Simple interventions – such as preventing food loss and waste, promoting household- and community-level composting, and enforcing basic operational standards at disposal sites – could yield immediate results with minimal investment.

Many countries and municipalities are demonstrating that significant methane mitigation in the waste sector can be achieved cost-effectively, and often at net savings. Successful implementation is underway in diverse contexts, supported by a growing body of international initiatives and financing tools.

Despite this progress, key barriers remain, particularly in low- and middle-income countries. Weak regulatory frameworks and enforcement, insufficient infrastructure and technical capacity, fragile financial systems with low fee collection, underdeveloped markets and limited demand for valorised outputs, fragmented governance, and low public awareness collectively constrain integrated waste management, limiting the prevention, separation and valorisation of organic waste as well as other methane mitigation opportunities in the sector.

Implementation of waste sector methane targeted technical measures should go hand in hand and align with longer-term decarbonisation and circular-economy objectives, prioritizing upstream measures such as mechanisms and incentives to prevent food loss and waste, together with mandatory source separation, while also considering consistent treatment of organic wastes and valorisation infrastructure, and improved landfill engineering to ensure the sector contributes meaningfully to global methane abatement goals. Cost-effective interventions, including composting, black-soldier-fly facilities and basic waste treatment operational standards, can deliver significant results. Economic and fiscal instruments are key to promoting the separate collection and valorisation of organic waste, enabling the development of infrastructure and driving methane mitigation solutions in the waste sector.

The Agricultural Sector

The agricultural sector is the largest source of anthropogenic methane emissions. Emissions vary by region, with the G20+ group of countries responsible for 61 per cent of agricultural methane, equivalent to one-quarter of total anthropogenic methane emissions.

Agricultural methane emissions are projected to increase by about 8 per cent by 2030 and around 17 per cent by 2050, compared with 2020 levels. This growth is driven largely by demand for food for a growing global population and the expansion of livestock numbers in Africa and Latin America, and with the non-G20+ regions experiencing the largest increases in emissions. Due to these drivers, even with the implementation of current NDCs and MAPs, emissions from agriculture would still rise by up to 4 per cent by 2030 compared with 2020 levels.

Yet, the agricultural sector has the technical potential to reduce emissions by 24 Mt per year by 2030, 8 per cent below 2020 levels in this decade, and 7 per cent by 2050.

Low-cost measures measures could be implemented at a total annual cost of US$2.5 billion, while reducing annual methane emissions by 17 Mt by 2030. This investment amounts to less than 3 per cent of the subsidies governments currently allocate to the sector every year. Repurposing even a small share of these subsidies could significantly help finance methane mitigation.

There has been a generally positive trend in the development of policies targeting agricultural methane emissions over the past decade, particularly in the areas of animal waste management. This progress has been most notable in Asia-Pacific, Europe and North America, where enabling policy environments and accessible technologies have driven the adoption of measures to reduce emissions from manure. Despite this progress, however, only a small share of GMP participating countries have policies directly addressing key methane sources in the sector.

This reflects a broader misalignment between the focus of methane policies and the actual sources of emissions. While animal waste is more commonly regulated, for example, enteric fermentation, a much larger source of methane emissions globally, remains under-addressed. Additionally, policies to reduce emissions from rice cultivation and agricultural biomass burning are often missing in key regions and high-emitting countries in Asia. In addition, there is still limited evidence for policies effectiveness in reducing emissions or the costs of their implementation. This lack of data presents a challenge for scaling up efforts in a targeted and efficient manner.

To close these gaps, countries must transition from short-term, fragmented measures to long-term, holistic and equity-based policies.

The Role of Empirical Data

Transparent, reliable data is essential for tracking progress toward methane-reduction commitments by governments and industries. The effectiveness of mitigation strategies hinges on data that are robust, accessible and credible, enabling stakeholders to maximize the impact of their commitments. Transparent, measurement-based monitoring – applied frequently and across representative areas – allows policymakers and operators to accurately assess progress, ensuring that operational and policy-driven shifts translate into tangible climate benefits. A new generation of policies, such as the European Union Methane Regulation, also rely on availability of such data to be implemented effectively.

Satellite-based coverage and global ground and airborne observation networks need to be strengthened. Dense, near-source regional studies continue to reveal significant underreporting of methane emissions, particularly within the fossil fuel sector. Increasing accuracy of data requires expanding satellite-based coverage and strengthening global ground and airborne observation networks. Reconciling differences between regional and global estimates through systematic gap analyses will improve the accuracy of emissions inventories by reducing the reliance on generic emission factors and enhance trust in the data that underpins mitigation planning. Without rigorous verification, persistent underreporting could compromise efforts to design effective policies and measure progress towards emissions-reduction goals.

Industries and regulators should be equipped with the capacity to deploy these measurement approaches and tools effectively. Measurement approaches fulfil two critical functions: identifying large-scale emission patterns to inform inventories and long-term tracking, and providing highly granular, site-level data to guide operational mitigation and regulatory enforcement. Ensuring the robustness of quantification methodologies through rigorous testing remains vital for maintaining data quality and stakeholder trust. The fossil fuel sector demonstrates how direct measurement tools can significantly improve mitigation effectiveness; extending their use to other anthropogenic methane sources offers substantial untapped potential. Equipping industries and regulators with the capacity to deploy these tools effectively, and ensuring the resulting data are actionable and relevant, will be key to accelerating methane reductions globally.

Unlocking Finance

Methane finance is growing, but still insufficient for meeting 2030 needs. Tracked methane finance has risen in recent years, with Climate Policy Initiative (CPI) analysis showing an 18 per cent increase to an annual average of US$13.7 billion in 2021 and 2022. This, however, remains far below the estimated US$127 billion net annual cost by 2030 to implement technical abatement measures consistent with the GMP target. While significant, these costs represent only about 6 per cent of global climate finance flows in 2023 and just over half of the year-on-year increase in climate finance from 2022 to 2023. The energy and agricultural sector mitigation costs also represent a small fraction of sectoral revenues or harmful subsidies, suggesting the financing challenge is surmountable.

Closing the investment gap requires supportive policies to attract private-sector leadership and secure commercial finance. Addressing the methane finance shortfall demands action from a diverse range of sources, but access to capital is not always the primary barrier. Policy gaps, limited institutional capacity, inadequate data and a lack of bankable projects often impede progress. Particularly in developing economies, catalytic public or philanthropic funding for technical assistance, capacity support and institutional strengthening, as well as project preparation, is crucial. With supportive policies in place, many methane abatement measures are cost-effective, spur private-sector action and secure commercial finance.

Development and private finance have a pivotal opportunity to scale support. Development finance institutions (DFIs) currently provide about US$3 billion annually for methane mitigation – small compared with their US$2.5 trillion in total yearly investments. Yet methane abatement delivers co-benefits aligned with development mandates and DFIs have an opportunity to scale support, while private-sector actors, including corporations, investors and financial institutions, are emerging as critical drivers of methane finance. Expanding engagement from both groups will be key to closing the methane investment gap and accelerating progress towards global climate goals.

Photo: Yellow Boat/Adobe Stock

01 Introduction

Methane (CH_4) is both a dangerous climate forcer and a harmful air pollutant. As the second most significant contributor to human-induced warming after carbon dioxide (CO_2), methane has a potent short-term warming effect and is a major precursor to ground-level ozone (O_3), which harms human health, agriculture and ecosystems

Over the past decade, methane has gained unprecedented political attention, driven in part by the findings of the 2021 Global Methane Assessment (GMA), which demonstrated that targeted measures across key sectors – energy, agriculture and waste – could deliver rapid methane reductions consistent with the Intergovernmental Panel on Climate Change (IPCC) pathways for limiting warming to 1.5°C and 2°C. Building on this momentum, the Global Methane Pledge (GMP) was launched at 2021 United Nations Climate Change Conference (COP26) by the European Union and the United States of America, who have since been joined by many other countries, as the first global policy initiative to reduce anthropogenic methane emissions. The GMP united countries around the collective goal of reducing global methane emissions by at least 30 per cent below 2020 levels by 2030.

2025 marks the half-way point of the GMP. As of April 2025, 159 countries plus the European Commission have joined the GMP, covering 57 per cent of global emissions. Some of these countries have now submitted methane action plans (MAPs) or methane roadmaps to the Climate and Clean Air Coalition (CCAC), while many more have included measures targeting methane emissions in their Nationally Determined Contributions (NDCs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), signaling strong political will to tackle this critical pollutant.

The purpose of this report is to provide GMP country participants and the international community with a clear picture of global progress on methane mitigation and the remaining gap to achieving the GMP and stay on a sustainable pathway towards midcentury. It also showcases successes to inspire increased ambition to rapidly deliver multiple climate and air-quality benefits.

The report starts by looking at the status of emissions and emission projections to 2030 and 2050 under different scenarios, then assesses associated costs and benefits (Chapter 2). It then presents the latest developments and trends in methane abatement policy, associated barriers and solutions, and provides key recommendations on the way forward to reap the full mitigation potential assessed in the previous chapter (Chapter 3). Chapter 4 discusses the importance of observed emissions in support of effective methane abatement policies, while Chapter 5 provides an analysis of the methane abatement financing landscape.

Box 1.1: The Global Methane Pledge

The GMP was launched at COP26 by the European Union and the United States of America who have since been joined by many other countries – by August 2025, a total of 159 countries together with the European Commission have participate in the Pledge. Participants to the Pledge agree to take voluntary action to collectively reduce global methane emissions at least 30 per cent from 2020 levels by 2030. This is a global, not a national, reduction target. When joining the GMP, participants commit to:

- take comprehensive domestic action to achieve the global methane reduction target;
- move towards using the highest tier IPCC good-practice inventory methodologies to quantify methane emissions and work to continuously improve the accuracy, transparency, consistency, comparability and completeness of national greenhouse gas inventories;
- maintain up-to-date, transparent and publicly available information on their policies and commitments; and
- support existing international methane emission reduction initiatives to advance technical and policy work that will serve to underpin participants' domestic action.

Since its launch, the GMP has generated unprecedented momentum for methane mitigation, with major work underway in six action areas: the energy pathway; the waste pathway; the food and agriculture pathway; methane plans and policies; data for methane action; and finance for methane abatement.

The GMP leadership guides and facilitates collective efforts under the Pledge. It is composed of the GMP co-conveners, the European Union and Canada, as well as other Champion countries including Germany, Japan, the Federated States of Micronesia, Nigeria, and the United Kingdom of Great Britain and Northern Ireland.

The UNEP-convened CCAC[3] provides secretariat services to the GMP. The CCAC has a comprehensive system to help countries deliver on methane abatement, from policy support, institutional strengthening, and sectoral transformation, to policy-relevant research and analysis. Information is available on the Methane Technical Assistance Portal[4].

3 https://www.ccacoalition.org/fr/content/global-methane-pledge

4 https://www.ccacoalition.org/content/methane-technical-assistance

Photo: Zig Koch/Adobe Stock

02 2025 Global Progress Analysis on Methane Emissions

Key messages

- Since 2020, global anthropogenic methane emissions have risen by a few per cent. Agriculture accounts for 42 per cent of emissions, energy 38 per cent, and waste 20 per cent. The G20 plus group of countries (G20+)[5] generates 65 per cent of emissions. The rest of the world (the non-G20+ regions) is dominated by emissions from Africa, Latin and Central America, the Middle East, and South-East Asia.
- Under current legislation anthropogenic methane emissions are projected to increase 5 per cent by 2030 and 21 per cent by 2050 from 2020 levels. In the non-G20+ regions, emissions could reach 16 per cent above from 2020 levels by 2030 and 53 per cent by 2050.
- Since the launch of the GMP, the projected 2020–2030 increase is 40 per cent lower than was projected in the 2021 GMA baseline. This translates into the 2030 emissions level being 4 per cent lower than in the older pre-GMP projections, but the 2030 emissions level is still projected to increase from the 2020 level.
- Implementation of measures in NDCs and MAPs would cut 2030 emissions by up to 8 per cent below 2020 levels, the largest and most sustained decline since the Industrial Revolution, but short of the GMP target.
- Implementing pledged measures would cost US$29 billion annually and yield US$107 billion in direct health, crop, and labour benefits by 2030. Adding the social cost of methane would provide additional benefits of US$100 billion in 2030 with cumulative potential climate damage avoided that could be worth US$1,900 billion by midcentury.
- With full implementation of maximum technically feasible reductions (MTFR) using technical methane control measures global methane emissions could be reduced by 32 per cent below 2020 levels by 2030.
- In 2030, the energy sector holds 72 per cent of global technical mitigation potential, agriculture 18 per cent and waste 10 per cent. The waste sector holds significant mitigation potential in the post-2030 timeframe, making early investment essential.

5 Throughout this report, the G20 plus group of countries (G20+) includes the 19 sovereign countries of the G20, i.e., Argentina, Australia, Brazil, Canada, China, France, Germany, Italy, India, Indonesia, Japan, Mexico, the Russian Federation, Saudi Arabia, South Africa, the Republic of Korea, Türkiye, the United Kingdom of Great Britain and Northern Ireland, and the United States of America, plus remaining 24 European Union countries, 3 Western European countries Norway, Switzerland and Iceland, and New Zealand.

- Full implementation of all technical measures comes at a net annual cost of US$127 billion. But, 83 per cent of the 2030 technical mitigation potential is low-cost – 86 per cent of the total mitigation potential in the energy sector, 70 per cent in the agricultural sector and almost 90 per cent in the waste sector – with a total annualized global net saving of US$8 billion when considering valorisation of recovered methane.

- The G20 plus group of countries (G20+) could reduce emissions by 36 per cent in 2030, compared to 2020, through full implementation of technical measures, which represents 72 per cent of the global MTFR. Both the G20+ and the non-G20+ regions have significant technical reduction potentials in the energy sector, respectively estimated at 63 and 35 Mt in annual reductions in 2030.

- Full implementation of MTFR measures would be associated with significant benefits including more than 180,000 avoided premature deaths per year by 2030, along with avoiding 560,000 asthma-related emergency-room visits, nearly 19 billion tonnes of losses in maize, rice, soybeans and wheat, and nearly 53 billion hours of lost labour for outdoor workers. The associated benefit valuation exceeds US$330 billion annually.

- If sustained to 2050, these benefits would rise to more than 290,000 avoided premature deaths per year by 2050, along with avoiding almost 900,000 asthma-related emergency-room visits, nearly 30 billion tonnes of crop losses, and more than 80 billion hours of lost labour for outdoor workers. The associated benefit valuation exceeds US$500 billion annually. The associated avoided warming averaged over 2060–2090 could be up to 0.31°C.

- Methane mitigation action and ambition must continue, and be strengthened, beyond 2030. Full implementation of MTFR measures combined with parallel efforts to both decarbonize the global energy system and implement demand-side measures, targeted at human dietary changes and reducing the generation of food waste, could deliver a reduction of 53 per cent by 2050, consistent with 1.5°C pathways.

2.1 Introduction

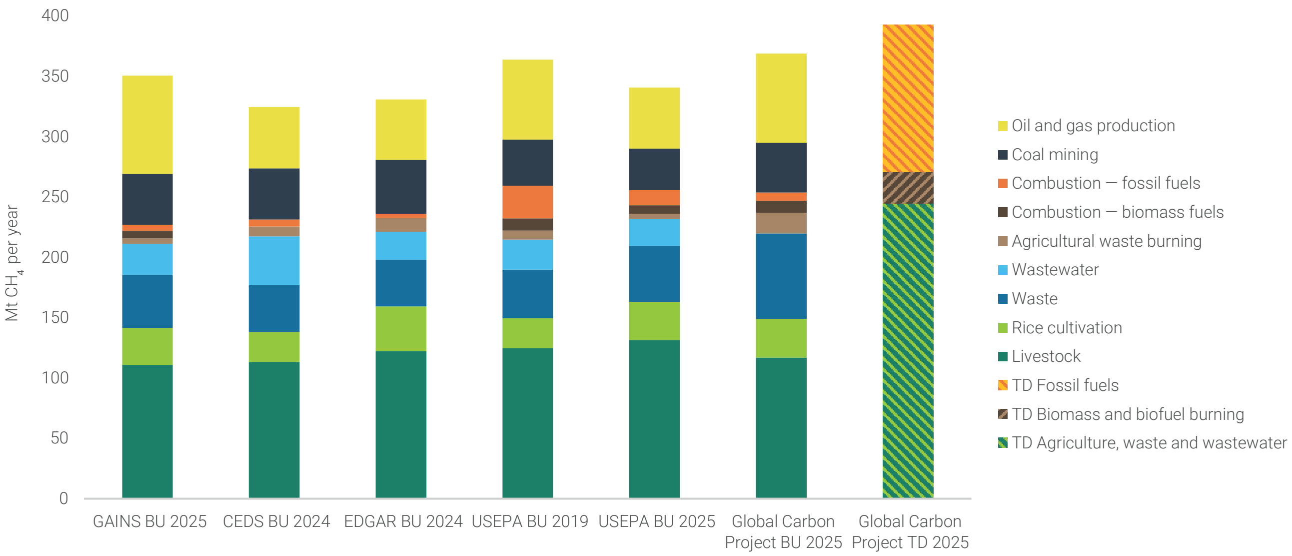
This chapter quantitatively assesses the status of progress, as of April 2025, on methane mitigation and the remaining gap to the 2030 target using the International Institute for Applied Systems Analysis' (IIASA) Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model.

It first reviews global methane emission sources and discusses the change in the baseline emissions scenario (Section 2.2). It then presents the mitigation scenario used in the modelling for this report (Section 2.3), analyses emissions trends compared across different scenarios for 2030 and 2050 as well as associated costs and benefits, presents top mitigation opportunities (2.4), and provides conclusions on global progress and trends (2.5).

2.2 Base year 2020 methane emissions and sources

For this report, global anthropogenic methane emissions are assessed in 2020 at 352 Mt, up from 300 Mt in 2000 and 325 Mt in 2010. The agricultural sector represented 146 Mt, almost 42 per cent; the energy sector 135 Mt, 38 per cent; and 71 Mt, 20 per cent, from the waste sector. Figure 2.1 shows how these estimates closely match other global bottom-up inventories from the Emissions Database for Global Atmospheric Research (EDGAR) (Crippa *et al.* 2024), the Community Emissions Data System (CEDS) (Hoesly *et al.* 2024), and the United States Environmental Protection Agency (USEPA) (2019; 2025), and to the most recent top-down inversion from the Global Carbon Project (Saunois *et al.* 2025). For biogenic sources from agriculture, and waste, the bottom-up inventories align well, even though the top-down estimate is somewhat higher. The GAINS and the USEPA bottom-up inventories from 2019 report higher emissions from fossil-fuel sources than EDGAR, CEDS and the most recent USEPA (2025) inventories.

Figure 2.1: **Global anthropogenic methane emissions in 2020 across various recent bottom-up (BU) and top-down (TD) inventories, million tonnes.**



Source: IIASA-GAINS 2025; CEDS Hoesly et al. 2024; EDGAR Cripps et al. 2024; USEPA 2019; USEPA 2025; Global Methane Budget Saunois et al. 2025

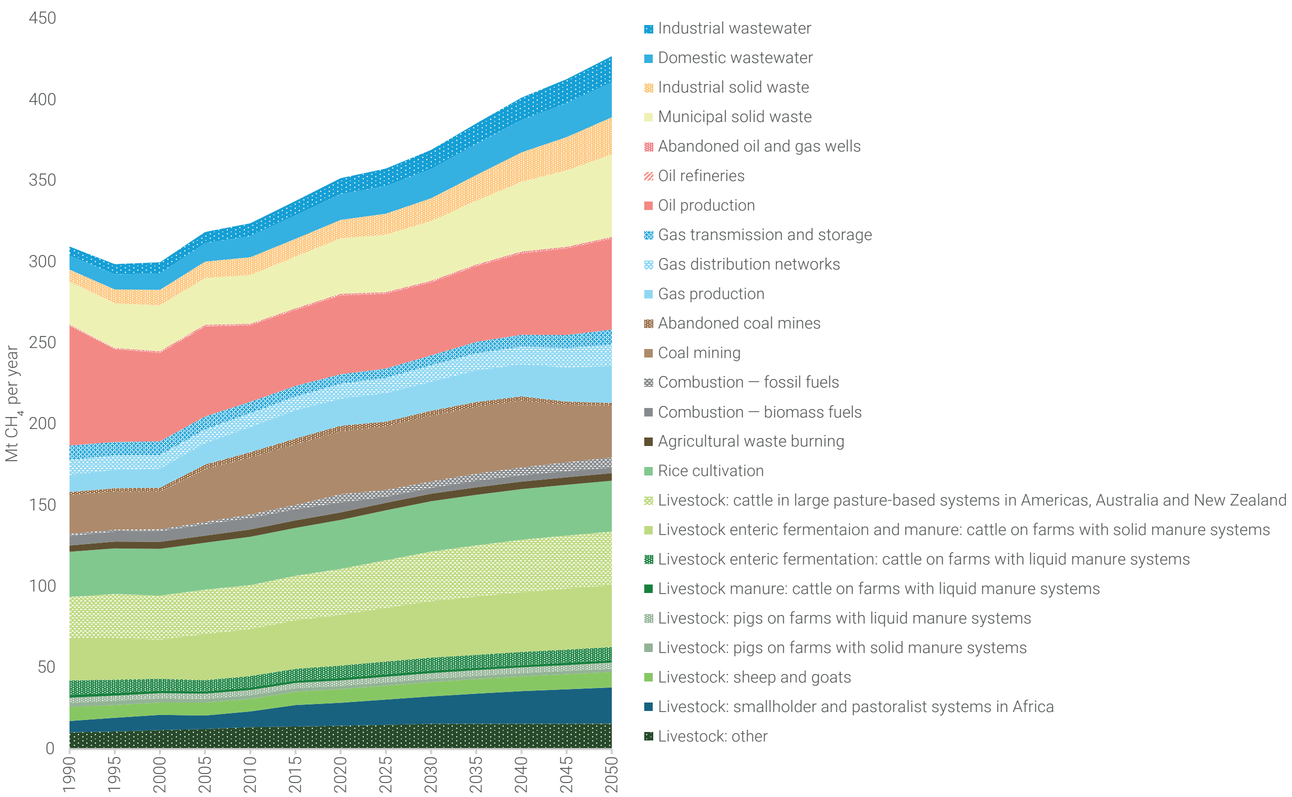
Most recent estimates point to enhanced methane emissions from tropical and mid-latitude wetlands, along with continued anthropogenic emissions. Methane emissions from wetlands are projected to rise in the coming decades, implying that larger reductions in anthropogenic methane may be needed to reach pathways consistent with a given warming target. Part of the growth in the methane atmospheric burden since 2007 may be due to changes in the main methane sink, atmospheric hydroxyl (OH) (Liu *et al.* 2025; Morgenstern *et al.* 2025). Moreover, there may have been a significant impact of COVID lockdowns on hydroxyl during the years 2020–2021, which may help explain the extreme growth in atmospheric methane concentration in those years (Chen *et al.* 2025). More details on natural emissions are presented in the Technical Annex.

2.3 Current legislation and mitigation scenarios

2.3.1 Current legislation emissions scenario

The current legislation emissions (CLE) scenario, developed as the baseline/business-as-usual (BAU) scenario for this report, assumes implementation of all legislation affecting methane emissions as of December 2024, with impacts through to 2030 and 2050. The scenarios use the GAINS model for country-specific uptake of methane control policies and measures (Höglund-Isaksson *et al.* 2012; 2020; 2023), with updates for the beyond 2015 period conducted for this report. Under the CLE scenario, annual global anthropogenic methane emissions increase to 369 Mt by 2030, 5 per cent above 2020 levels, and then reach 427 Mt by 2050, 21 per cent above 2020 levels (Figure 2.2). The methodology and assumptions for the CLE scenario are detailed in the Technical Annex.

Figure 2.2: Global anthropogenic methane emissions in the CLE scenario, 1990–2050, million tonnes per year.

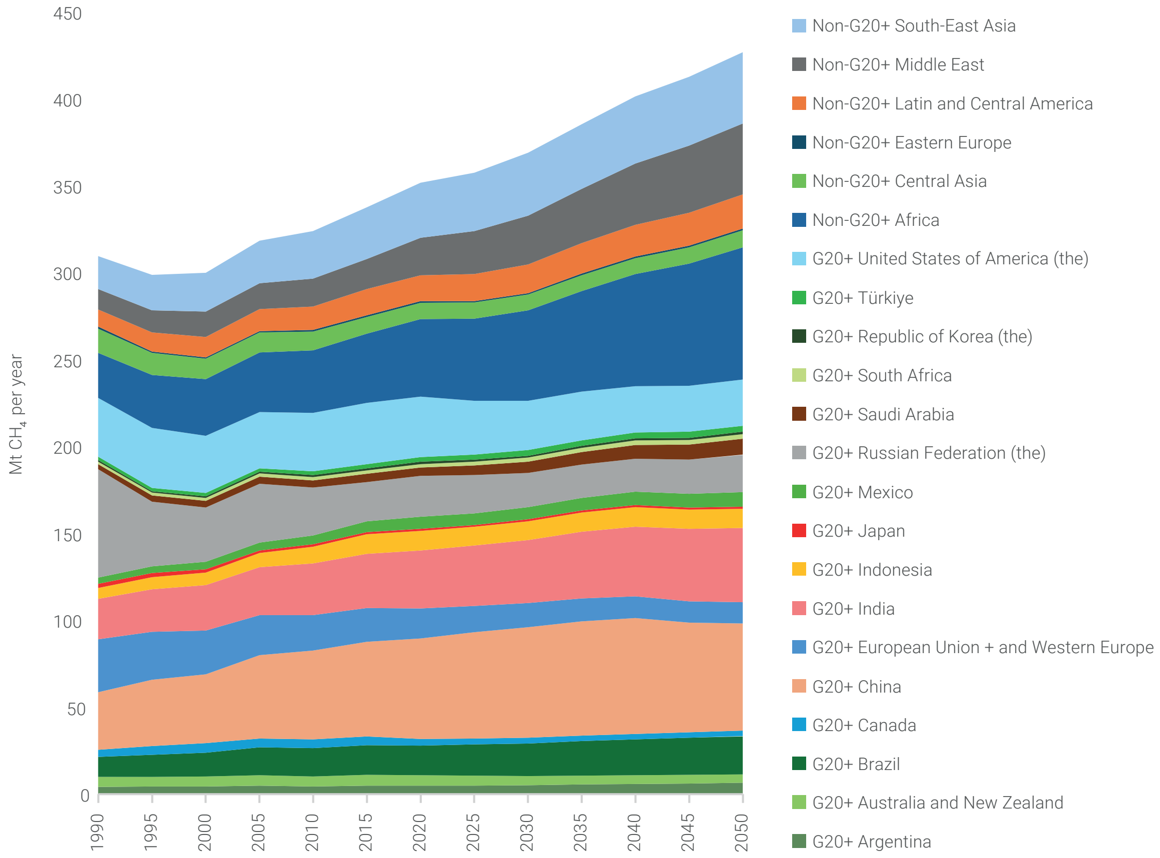


The energy sector shows a slight decline in emissions between 2020 and 2030, driven by a 12 per cent projected drop in oil production, and a modest 8 per cent increase by 2050. The agricultural and waste sectors both display strong growth, up by 8 and 13 per cent, respectively, between 2020 and 2030, with population growth and economic development driving demand for food and waste generation. In the agricultural sector, livestock emissions grow by 10 per cent between 2020 and 2030 and by 21 per cent by 2050, both relative to 2020, with growing cattle herds the main driver, in particular in Latin and Central America where annual cattle emissions grow by 12 per cent by 2030 and 26 per cent by 2050, relative 2020 level. Rice cultivation accounts for about 20 per cent of agricultural emissions in 2020 with only a few per cent increase expected to 2030 and 2050, but with strong regional differences including a slight decline in China and increases of 8 per cent in India and more than 40 per cent in Africa between 2020 and 2030. In the waste sector, sharp increases in emissions of 13 per cent by 2030 and 56 per cent by 2050, relative to 2020 respectively, are expected, driven by population and economic growth and improved waste and wastewater collection rates. These changes bring important health and environmental benefits by replacing open burning and scattered waste with managed landfills; however, because large amounts of waste are currently scattered or openly burned, about 40 per cent or more in Africa, India and South-East Asia, moving this waste to landfills tends to temporarily increase methane emissions before they drop with landfill upgrades and diversion to circular treatment measures.

The G20+ emits 65 per cent of global anthropogenic methane emissions in 2020 (Figure 2.3). Within this group, China released 58 Mt in 2020, 16 per cent of global emissions; followed by the United States of America at 35 Mt, 10 per cent; India at 31 Mt, 9 per cent; the Russian Federation at 24 Mt, 7 per cent; the European Union with rest of Western Europe and the United Kingdom of Great Britain and Northern Ireland at 17 Mt, 5 per cent; and Brazil likewise at 17 Mt, 5 per cent of global emissions. Between 2020 and 2030, the G20+ is projected to maintain, or slightly reduce, emissions primarily due to policy-driven declines in Australia, Canada, Europe, the Russian Federation and the United States of America. Key contributors are regulations to improve waste and wastewater management and regulations to control emissions from fossil-fuel production and gas infrastructure. The overall decline is a combined effect of policies already implemented and an expected decline in some activities, in particular oil and coal extraction in key producing regions. Without further policy interventions targeted at methane, however, emissions rise above the 2020 level by 2050, mainly due to increases in fossil-fuel extraction and livestock numbers.

All countries not included in the G20+ are categorized as belonging to the non-G20+ regions, i.e., most of countries in Africa, Middle East, Latin and Central America, Eastern Europe, Central Asia and South-East Asia. For the entire non-G20+ regions, methane emissions are expected to rise by 16 per cent by 2030 from the 2020 level and by 53 per cent in 2050 relative to 2020. Major contributing sources are an increase in oil and gas production in some African and Middle Eastern countries, and fast economic and population growth in Africa and Latin America, driving increases in the generation of organic waste and cattle herds.

Figure 2.3: **Global anthropogenic methane in the GAINS CLE scenario by region, 1990–2050, million tonnes per year.**



2.3.2 Mitigation scenarios

Alternate future emission scenarios (Table 2.1) define different pathways to reduce emissions below the CLE scenario through methane-targeted measures. The GAINS model considers over 40 readily available technical methane mitigation measures across the agricultural, energy, and waste sectors. For ease of communication, measures have been aggregated into groups (Table 2.7). More than 80 per cent of the technical mitigation potential in 2030 is available at a low average cost of less than US$1,000 per tonne of methane reduced, or US$36 per tonne of carbon dioxide equivalent (CO_2eq). In addition to technical measures, demand-side measures, including shifts to healthier and more sustainable human diets and reductions food waste generation, are considered. Finally, the sensitivity of methane emissions to dedicated efforts for phase out the use of fossil fuels and deep decarbonization of energy systems is analysed. More details on the mitigation scenarios are available in the Technical Annex.

Table 2.1: **Scenarios used in this report to project future anthropogenic methane emissions.**

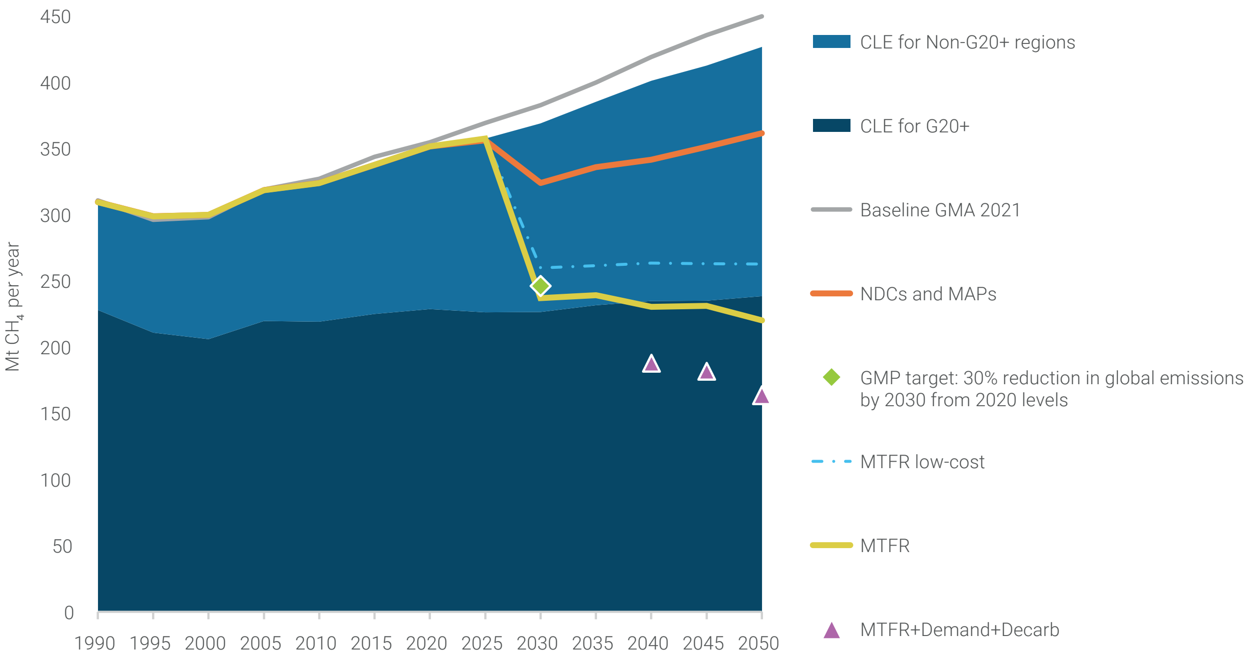
Scenarios name	Abbreviation	Definition
Current legislation emissions	CLE	This scenario considers no further uptake of methane control measures beyond those prescribed in legislation as of December 2024.
Current NDCs and MAPs	NDCs and MAPs	This scenario assesses a high ambition implementation of technical measures stated in NDCs and MAPs as of May 2025, see Technical Annex for details. The formulation of measures in NDCs and MAPs is often vague with limited quantifications of expected future impacts on emissions. Uncertainty remains high, in particular regarding implementation effectiveness and enforcement. To the extent that demand-side measures, such as human dietary changes and reduction in food waste are mentioned in the NDCs, the effects are integrated into this scenario.
Maximum technically feasible reduction at low cost	MTFR low-cost	This scenario projects the impact of maximum technically feasible reduction, through implementation of low-cost measures, defined as existing methane control technologies available at an average abatement cost below US$1,000 per tonne of methane (i.e., below US$36 per tonne of CO_2eq when using a Global Warming Potential (GWP) over 100 years from the IPCC (2015).
Maximum technically feasible reduction	MTFR	This scenario assesses the impact of maximum technically feasible reduction, through implementation of more than 40 existing methane control technologies. It excludes high-cost measures above an average abatement cost of US$15,000 per tonne of methane (i.e., above US$500 per tonne of CO_2eq). The scenario assumes a full technical potential implemented from 2030 and beyond, although for some measures the full impact on emissions appears with a delay, for example, targeted breeding of livestock and upgrades of landfills.
Demand-side measures	Demand	This scenario projects demand-side measures to stimulate shifts towards healthier and more sustainable human diets, and reductions in food waste generation in the retail and consumer segments. Implementation of these measures is examined in the context of the MTFR (MTFR+Demand) scenario, with demand-side measures added on top of MTFR technical measures. Substitutions between demand-side and technical measures may reach emission reduction targets, e.g., combining less than full implementation of MTFR with uptake of demand-side measures. As demand-side changes are typically slow, impacts on emissions are assumed from 2040 onward, provided measures start in the pre-2030 period.
Decarbonization	Decarb	This scenario projects a strong decline in the supply and demand for fossil fuels leading to deep decarbonization of energy systems. It is based on IPCC Shared Socioeconomic Pathway 1 (SSP1) energy drivers. In the analysis below, it combines with the MTFR scenario (MTFR+Decarb) to assess the impact of combined uptake of decarbonization and targeted methane control technologies.

2.4 Results

The scope for reducing anthropogenic methane emissions in each scenario above is illustrated in Figures 2.4 and 2.5 and analyzed in subsequent sections for 2030 and 2050. The analysis also calculates costs of mitigation. In addition, with methane being a precursor of tropospheric ozone, the effects of the reduced ground-level ozone exposure associated with methane emissions reductions are also analysed. These include effects on human health, reduced climate change, ground-level ozone exposure on crop yields, and the effects of reduced heat exposure on labour productivity for outdoor workers. The methods largely follow those used in the GMA (UNEP and CCAC 2021), with the addition of ozone-related premature deaths in children under 5 years old as described in Shindell *et al.* (2024)[6]. Additional benefits and impacts, such as differentiated gender impacts, are likely but were not quantified in this study.

While gender-based differences in vulnerability to ambient air pollution have not been widely explored (Liu *et al.* 2020), studies suggest that health responses may differ between women and men and between girls and boys (Clougherty 2010). Women, for example, tend to be more vulnerable to the adverse health effects of tropospheric ozone exposure. Climate change impacts also differ for men and women, largely as a result of and amplification of existing gender dynamics – with women being disproportionally negatively affected (UN Women 2022).

Figure 2.4: **Comparison of global anthropogenic methane emissions under different scenarios, 1990–2050, million tonnes per year.** Global anthropogenic methane emissions from 1990 to 2050 in the analyzed scenarios and in comparison to the GAINS model baseline scenario used in the CCAC GMA.

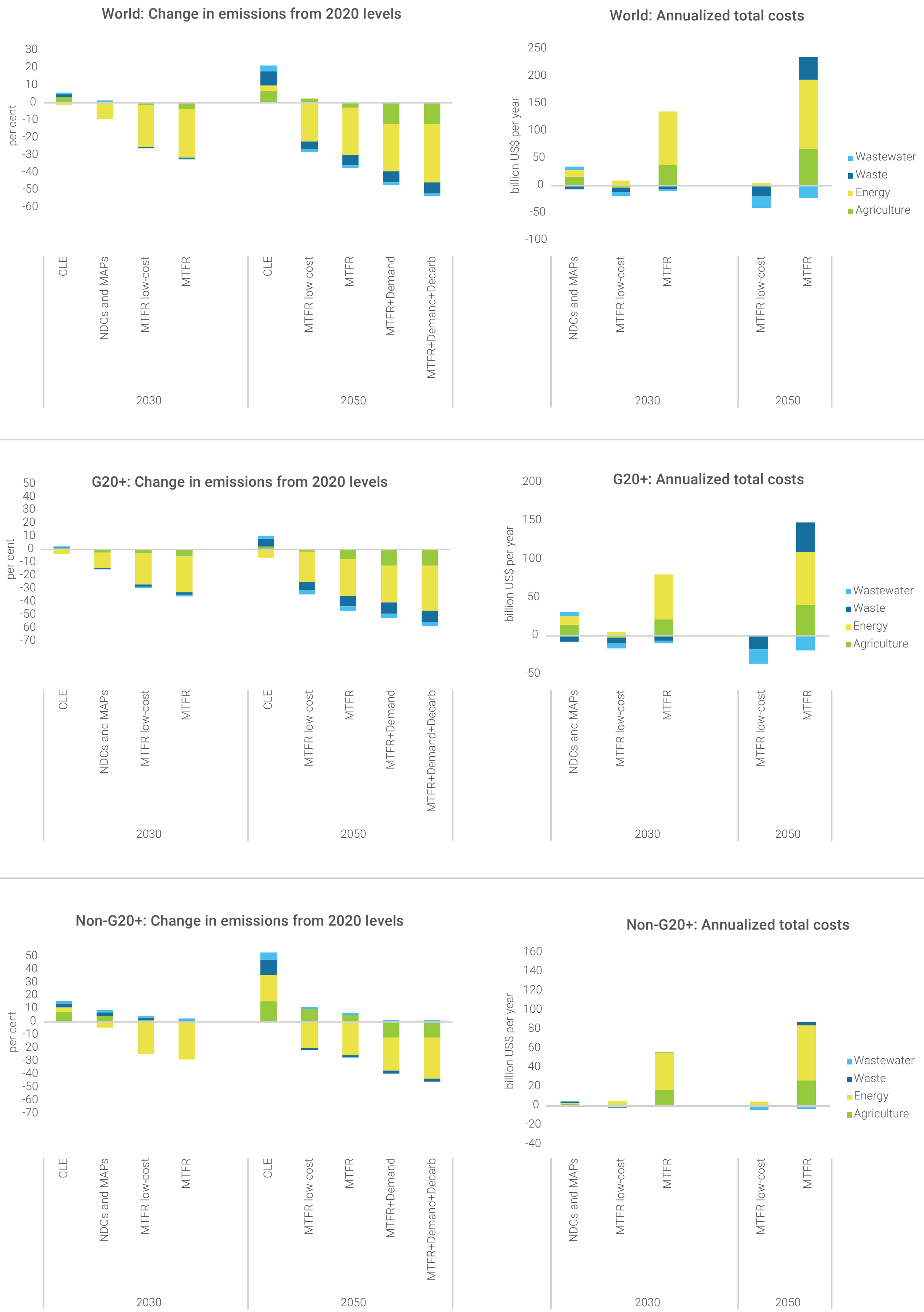


Note: Since NDC 3.0 mitigation pledges end in 2035, the benefits relative to 2020 emissions peter out over time in the NDCs and MAPs scenarios, as underlying drivers for emissions continue to increase.

Source: IIASA-GAINS 2025; UNEP and CCAC 2021.

6 Uncertainties around these central estimates are approximately ±45 per cent for premature deaths, ±40 per cent for crop yields, ±37 per cent for emergency-room visits, ±84 per cent for hospital admissions, ±70 per cent for lost work hours and ±50 per cent for valuation.

Figure 2.5: **Changes in methane emissions from 2020 level and associated costs, global and for G20+ and non-G20+ regions, 2030 and 2050, per cent and billion United States dollars per year.**



2.4.1 The 2030 picture

Since 2020, global anthropogenic methane emissions have increased by a few per cent, rising to 5 per cent by 2030 without further action, according to the CLE scenario (Figure 2.2). This causes substantial growth in adverse health, agricultural output and labour impacts (Table 2.2), with annual damage from those impacts alone estimated at about US$43 billion in 2030.

Table 2.2: Global impacts of increases in methane emissions in the CLE 2030 scenario relative to 2020 emission. Temperature results are an average 10–40 years after emissions reductions.

Additional warming (°C)	Additional deaths from ground-level ozone exposure (people per year)	Crop losses (Mt per year)	Additional asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Additional lost work hours (million hours per year)	Total valuation (billion US$ per year)
0.025	24,000	2.5	73,000	1,500	6.9	43

Source: *Adaptation of GMA 2021 benefits estimates.*

Yet, as shown in Figure 2.4, the increase in emissions between 2020 and 2030 in the CLE scenario is about 40 per cent less than the increase projected in the baseline used in the 2021 GMA (UNEP and CCAC 2021), resulting in 2030 annual emissions being 4 per cent or 14 Mt lower in the more recent CLE scenario. The lower projected emissions are explained primarily by three factors. First, growth in natural gas production and consumption has been lower than previously projected, contributing to 17 Mt lower annual emissions in 2030. Second, improved waste management regulations in Europe and North America have contributed to a saving of 4 Mt projected emissions from the waste subsector in 2030. Finally, 2030 emissions from the wastewater subsector are projected to be 7 Mt higher, primarily attributed to its extended centralized collection without improved sewage treatment in many developing countries.

Taken together, these changes mean a slower growth in global anthropogenic methane emissions to 2030 than was assumed at the time the GMP was negotiated in 2021, partially attributable to the increased attention to methane mitigation since its launch. The lower projection extends beyond 2030, resulting in cumulative 480 Mt less methane entering the atmosphere between 2020 and 2050.

While emissions, and resulting impacts, are projected to continue rising in the CLE scenario, the avoided emissions relative to those in the GMA baseline translate into substantial benefits for the climate, public health and the environment (Table 2.3).

Table 2.3: **Annual global benefits of the reduction of methane emissions from the 2021 GMA baseline to the CLE 2030 scenario.**

	Avoided warming 2040–2070 (°C)	Avoided deaths from ground-level ozone exposure (people per year)	Avoided crop losses (Mt per year)	Avoided asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Avoided lost work hours (million hours per year)	Total valuation (billion US$ per year)
CLE 2030 vs 2021 GMA baseline 2030	0.021	20,000	2	60,000	1,200	5,700	36

Source: Adaptation of GMA 2021 benefits estimates.

Methane mitigation commitments, formulated in the NDCs and MAPs, and interpreted in the GAINS model framework assuming an ambitious level of implementation of measures mentioned in the NDCs and MAPs, could reduce annual global emissions by up to 8 per cent below the 2020 level by 2030. This suggests the ambition in current commitments would not meet the GMP global target of at least 30 per cent reduction below 2020 levels by 2030. Globally in 2030, the methane mitigation from full implementation of all measures mentioned in the NDCs and MAPs scenarios represents up to 24 per cent of the reductions possible in the MFTR scenario, indicating scope for substantial additional technical mitigation potential this decade.

While the methane reductions embodied in the NDCs and MAPs are insufficient to achieve the GMP target, they would nonetheless likely represent the largest and most sustained decrease in anthropogenic methane emissions in the entire historical record since the industrial revolution (Jones *et al.* 2023)[7].

In the energy sector, the model shows NDC and MAP measures could reduce annual emissions in 2030 by up to 26 Mt, with almost 90 per cent coming from low-cost measures. In the agricultural sector, despite measures reducing annual emissions in 2030 by up to 11 Mt, including 9 Mt at low cost, net 2030 emissions from agriculture are expected to stabilize at about the 2020 level, primarily due to expected increases in livestock numbers. Measures in the waste sector in the NDCs and MAPs could reduce annual methane emissions in 2030 by up to 5 Mt, although net annual emissions from the sector would still increase by 3 Mt above 2020 levels, due to population and economic growth and extended waste collection without upgraded treatment in some world regions. About 85 per cent of the emission reduction from waste measures mentioned in the NDCs and MAPs is available at low-cost. Most of the emission reduction potential in this sector would materialize post-2030 due to the large amounts of organic waste already stored in landfills and the delay in the release of emissions caused by the time it takes for organic waste to decompose. This means that pre-2030 investment in improved waste management in the NDCs and MAPs is expected to reduce annual emissions by up to 8 Mt from 2040 onward, underlining the urgent need for investment to reap the considerable emissions-reduction potential in this sector in the coming few decades.

7 The largest previous drop in the historical record was a decrease that lasted for 4 years and reached a maximum of 7 Mt per year in 1979–1983.

The total annualized cost in 2030 for implementation of measures mentioned in latest NDCs and MAPs is estimated at US$29 billion per year, of which US$17 billion per year will come from the agricultural sector, US$12 billion per year from the energy sector, US$7 billion per year from the wastewater subsector and a net saving of US$7 billion per year in the waste subsector. The last is the result of valorisation of recovered biogas and recycled materials outweighing costs. Given the significantly larger technical mitigation potential available at low cost in the energy sector than in agriculture, it is noteworthy that the total annualized costs for NDCs and MAPs measures in the energy sector are lower than for measures in the agricultural sector.

For the G20+, the annual cost of the measures mentioned in the NDCs and MAPs is estimated at US$23 billion per year, with US$14 billion per year invested in agricultural measures, US$11 billion per year in energy sector measures, US$6 million per year in the wastewater subsector and net savings of US$8 billion per year from improved waste-management measures. The annual cost for the NDCs and MAPs measures mentioned for the non-G20+ regions is estimated at a more modest US$5.1 billion per year, with US$1.9 billion per year for agricultural measures, US$1.0 billion per year for energy-sector measures, US$0.9 billion for the wastewater subsector and a net cost of US$1.3 billion for improved waste-management measures.

Globally, the projected decrease in methane emissions from measures included in latest NDCs and MAPs, lead to 60,000 avoided premature deaths from reduced ozone exposure, 6 Mt of avoided crop losses and 17 billion avoided hours of work losses. Achieving the methane mitigation envisioned in the NDCs and MAPs leads to benefits valued at US$107 billion per year by 2030 from the impacts considered here (Table 2.4).

Incorporating the social cost of methane to account for a broad array of climate-related damage would lead to additional benefits with an approximate valuation of US$100 billion in 2030 depending on the social cost chosen and the use of the NDCs and MAPs scenario. Some recent studies have performed retrospective analyses of climate and gross domestic product (GDP) to explore the potential economy-wide effects of multiple climate factors. These suggest even larger potential benefits from the avoided climate-related damage of around US$1,900 billion by mid-century (Kotz *et al.* 2024), though calculation of the exact values using their methods for methane-induced climate changes is complex and has not yet been performed.

Examining global mean temperature changes, relative to the CLE scenario methane reductions through 2030 under the NDCs and MAPs scenario could achieve between 0.03–0.07°C of avoided warming averaged over 2040–2070 (Table 2.4).

Table 2.4: Annual global benefits of reduction in methane emissions from CLE scenario to the NDCs and MAPs scenario, 2030.

	Avoided warming 2040–2070 (°C)	Avoided deaths from ground-level ozone exposure (people per year)	Avoided crop losses (Mt per year)	Avoided asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Avoided lost work hours (million hours per year)	Total valuation (billion US$ per year)
NDCs and MAPs vs CLE	0.06	60,000	6.1	180,000	3,600	17,000	107

Source: *Adaptation of GMA 2021 benefits estimates.*

With full implementation of maximum technically feasible reductions using technical methane control measures listed in Table 2.7, the model analysis shows that annual methane emissions in 2030 could be 114 Mt lower than in 2020, a reduction of 32 per cent. A reduction of 26 per cent from 2020 to 2030 could be realized at low-cost. This means that meeting the GMP target is technically possible but requires close to full implementation of the MTFR measures and goes beyond those of the MTFR low-cost scenario.

At the sectoral level, in year 2030, 72 per cent of the total mitigation potential from the MTFR measures lies in the energy sector, 18 per cent in the agriculture sector and 10 per cent in the waste sector. The reduction potential from MTFR measures in 2030 compared to CLE 2030, is estimated at 78 per cent (94 Mt per year) for the energy sector, 15 per cent (24 Mt per year) for the agricultural sector, and 16 per cent (13 Mt per year) for the waste sector combined. This translates in net reductions in annual emissions in 2030 under the MTFR scenario, compared to 2020 levels, of 73 per cent for the energy sector, 8 per cent in the agricultural sector and 5 per cent in the waste sector. In the agricultural sector and solid waste subsector sectors, low net reduction potentials are partly explained by growth in underlying drivers such as increased demand for food and waste generation in response to population and economic development, and partly by technical limitations to control emissions, in particular within this decade. Practical concerns regarding feed apportionment, for example, constrain the applicability and effectiveness of feed additives to control enteric fermentation emissions from livestock, and breeding schemes typically need years to run for full effect on emissions. This speaks to a need for further research and development of methane abatement technology, particularly in the agricultural sector.

The total annual mitigation cost for MTFR measures in 2030 is estimated at US$127 billion per year, US$223 billion per year in investment and operational costs less US$96 billion per year in cost savings from valorisation of recovered natural gas and biogas. The net annual cost for the agricultural sector to fully implement MTFR measures in 2030 amounts to US$38 billion per year, US$67 billion per year in annualized investment and operational costs less US$29 billion per year from the valorisation of recovered biogas from livestock manure. For the energy sector, the net annual cost of MTFR measures in 2030 is estimated at US$98 billion per year, including US$138 billion per year in investment and operational costs and savings of US$40 billion per year from the valorisation of natural gas recovered through reduced leaks and venting in the oil and gas subsector. The annual cost of MTFR in the waste sector in 2030 is estimated at a net saving of US$9 billion per year, including US$18 billion per year in investment and operational costs and US$27 billion per year from the valorisation of recovered biogas from landfill gas capture and anaerobic digestion of food waste and wastewater.

The emissions reduction potential for low-cost technical measures by 2030, from the MTFR low-cost scenario, represents 86 per cent of the technical mitigation potential in the energy sector, 70 per cent in the agricultural sector, and almost 90 per cent in the waste sector. Net annual costs for implementation of these measures in 2030 are, however, considerably lower than the cost of MTFR measures, amounting to a net saving of US$8 billion per year. For the energy sector, this means a net annual cost of US$10 billion per year, for the agricultural sector a net saving of US$4 billion per year, and for the waste sector a net saving of US$14 billion per year. Accordingly, there is considerable cost-effective and even net-profitable potential to reducing methane emissions in all sectors.

For the G20+, the MTFR reduction potential in annual emissions is estimated at 36 per cent between 2020 and 2030, which corresponds to 72 per cent of the global MTFR emissions reduction potential. With 60 per cent of global oil and gas production in this group of countries, the energy sector can contribute the largest reduction at 63 Mt in annual emissions between 2020 and 2030, of which 54 Mt is available at low or even negative cost. The non-G20+ regions have an MTFR reduction potential of 26 per cent between 2020 and 2030. For this group of countries, the energy sector can achieve a 35 Mt reduction in annual emissions between 2020 and 2030 by implementing the full MTFR measures, of which 30 Mt come at low cost. Almost the entire net global reduction potential in agriculture between 2020 and 2030 occurs in the G20+, with the largest reductions coming from measures to control enteric fermentation and emissions from livestock manure on large commercial farms, defined as farms with more than 100 livestock units (LSUs), as well as improved water management and use of low-methane rice varieties in rice cultivation. For the non-G20+, a full implementation of the MTFR measures in the agricultural sector could approximately compensate for the expected increase of 10 Mt in annual emissions in 2030 from the 2020 level.

The waste sector in the G20+ can reduce annual emissions by 7 Mt between 2020 and 2030, with net reductions primarily possible in high-income countries with relatively slow economic and population growth. For the non-G20+ regions, faster economic and population growth is expected, resulting in an increase in annual methane emissions from waste of 3 Mt between 2020 and 2030, despite full implementation of MTFR measures. The annual cost of a full implementation of the MTFR potential in 2030 is estimated at US$70 billion for the G20+ and US$57 billion for the non-G20+ regions.

Full implementation of the MTFR scenario would lead to approximately 0.20°C of avoided warming over 2040–2070 (Table 2.5), relative to projections under the CLE one.

Table 2.5: Annual benefits of global reductions in methane emissions from the MTFR and the MTFR low-cost scenarios compared to the CLE scenario, 2030.

	Avoided warming 2040–2070 (°C)	Avoided deaths from ground-level ozone exposure (people per year)	Avoided crop losses (Mt per year)	Avoided asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Avoided lost work hours (million hours per year)	Total valuation (billion US$ per year)
MTFR vs CLE	0.20	180,000	19	560,000	11,000	53,000	330
MTFR low-cost vs CLE	0.16	150,000	16	470,000	9,300	44,000	280

Source: Adaptation of GMA 2021 benefits estimates.

Full implementation of MTFR measures represents between a doubling and a fivefold scaling up of the emissions-reduction ambition from current commitments under NDCs and MAPs.

Such an increase in ambition compared to the NDCs and MAPs scenario could annually lead to an additional 130,000 avoided premature deaths from ground-level ozone exposure, 13 Mt of avoided crop losses, and roughly 36 billion avoided hours of work losses, translating to additional benefits valued at US$230 billion per year by 2030 (Table 2.6).

Table 2.6: Annual benefits of global reductions in methane emissions from the MTFR compared to the NDCs and MAPs scenario, 2030.

	Avoided warming 2040–2070 (°C)	Avoided deaths from ground-level ozone exposure (people per year)	Avoided crop losses (Mt per year)	Avoided asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Avoided lost work hours (million hours per year)	Total valuation (billion US$ per year)
MTFR vs NDCs and MAPs	0.13	130,000	13	380,000	7,600	36,000	230

Source: Adaptation of GMA 2021 benefits estimates.

A summary of 2030 changes in annual emissions and abatement costs from implementation of technical measures in the NDCs and MAPs and MTFR scenarios is shown in Table 2.7.

Table 2.7: **Summary of changes in annual emissions and abatement costs in 2030 in scenarios NDCs and MAPs, MTFR, and MTFR low-cost relative CLE in 2030.** Sum of columns may deviate from totals due to rounding.

Sector	2030 emissions under current legislation	Technical methane mitigation potential by sector in 2030			Implementation Costs		Methane mitigation measures
		NDCs and MAPs	MTFR	MTFR low-cost	MTFR	MTFR low-cost	
	Mt / yr	Mt / yr	Mt / yr	Mt / yr	bUS$/yr	bUS$/yr	
ENERGY							
Oil and gas sector upstream emissions	64	18	56	55	6.6	3.4	Extended recovery and utilization of vented gas: capture of associated gas from oil wells; blowdown capture; recovery and utilization of vented gas with vapor recovery units and well plungers. Addressing unintended leaks from equipment through leak detection and repair programs (LDAR): regular inspections (and repair); replace pressurized gas pumps and controllers with electric or air systems; replace gas-powered pneumatic devices and gasoline or diesel engines with electric motors; early replacement of devices with lower-release versions; replace compressor seals or rods; cap unused wells. Plug abandoned oil and gas wells.
Oil and gas sector downstream emissions	17	0.1	11	0.9	80.2	0.2	Oil refineries: leakage control through LDAR programs; extended flaring. Consumer gas distribution networks: leakage control through LDAR programs; upgrade to PE or PVC networks. Long-distance gas transmission pipelines and storage: leakage control through LDAR programs; equipping all new pipelines with compact (non-leak) flanges; refurbishment or replacement of existing pipelines.
Coal mining	43	8.3	27	25	10.8	6	Oxidation of ventilation air methane through use of Regenerative Thermal Oxidizers, RTOs. Pre-mining degasification. Abandoned coal mines: flooding of mines.
ENERGY TOTAL	**124[1]**	**26**	**94**	**81**	**98**	**10**	
AGRICULTURE							
Rice cultivation	31	8.1	9.8	9.2	2	0.5	Water management measures e.g., intermittent aeration and dry direct seeding; alternative rice hybrids; soil amendments e.g., sulphate-containing substrates and biochar.
Agricultural waste burning	4.7	0.7	4.7	4.7	0	0	Ban or enforcement of existing bans.
Livestock manure emissions	9.7	1.4	2.6	1.5	1.9	-4.2	Pigs on farms > 100 Livestock units[4] with liquid manure systems: Anaerobic digesters with biogas recovery.

Sector	2030 emissions under current legislation	Technical methane mitigation potential by sector in 2030			Implementation Costs		Methane mitigation measures
		NDCs and MAPs	MTFR	MTFR low-cost	MTFR	MTFR low-cost	
	Mt / yr	Mt / yr	Mt / yr	Mt / yr	bUS$/yr	bUS$/yr	
Livestock enteric fermentation emissions	112	0.7 (7.7)[2]	7 (16)[2]	1.2 (3)[2]	34	0.2	Smallholder & pastoralist systems in Africa: climate resilience measures i.e., human and animal vaccination against zoonotic diseases, emergency feed storage, and female empowerment. Dairy and non-dairy cattle on farms > 50 Livestock units and at least partly housed: Breeding for multiple traits to enhance productivity and animal longevity and fertility; enhanced feed efficiency; use of feed additives (3-NOP or red seaweed). Dairy and non-dairy cattle on farms >50 Livestock units in pasture-based systems in Americas, Australia & New Zealand: Breeding for multiple traits to enhance productivity and animal longevity and fertility; inter-seeding with grass legumes to improve quality of feed. Sheep and goats on farms > 50 Livestock units: Breeding for multiple traits to enhance productivity and mal longevity and fertility.
AGR TOTAL	**157**	**11**	**24**	**17**	**38**	**-3.5**	
WASTE							
Municipal solid waste	37	4.3 (7.7)[3]	5.9 (15)[3]	5.7 (14)[3]	-6.5	-7.2	Upgrade to managed landfills with gas recovery & utilization; source separation and treatment of organic waste in biogas digesters, composts or through recycling.
Industrial solid waste	14	0.1 (0.7)[3]	1.8 (5.9)[3]	1.2 (5.6)[3]	0.4	-0.8	Upgrade to managed landfills with gas recovery & utilization; anaerobic digestion with biogas recovery; composting; energy recovery.
Domestic wastewater	18	0.1	0.5	0	4	0	Two-stage anaerobic treatment with biogas recovery followed by aerobic treatment; upgrade of existing capacity at end of plant lifetime.
Industrial wastewater	12	0.2	4.8	4.8	-6.5	-6.5	Two-stage anaerobic treatment with biogas recovery followed by aerobic treatment; upgrade of existing capacity at end of plant lifetime.
WASTE TOTAL	**81**	**5 (8)**	**13 (21)**	**12 (20)**	**-9**	**-14.5**	
TOTAL	**369**	**42**	**131**	**109**	**127**	**-8**	

1 Other fuel combustion sources are projected to contribute 7.4 Mt/yr in 2030, but are not included in this table due to limited identified mitigation options.

2 Emissions reduction potential from enteric fermentation measures in 2040 including full effect of breeding measures implemented pre-2030. Effects on methane emissions reductions from breeding through selection of traits that target enteric methane both at individual and stock levels are only assumed to be realized from 10 years after the start of the breeding scheme.

3 Emissions reduction potential in 2040 from the waste sector measures implemented pre-2030. Full effect on methane emissions are realized with a time-lag of 10–20 years due to continued decomposition of organic waste deposited in landfills.

4 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)

2.4.2 The 2050 picture

Methane mitigation action and ambition must continue, and be strengthened, beyond 2030. The 1.5°C-consistent scenarios developed for the IPCC's Sixth Assessment Report (IPCC AR6) project that global methane emissions will continue to decrease steadily beyond the middle of this century. By 2040, global methane emissions will have fallen to approximately 45 per cent below 2020 levels and decrease further to 52 per cent below 2020 levels by 2050 (IPCC 2023).

Since NDC 3.0 mitigation pledges end in 2035, the benefits relative to 2020 emissions peter out over time in the NDCs and MAPs scenarios, as underlying drivers for emissions continue to increase, in particular in the agricultural, and waste sectors. This shows that substantial strengthening of the NDCs is needed both in the near term to reach the goals of the GMP and over the longer term to provide absolute sustained benefits.

Extending to 2050, mitigation under the MTFR scenario could achieve a 37 per cent reduction below 2020 levels and bring the world closer to a 1.5°C pathway. Implementation of technical measures achieves a reduction in annual emissions of 207 Mt per year in 2050 compared to CLE for this same year, however, because of projected increases in activity drivers, in particular in agriculture and the waste sector, the net technically feasible reduction in annual emissions in 2050 is 132 Mt below the 2020 level. Of this, 73 per cent comes from the energy sector, 20 per cent from waste sector, and 7 per cent from agriculture.

Almost 80 per cent of the MTFR mitigation potential in 2050 is attainable at a low cost, amounting to a net annual saving of US$35 billion, of which annual investment and operation costs are US$123 billion and savings from the valorisation of recovered gas to 158 billion per year. Just over half of the low-cost reduction potential occurs in the energy sector, 36 per cent in the waste sector, and just 10 per cent in the agricultural sector. Again, this speaks to the need for further development of methane abatement technology, particularly in agriculture. A prerequisite for realizing the large low-cost reduction potentials in the waste subsector in 2050 is a scale-up of investment in upgraded landfills and circular waste-management systems before 2030, as the full effect on emissions appears after decomposition of the large amounts of historic organic waste stored in landfills.
The annual cost of full implementation of the MTFR potential in 2050 is estimated at US$129 billion in the G20+ and US$85 billion for the non-G20+ regions.

Table 2.8: Annual benefits from global reductions methane emissions from the MTFR relative to those of the CLE 2050 scenario.

	Avoided warming 2060–2090 (°C)	Avoided deaths from ground-level ozone exposure (people per year)	Avoided crop losses (Mt per year)	Avoided asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Avoided lost work hours (million hours per year)	Total valuation (billion US$ per year)
MTFR vs CLE 2050	0.31	293,000	30	890,000	18,000	84,000	530

Source: Adaptation of GMA 2021 benefits estimates.

The decarbonization of the energy system alone will not be sufficient to meet the GMP by 2030 or follow a 1.5°C pathway to 2050. To meet a 1.5°C consistent pathway to 2050, full implementation of MTFR measures must be combined with simultaneous efforts to both decarbonize the global energy system and implement demand-side measures targeted at shifts to healthier and more sustainable human diets and reduced generation of food waste. Combining decarbonization with full implementation of MTFR measures, allows a 34 per cent reduction between 2020 and 2030, extending to 44 per cent by 2050. If demand-side measures such as shifts to healthier and more sustainable diets and less generation of food waste are added, a 53 per cent reduction is possible by 2050. This is the only scenario that comes within reach of consistent with the 1.5°C scenarios developed for IPCC AR6.

Table 2.9: **Annual benefits of global reduction of methane emissions from the CLE 2050 scenario to MTFR + Decarb + Demand 2050 scenario.**

	Avoided warming 2060–2090 (°C)	Avoided deaths from ground-level ozone exposure (people per year)	Avoided crop losses (Mt per year)	Avoided asthma-related emergency-room visits (people per year)	Avoided hospitalizations of 65+ year-olds (per year)	Avoided lost work hours (million hours per year)	Total valuation (billion US$ per year)
MTFR + Decarb + Demand 2050 vs CLE 2050	0.36	345,000	36	1,050,000	20,900	100,000	620

Source: Adaptation of GMA 2021 benefits estimates.

2.5 Conclusion

This analysis shows that while progress has been made since the launch of the GMP, current commitments under NDCs and MAPs fall short of achieving the target of a 30 per cent reduction in global anthropogenic methane emissions below 2020 levels by 2030. Yet, implementation of existing pledges would deliver the largest and most sustained decline in methane emissions in recorded history but only achieve up to 8 per cent reductions from 2020 levels by 2030. A decline in emissions due to implementation of NDCs and MAPs measures is partly counteracted by expected future increases in activities driving methane emissions, including continued production of fossil fuels, demand for dairy and meat products, and generation of organic waste.

In the 2030 timeframe, methane mitigation will rely heavily on existing technical solutions and the technical potential to reach the GMP target. Full uptake of MTFR measures could cut 2030 emissions by 32 per cent relative to 2020, with more than 80 per cent of this potential available at low or even negative cost. The energy sector offers the greatest cost-effective opportunities, followed by targeted measures in agriculture, and waste and wastewater management. Early investment in waste and wastewater infrastructure is essential to unlock considerable mid- and long-term reductions.

Efforts to mitigate methane should continue beyond 2030. Achieving a 1.5°C-consistent pathway requires an integrated strategy that combines technical methane controls with deep decarbonization of the energy system, and demand-side action such as shifts to healthier and more sustainable human diets and reduced food waste generation. Such an approach could deliver a 53 per cent reduction in global methane emissions by 2050, generating substantial health, agricultural, labour and climate benefits valued at hundreds of billions of dollars annually.

The findings underline the urgent need to raise ambition, accelerate implementation and broaden mitigation strategies. Doing so will yield rapid climate benefits while delivering major co-benefits for public health, food security and economic productivity.

Photo: evgenii_v/Adobe Stock

03 Global Outlook of Methane Policies and Measures

Key messages

- While recent years have seen growing momentum in methane abatement policy development across the three main emitting sectors, a significant scale-up in effective policy design, implementation, and MRV systems is still required to fully realize the mitigation potential needed to meet global climate and clean-air goals.

- Methane mitigation policy is increasingly incorporated into NDCs, reflecting broader global ownership of national methane mitigation planning. Since the launch of the GMP, many countries have strengthened methane coverage in their NDCs. As of June 2025, 65 per cent of countries who are party to the Paris Agreement have included methane measures in their NDCs, with particularly notable increases among UNFCCC Non-Annex I countries[8]. Between June and the end of September 2025, this number rose to 67 per cent.

- The fossil-fuel sector offers the largest and most cost-effective opportunity for rapid methane abatement, with industry revenues far exceeding the investment needed to achieve full mitigation potential. Policy innovation, particularly in the oil and gas sector, has accelerated in recent years, with jurisdictions such as Brazil, Canada, the European Union and Kazakhstan introducing new regulatory frameworks, including the world's first methane import standard. Voluntary initiatives such as the Oil and Gas Methane Partnership (OGMP) 2.0 now cover up to 45 per cent of global oil and gas production. In contrast, progress in the coal sector remains slow, although new regulations in Australia and China signal emerging momentum.

- Early investment in technically feasible methane abatement measures in the waste sector is critical to achieving the necessary emissions reductions by midcentury. While global action on waste-related methane has increased, adoption of best practice remains uneven. Examples, such as these from Brazil, China, Germany and Sweden, illustrate a wider shift towards technologies that cut methane and generate renewable energy. Governments are also increasingly recognizing the importance of proper waste collection, separation and treatment hierarchies.

- In agriculture, policy development is on an upward trend, and significant mitigation can be achieved at a net cost saving. Required investment is small compared to the inefficient and harmful subsidies currently provided to the sector. Current policy coverage is limited, with only 2–18 per cent of GMP participating countries having policies directly addressing key agricultural sources such as enteric fermentation, rice or manure management.

8 Annex I Parties include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states?field_national_communications_target_id%5B514%5D=514

- Across the three main emitting sectors, immediate implementation of targeted methane measures must be part of holistic, equity-based policies that are integrated with efforts to decarbonize the energy system, promote circular economies and encourage behavioural change in agrifood systems.
- Few countries have adopted quantified methane reduction targets. Despite more than 150 countries participating in the GMP, only six, Canada, Japan, the Republic of Moldova, Norway, the United States of America, and Viet Nam, have targets comparable to the GMP goal.
- Persistent barriers hinder progress from commitments to fully effective enforcement and implementation. Strengthening MRV systems and securing appropriate financing are essential to accelerating the development, enforcement and impact of methane policies.

3.1 Introduction

The GMP includes specific provisions to which participants commit. The most well-known of these provisions is the commitment to work together to achieve at least a 30 per cent reduction in global methane anthropogenic emissions by 2030 compared to 2020 levels. Country participants to the GMP, however, also commit to:

- take comprehensive domestic action to achieve the global methane reduction target, specifically focusing on standards to reduce methane emissions as much as possible from the energy, and waste sector, and to reduce agricultural emissions through technological developments, incentives and collaboration with farmers;
- maintain publicly available information on policies and commitments;
- move towards the highest tier IPCC methods to quantify methane emissions, particularly from major emission sources; and
- support international initiatives aimed at reducing methane emissions including the CCAC, the Global Methane Initiative and the International Methane Emissions Observatory (IMEO).

While the primary marker of progress towards the goals of the GMP is the extent to which global anthropogenic methane emissions are being reduced, the Pledge also emphasizes the importance of effective domestic policies and measures. These are essential to turning the Pledge from aspiration into reality. Progress has been made since the Pledge's launch in 2021 on the identification of methane policies and measures, their integration into national plans and strategies, and their implementation and enforcement.

Following the quantitative assessment emission projections to 2030 and 2050 under different scenarios, and of associated costs and benefits (Chapter 2), this chapter looks at the latest developments and trends in methane abatement policy, associated barriers and solutions, and provides key recommendations on the way forward to reap the full mitigation potential.

It begins with a review of national level planning efforts, using five key building blocks to evaluate the extent to which countries have integrated methane into their climate and environmental national planning frameworks (Section 3.2). Subsequent sections then explore sector-specific dynamics through a review of global policy trends, identification of key challenges and innovative policy responses, and recommendations for scaling up best practices and technologies in the fossil-fuel (Section 3.3), waste (3.4) and agriculture (3.5) sectors.

3.2 National planning for action on methane emissions

Key messages

- Global Methane Pledge participating countries commit to increasing transparency on methane policies as well as accuracy in methane emission quantification. Since the GMP was established, different components of methane-mitigation planning have improved across an increasing number of countries.

- Much of this improvement has been achieved through the efforts of UNFCCC Non-Annex I countries, including those that make small contributions to global methane emissions:

  - Since the GMP was established, Non-Annex I countries have increasingly adopted more detailed methodologies to quantify methane emissions, moving from Tier 1 to Tier 2 or 3, with over a 69 per cent increase number using Tier 2+ methods to quantify livestock methane emissions, and more than a 50 per cent increase in those using Tier 2 methods to quantify waste methane emisions;

  - New NDC submissions continue to add more methane mitigation action;

  - 31 Non-Annex I countries include methane-specific targets or mitigation potential in their NDCs.

- As of June 2025, 127 countries, 65 per cent of countries who are Parties to the Paris Agreement, have identified policies and measures that address sectoral sources of methane in their latest NDCs. Among these, 115 countries include waste methane measures (59 per cent), 85 include agricultural methane measures (44 per cent), and 35 (18 per cent) identify measures to address methane emissions from fossil fuel production. This represents a growth of 58 per cent, 89 per cent and 52 per cent respectively in comparison to pre-2020 NDCs.

- There is substantially more that could be done to improve national methane planning, particularly among the highest methane-emitting countries.

3.2.1 Introduction

The GMP sets a collective global goal of reducing methane emissions by at least 30 per cent by 2030, compared to 2020 levels. It provides no instruction, however, for how the burden of achieving these emission reductions should be shared between countries and methane-emitting sectors. This aspect of the GMP prompted the CCAC, through its Methane Roadmap Action Programme (M-RAP), to develop a framework enabling countries to understand and communicate their contribution to achieving the GMP.

The framework provides five building blocks for evaluating the comprehensiveness of national methane-reduction plans. The framework aims to support GMP participating countries in developing national methane roadmaps that are complete and comparable across countries. The framework is also useful for assessing strengths and gaps in these national policy-planning instruments. The five building blocks within the CCAC's M-RAP are:

1. **emissions:** the ability to quantify emissions from all methane-emitting sectors using an appropriately detailed IPCC methodology;

2. **analytics:** the ability to identify, evaluate and prioritise methane policies and measures based on their methane emission-reduction potential and other co-benefits;

3. **targets:** setting methane emission-reduction targets aligned with the GMP;

4. **implementation pathways:** clear plans for how policies and measures to reduce methane will be implemented;

5. **monitoring and evaluation:** the ability to assess progress in reducing emissions and policy implementation.

In this section, these five building blocks are used to evaluate national methane planning since the establishment of the GMP. Through national documents, including NDCs, Biennial Transparency Reports (BTRs) and national methane roadmaps, statistics were extracted to indicate progress across countries for each of the building blocks.

3.2.2 Emissions: progress on methane emission inventories

Methane-emission inventories are a key prerequisite for the monitoring of and taking action to reduce methane emissions. They track total national methane emissions and contributions from major sources. When quantified for multiple years, trends in methane emissions, resulting from socioeconomic drivers, including population and economic growth, fuel or food demand, and mitigation action, can be robustly assessed. Methane emissions are commonly reported within national greenhouse gas emission inventories, regularly submitted to the UNFCCC by Parties through National Inventory Reports (NIRs), BTRs and National Communications (NCs).

The IPCC has developed detailed methodologies to estimate methane emissions across sectors. These range from the simplest (Tier 1) to the most detailed (Tier 3), allowing all countries, even with limited data, to make estimates, while offering robust methods for those with more data and for key categories. Moving from Tier 1 to Tier 2 or Tier 3 methods has several advantages for national methane-mitigation planning. First, it improves understanding of emissions by source, enabling targeted mitigation and better monitoring.

Second, Tiers 2 and 3 are better suited for evaluating impacts of mitigation options, using process-based methodology with variables linked to measures.

Understanding the coverage of methane-emission quantification within national methane-emission inventories, and the extent to which Tier 1 or Tier 2 methods are used, is therefore essential for assessing whether countries are strengthening their ability to identify methane sources and track progress since the establishment of the GMP. By reviewing countries' latest inventories, the share using different tiers has been identified (Tables 3.1 and 3.2).

An increasing number of countries, mainly developing ones, are using Tier 1, Tier 2 and Tier 3 methods to quantify methane emissions in their national inventories. Before the GMP was established, most Annex I countries already used Tier 2 or Tier 3 for major sources, so the number of Annex I countries applying each tier in 2024 BTRs is broadly similar to pre-GMP levels.

For Non-Annex I countries, progress in using higher tier methods has accelerated since 2021. Among Non-Annex I countries that have submitted 2024 Biennial Transparency Reports, 47 per cent, 27, use Tier 2 methods to quantify enteric-fermentation emissions. In 2021, only 28 per cent, 16, of these countries used Tier 2 or higher methods. Similarly, 45 per cent, 26, of Non-Annex I countries in their 2024 national greenhouse gas inventories quantify methane from solid waste using Tier 2 approaches, compared to 26 per cent, 15, of these countries in 2021. There has also been a substantial reduction in the number of countries not quantifying methane from agriculture, and waste. Only the Maldives, which lacks an agricultural sector and burns its waste, omitted these sectors in 2024.

Table 3.1: Quantification of methane emissions in national inventories of Annex I countries, 2021 and 2024. Number of Annex I countries quantifying methane emissions from major emission sources using IPCC Tier 1, Tier 2 and Tier 3 national emission inventory guideline methodologies. Countries included are those that have submitted 2024 BTRs with NIRs (summarized in the 2024 rows), and are compared with the latest national greenhouse gas inventory submitted before the establishment of the Global Methane Pledge in 2021 (summarized in the 2021 row).

Annex I		Fugitive oil and gas	Fugitive coal	Enteric fermentation	Manure management	Rice cultivation	Solid waste	Wastwater
2021	Not quantified/ not occurring	13	3	1	1	26	1	0
	Tier 1	9	12	2	3	10	2	18
	Tier 2*	9	11	30	31	1	32	19
	Tier 3*	8	13	6	4	2	4	2
2024	Not quantified/ not occurring	12	2	1	1	26	1	0
	Tier 1	8	14	1	4	10	2	18
	Tier 2*	9	6	29	32	1	29	16
	Tier 3*	4	13	3	0	2	3	2

**Includes countries that may quantify methane emissions from non-key categories within these emitting sectors using lower tier methods.*

Table 3.2: **Quantification of methane emissions in national inventories of Non-Annex I countries, 2021 and 2024.** Number of Non-Annex I countries quantifying methane emissions from major emission sources using IPCC Tier 1, Tier 2 and Tier 3 national emission inventory guideline methodologies. Countries included are those that have submitted 2024 BTRs with NIRs (summarized in the 2024 rows), and are compared with the latest national greenhouse gas inventory submitted before the establishment of the Global Methane Pledge in 2021 (summarized in the 2021 row).

Non-Annex I		Fugitive oil and gas	Fugitive coal	Enteric fermentation	Manure management	Rice cultivation	Solid waste	Wastwater
2021	Not quantified/ not occurring	26	18	7	7	14	8	7
	Tier 1	26	33	34	41	39	33	43
	Tier 2*	3	2	16	9	3	15	6
	Tier 3*	1	3	0	0	1	1	0
2024	Not quantified/ not occurring	25	15	1	1	17	1	1
	Tier 1	27	35	29	30	32	30	47
	Tier 2*	5	3	27	26	7	26	9
	Tier 3*	1	4	0	0	0	1	0

**Includes countries that may quantify methane emissions from non-key categories within these emitting sectors using lower tier methods*

3.2.3 Analytics and targets: progress on methane inclusion in Nationally Determined Contributions

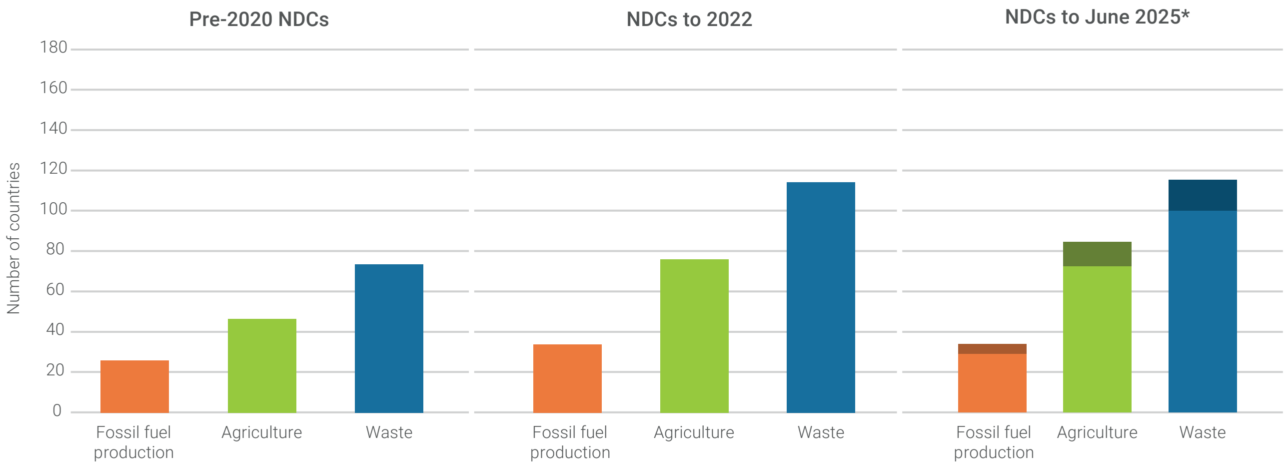
A key provision of the GMP is that action to reduce methane emissions must be identified and implemented. Methane mitigation action is identified by many countries in their climate change planning, for example through NDCs.

Previous assessments (Malley *et al.* 2023) found that NDCs include hundreds of methane mitigation measures, which, collectively and only if implemented to their full technical potential, could reduce global methane emissions by more than 30 per cent by 2030 compared to 2020 levels, consistent with the results presented in Chapter 2. As countries have not committed to full technical implementation, achieving the GMP solely through action identified in NDCs at the time the Pledge was made is unlikely.

An increase in the number of policies and measures included and prioritized in national planning is necessary if GMP targets are to be achieved. An increase in the inclusion of mitigation action targeting methane in NDCs needs to be coupled with faster implementation of action already included in NDCs and national policy.

The second building block within the CCAC M-RAP framework is the extent to which countries have prioritised policies and measures. To monitor progress on this, the number of methane policies and measures included within the NDCs of countries who are Party to the Paris Agreement[9] and supporting documents are tracked (Figure 3.1).

Figure 3.1: **Inclusion of methane mitigation measures in Nationally Determined Contributions by sector, pre-2020, 2022 and 2025.** Number of countries including methane mitigation measures in NDCs in the fossil fuel production (orange), agriculture (green) and waste (blue) sectors over time. NDC3.0 indicated by darker shade in the NDCs to June 2025 panel. *Submitted as of 01 June 2025.



Source: *CCAC (2025)*

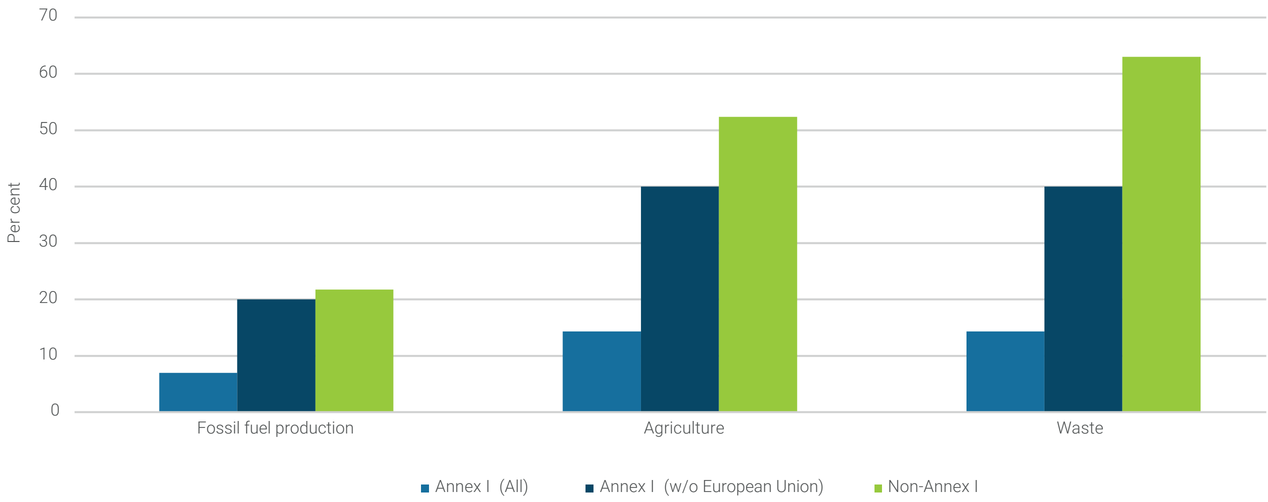
Since the GMP was established, there has been substantial growth in the inclusion of methane mitigation actions within NDCs. As of June 2025, 127 countries (65 per cent) list methane measures in their NDCs. Among these, 115 countries include waste methane measures (59 per cent), 85 include agricultural methane measures (44 per cent), and 35 (18 per cent) identify measures to cut fossil fuel methane. This represents increases of 58 per cent, 89 per cent, and 52 per cent respectively compared with pre-2020 NDCs. These results match broader NDC trends: the waste and agricultural sectors are more often addressed than the fossil-fuel sector. Many countries, however, do not produce fossil fuels, so measures in this sector are not relevant for them. This is discussed in more detail in Section 3.2.3.1.

Since June (to 30 September 2025) an additional 42 countries have submitted their final or draft NDC 3.0. Increasing the number of countries including methane mitigation measures to 130 (67 per cent). An additional 4 countries include waste methane measures, however the number of countries including fossil fuel and agriculture methane measures has fallen by 4 and 1 respectively. This decline can be explained by a number of countries who have submitted drafts of their NDC 3.0, stating that additional details will be communicated in their final submission. Only the measures in NDCs submitted to June 2025 are included in the analysis presented in Chapter 2.

9 Unless otherwise indicated, per centages indicate the proportion of countries party to the Paris Agreement, with 100 per cent representing 194 countries. More detail on the CCAC's NDC tracking methodology can be found in the Technical Annex.

Comparing the inclusion of methane measures between Annex I and Non-Annex I countries in their latest NDCs as of 30 September 2025 shows Non-Annex I countries are more likely to include methane measures across all three sectors (Figure 3.2). The European Union[10] make up more than half of the Annex I countries and their collective approach, with one NDC submission for all European Union countries, significantly influences the trend for this group. Despite the European Union's established climate policy framework, including its Methane Strategy and sector-specific regulations, the European Union does not describe any measures that address methane emissions in its NDC. Because the European Union's NDC is collective, it does not reflect the measures of individual member states.

Figure 3.2: **Proportion of countries who are Parties to the Paris Agreement including methane measures in their NDCs by country groups and sector, per cent** (NDCs to June 2025).



Note: While the European Union submit one NDC, they are considered as separate submissions in Annex I (all), Malta and Cyprus, while not formally Annex I countries, are treated here as functionally Annex I, in line with the UNFCCC.

Data source: CCAC (2025)

Several of the countries with the largest methane emissions have identified action in their NDCs to reduce methane (Table 3.3). Even when action is listed, however, specific policies and measures, or quantitative targets and timelines are often missing. Providing greater clarity and transparency on action already identified in NDCs and other climate change plans would make it easier to assess whether commitments are sufficient to meet the GMP.

There are, however, many major emitters that have not included national methane action in their NDCs. India is the world's third largest emitter of methane in absolute terms but does not identify action to reduce emissions from its largest source, agriculture, within its NDC. (Table 3.3).

10 Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.

Table 3.3: **Inclusion in NDCs of methane abatement measures, 20 countries with the largest methane emissions and the European Union, 2018–2022, by sector and total, per cent share of global methane emissions.** Contributions of 20 countries with the largest methane emissions and the European Union to global methane emissions by sector (cumulative 2018–2022). Asterisks (*) indicate countries that rank among the top 10 emitters in the respective sector. Green shaded cells indicate the inclusion of sectoral mitigation measures in a country's NDC, countries shaded light green have either not ratified or have announced their intent to withdraw from the Paris Agreement. Blue tick marks indicate where a country has submitted its NDC 3.0 between June and the end of September 2025. Cells shaded blue indicate the inclusion of measures in NDC 3.0 not included their previous submission.

Country	GMP Party	NDC 3.0 submitted	Per cent of global methane emissions by sector (2018-2022) Agriculture	Fossil fuel production	Waste	All sectors
China			14 *	21 *	19 *	17
United States of America (the)	✓	✓	5.8 *	14 *	7.8 *	8.6
India			12 *	2.6 *	6.9 *	8.3
Brazil	✓	✓	9.9 *	1.1	6.9 *	6.6
Russian Federation (the)		✓	1.4	8.8 *	6.9 *	4.7
European Union	✓		5.4	2.0	7.3	4.7
Indonesia	✓		2.5*	6.9 *	2.7 *	3.9
Pakistan		✓	4.2 *	0.5	1.2 *	2.5
Nigeria	✓	✓	1.2	3.2 *	1.6 *	1.9
Mexico	✓		1.9 *	0.4	3.4	1.7
Iraq	✓		0.1	4.9 *	0.6	1.7
Iran (Islamic Republic of)			0.5	3.6	0.8	1.5
Australia	✓	✓	1.6	1.9	0.7	1.5
Argentina	✓		2.3 *	0.4	0.6	1.4
Bangladesh	✓	✓	2.3 *	0.1	0.8	1.3
Canada	✓	✓	0.7	2.3 *	1.2	1.3
Türkiye	✓		1.1	0.3	3.5	1.3
Viet Nam	✓		1.6	0.8	0.8	1.2
Thailand	✓		1.7	0.3	1.4	1.2
Saudi Arabia	✓		0.1	2.4 *	1.7	1.1
Ethiopia	✓	✓	1.7 *	0.2	0.7	1.0
Total			**73**	**78**	**76**	**75**

Note: columns may not sum due to rounding. *Source: Emissions data EDGAR v8.1 (2024).*

3.2.3.1 How Nationally Determined Contributions address methane emissions from fossil-fuel production

While 35 countries, ranging from major global producers through regional producers, to a few with little or no production, such as Costa Rica, the Republic of the Marshall Islands and Mauritius, include fossil-fuel production measures in their NDCs, the majority of countries are not major producers.

Countries with measures to reduce methane emissions from fossil-fuel production include seven of the 10 largest emitters (Table 3.3) and just under half (24) of the 50 biggest sectoral emitters. Together, these 24 countries are responsible for 59 per cent of the sector's methane emissions.

Measures in NDCs focus on upstream interventions to cut fugitive emissions, such as leak detection and repair (LDAR) and reducing venting and flaring, 27 countries, plus coal-mine methane emission-reduction measures, 5 countries, such as pre-mining drainage and oxidation. A few countries, for example, Canada and the Republic of the Marshall Islands, mention regulatory measures such the phasing out of fossil-fuel subsidies.

3.2.3.2 How Nationally Determined Contributions address methane emissions from waste

More than 90 per cent of countries' latest NDCs include commitments on waste sector. In total, 169 countries who are Parties to the Paris Agreement include the waste sector in the scope and coverage of their target. Over half of countries who are Parties to the Paris Agreement define concrete measures for either waste or wastewater.

Measures for the waste subsector focus on improving systems with circular-economy practices, including reducing the generation of food waste, source segregation, separate waste collection, the adoption of composting and waste-valorisation technologies such as anaerobic digestion, diversion of organic waste from landfills, and closure or upgrading of disposal sites with gas recovery for flaring or energy.

Measures in the wastewater subsector include capturing methane from anaerobic treatment to produce energy. The number of countries including wastewater mitigation or adaptation measures has more than doubled, from 38 pre-2020 NDCs to 84 in the latest NDCs.

Examples of good practice include the following.

- Cameroon: strengthening waste-management policies – by 2035, all major cities should have landfills with at least 70 per cent methane capture (UNFCCC 2021).
- Nepal: by 2025, 380,000 cubic meters (m^3) of wastewater per day will be treated before discharge and 60,000 m^3 of faecal sludge managed per year, reducing emissions of CO_2eq by more than 250,000 tonnes compared with BAU (Government of Nepal 2020).
- Venezuela (Bolivarian Republic of): the National Sanitation Plan stipulates the recovery of 35 landfill sites and the capture of methane from them. There is also a plan to construct two sanitary landfills, from which it is estimated that 17,134 tonnes of CO_2eq will be captured per year.

Integrating these targets into instruments such as National Waste Management Plans with clear implementation plans is essential to show commitment and align with NDCs. Many countries mention methane in their NDCs, but few set quantified targets for methane emissions from the waste sector. Best examples include:

- Colombia: reduction of methane emissions from waste fully integrated into national climate strategies;
- Indonesia: quantifies wastewater measures equal to 1.2 Mt of methane recovery;
- Viet Nam: commitments to methane capture from wastewater treatment plants.

3.2.3.3 How Nationally Determined Contributions address methane emissions from agriculture

Overall, 82 per cent of countries include economy-wide greenhouse gas emissions-reduction targets covering multiple IPCC sectors and gases, including agriculture and methane, in their NDCs. They are not, however, disaggregated by sector or gas. 26 per cent of NDCs include sector-specific targets covering methane and none provide methane-specific reduction targets (FAO 2025).

As with the waste sector, countries increasingly include mitigation action in their NDCs to reduce agricultural methane. Over a third of countries who are Parties to the Paris Agreement, 44 per cent, directly identify agricultural methane mitigation measures in their NDC (FAO 2025).

Measures include improved fertilizer management, 27 per cent; manure management and bioeconomy, 23 per cent; improved rice management, 14 per cent; livestock-feed management, 13 per cent; livestock breeding, 7 per cent; reduced crop-residue burning, 5 per cent; animal health and welfare, 4 per cent; shifts to sustainable healthy diets, 2 per cent; reduced savanna/grassland fires, 2 per cent; and emerging foods and production technologies, 1 per cent (FAO 2025).

Only 34 per cent of NDCs, however, include mitigation measures with time-bound, quantified greenhouse gas targets (not methane-specific), and only one country includes a methane-specific target at the action level (FAO 2025).

3.2.3.4 Progress on methane targets

As outlined in the previous sections, many countries include action to reduce methane in their NDCs as part of their overall climate targets. The magnitude of methane emissions to be reduced is, however, often unclear or not specified. Methane-specific targets, building block three, should clearly stipulate how much methane a country intends to reduce.

Despite more than 150 countries participating in the GMP, only six have defined methane-reduction targets directly comparable with the GMP targets, i.e., reductions by 2030 relative to 2020. A number of countries have established methane-relevant targets within their NDCs, though these vary in clarity and ambition. The majority, 181, of countries who are Parties to the Paris Agreement include methane within their overall greenhouse gas targets, an increase of more than 20 per cent compared with pre-2020 NDCs.

The inclusion of methane in the overall target is important, as it provides an incentive for countries to reduce methane emissions because it contributes to international climate commitments. This contribution is not, however, transparent, as it is rarely specified how much methane reductions will contribute, and targets are usually given in carbon dioxide equivalent (CO_2eq). The IPCC AR6 and UNEP's 2021 GMA highlight that meeting temperature goals requires methane reductions alongside, not instead of, rapid carbon dioxide reductions. Methane-specific targets therefore provide a clearer statement of national ambition.

Less commonly, countries include methane-specific targets. These outline reductions that, depending on their formulation, can be directly compared with the GMP. From NDCs, those with methane targets were extracted and are summarised in Table 3.4. Some countries do not include specific methane targets but instead assess the mitigation potential of NDC measures.

Countries such as Côte d'Ivoire and Nigeria state that achieving their overall greenhouse gas targets will reduce methane emissions by 25–30 per cent by 2030. However, because these are compared with baseline scenarios, linking them directly to the GMP is difficult.

Methane-specific targets take several forms. Canada, for example, has an overall methane-reduction target, while Uruguay commits to a 35 per cent reduction by 2035 plus a methane ceiling. Canada and Uruguay, as well as others, also set sector-specific targets. Canada and Ghana, for example, target methane from oil and gas, while Uruguay sets a methane-intensity target for livestock.

Table 3.4: Summary of inclusion of national methane emissions-reduction in countries' latest NDCs as of October 2025. Overall methane emissions-reduction targets with a tick indicate targets which can be directly compared with the GMP formulation, i.e. which can be expressed as methane emissions reductions relative to 2020 emissions levels. See Technical Annex for details and all-time inclusion.

Country	Methane emissions reductions from overall greenhouse gas target specified	Sectoral methane emissions-reduction target/estimation	Overall methane emissions-reduction target
Albania	■		
Armenia		■	
Benin	■		
Bhutan		■	
Cameroon		■	
Canada		■	■ ✓
Chile			■
Cote d'Ivoire	■		
Dominica		■	
Dominican Republic (the)	■		
Equatorial Guinea		■	
Micronesia (Federated States of)		■	
Gambia (the)	■		
Ghana	■		
Guatemala		■	

Country	Methane emissions reductions from overall greenhouse gas target specified	Sectoral methane emissions-reduction target/estimation	Overall methane emissions-reduction target
Guinea			
Indonesia			
Japan			√*
Mauritius			
Mexico			
Morocco			√
New Zealand			†
Nigeria			
North Macedonia			
Norway			√ ‡
Oman			
Palestine			
Republic of Moldova (the)			√
Seychelles			
Solomon Islands			
Togo			
United Arab Emirates (the)			
Uruguay			
United States of America (the)			
Viet Nam			√
Zimbabwe			

* Japan's NDC 3.0 does not directly specify an overall methane emissions reduction target, however, indicates supplementary documentation that includes targets and estimates by greenhouse gas including for methane.

† New Zealand's target is for biogenic methane only.

‡ Norway's NDC 3.0 does not directly specify an overall emissions reduction, however notes that it maintains the target(s) included in its NDC 2.0.

3.2.4 Implementation pathways and monitoring and evaluation: progress in the Global Stocktake

Implementation pathways translate goals into concrete steps for real-world action. These steps include technical and human capacity building, financing, resource mobilization, infrastructure development, technology transfer, communication, regulation and enforcement. The first Global Stocktake took place in 2023 to assess progress towards the goals of the Paris Agreement. It highlights a substantial gap between targets, identified policies and actual implementation. This applies to methane mitigation as well as other greenhouse gases.

Some of the key findings of the Global Stocktake relevant for methane mitigation across all sectors are:

i) the private sector and other non-state actors are essential for NDC ambitions;
ii) tracking progress of non-state actors is essential;
iii) international support is needed to scale up implementation;
iv) many mitigation measures are cost-effective, including those that target methane emissions reductions but barriers, such as weak governance, limited finance and technology, and slow behavioural change, hinder uptake; and
v) multiple benefits can accelerate implementation. Highlighting socioeconomic, health, and energy-security benefits, especially within affected communities, can drive faster methane action.

Regarding monitoring, reporting and verification (MRV), methane is a greenhouse gas, and progress is usually tracked in climate MRV frameworks. Methane must be monitored on two levels: first, priorities such as reduction targets, and second, progress toward these overall goals (i.e. actual reductions). This tracking is done through national GHG inventories. As outlined in Section 3.2.2, the vast majority of countries quantify methane emissions in their inventories. Improved quantification will strengthen tracking of mitigation progress during the rest of the GMP period.

3.2.5 Conclusion

The CCAC M-RAP building blocks provide a framework for tracking progress across several areas of national methane planning. Since the GMP was established, trends have been positive. More countries are tracking methane emissions using detailed, robust methods; the number of countries setting targets on methane has increased; and the number of measures identified to achieve climate change targets continues to grow with each round of NDC submissions.

In addition, in some countries progress has come from the development of bespoke methane mitigation roadmaps. As part of their commitment to the GMP, countries submitted MAPs or roadmaps to the CCAC, outlining existing policies and future activities to reduce methane by 2030 and beyond. Currently, more than 20 countries have submitted such plans or roadmaps. These typically bring together information on national methane planning, summarising emission sources, quantifying methane-mitigation potential, establishing targets, and outlining key action.

Despite the progress, achieving the GMP by 2030 will require substantially more action to cut methane emissions. For countries missing key elements of methane plans, the CCAC is supporting mitigation planning through the M-RAP. To date, 90 countries have engaged in the programme to enhance methane inclusion in NDCs and 35 countries in NDC implementation.

Box 3.1: The Climate and Clean Air Coalition support for national planning on methane

The CCAC supports countries on national planning for methane abatement. This includes enhanced inclusion of methane in NDCs, the development of methane roadmaps, the design of policies to reduce methane emissions through technical expert assistance service. As of June 2025, the CCAC has been supporting over 30 countries on enhancing inclusion of methane in their NDC and their implementation as well as 33 countries on the development of their National Methane Roadmap. More than 90 countries engaged in the CCAC M-RAP which additionally supports NDC enhancement for methane through awareness raising and capacity building. In 2024, the CCAC published a Guidance on Including Methane in NDCs that provides practical and strategic recommendations for experts and teams involved in preparing NDC 3.0 on how to set goals and identify specific measures suitable to the national context.

Box 3.2: Potential to control methane under the Gothenburg Protocol of the Convention on Long-Range Transboundary Air Pollution

Methane is a key precursor of tropospheric ozone, a super pollutant that has harmful effects on air quality, human health, vegetation including crops and climate. Levels of tropospheric ozone and emissions of non-methane precursors – nitrogen oxides (NO_x), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs) – are controlled through regional, national and sub-national air-quality policies and legal mechanisms. While some frameworks acknowledge methane's role in ozone formation, they do not set binding methane emissions limits.

One of the most successful regional air-quality agreements is the Convention on Long-Range Transboundary Air Pollution (CLRTAP), and its Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-Level Ozone. Under the Protocol, ratifying Parties[11] agree to national emissions reduction commitments for nitrous oxides and non-methane volatile organic compounds.

Despite the Protocol's success in reducing peak ground-level ozone, background ozone[12] concentrations increased from 2000 to 2018, largely due to rising global methane emissions (UNECE, 2021). Global methane emissions have the potential to offset projected reductions in nitrous oxides and non-methane volatile organic compounds (UNECE, 2021) and could increase ozone-related mortality and crop losses within the UNECE region (UNECE, 2022).

The Gothenburg Protocol is currently under revision; Parties are considering whether and how methane could be integrated. At a meeting of CLRTAP's Working Group on Strategies and Review in May 2025, delegations recommended that the Executive Body consider options for expressing support for the GMP and to include methane in the revised Protocol (UNECE, 2025).

The inclusion of methane in the Protocol would mark a significant development in the global effort to reduce methane emissions. It would be the first formal integration of methane into a regional air-quality agreement and could establish the Protocol as the first legally binding international instrument regulating methane. Regardless of the form methane inclusion takes in the Gothenburg Protocol, its consideration alone sets a precedent for other regional agreements, and is a recognition of the need for coordinated, integrated action to mitigate air pollution and climate change.

11 North America, Europe, Caucasia and Central Asia. The full list of Parties to the Protocol can be found at: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-1-k&chapter=27&clang=_en

12 Tropospheric ozone concentrations that remain unaffected by emissions of precursors in the region of study.

3.3 The fossil-fuel sector

Key messages

- The fossil-fuel sector is the second largest source of anthropogenic methane emissions, responsible for approximately one third of the global total. Under current legislation emissions from the sector are expected to rise by 8 per cent in 2050 compared to 2020.

- This sector presents the single greatest potential for rapid, cost-effective methane abatement. Full implementation of the MFTR scenario, aligned with the GMP target, could reduce emissions by 78 per cent in 2030 compared to 2030 projected emissions under current legislation. These reductions could be achieved through readily available technologies and practices, often at low cost. Varying cost estimates for energy sector measures represent just 2–4 per cent of the sector's 2023 income, although significant financial and structural barriers remain in certain regions.

- Decarbonization of the energy system will lead to a reduction in methane emissions, but will not reduce methane fast enough without additional, immediate action to abate those from fossil-fuel sector. Without a dual strategy of reducing methane and deep decarbonization it will not be possible to meet the Paris Agreement objective.

- Since the launch of the GMP, methane abatement policies in the oil and gas sector have become more innovative and widespread. The rate of policy development and country participation, however, still fall short of what is needed to achieve the 2030 targets. Implementation and enforcement must also be strengthened.

- The coal sector, by contrast, has not experienced the same level of policy growth. There is an urgent need for innovative approaches to overcome barriers, with particular attention to no-regrets policies such as pre-mining degasification, abandoned-mine methane capture and mine-closure planning.

- Barriers still exist throughout the system, blocking progress – such as fragmented regulatory regimes, limited access to finance in certain regions and countries, and uneven data transparency.

- The number of voluntary industry initiatives has also grown significantly. These initiatives help translate high-level climate commitments into concrete methane-management practices. In contexts in which methane policy is still developing or enforcement capacity is limited, such voluntary measures offer an important pathway to near-term mitigation.

- The recent adoption of novel approaches, such as the European Union import standard, offers a potential to use the market to mitigate methane in oil and gas sector more rapidly at the global scale.

- The sector offers unparalleled potential for rapid, cost-effective abatement that must be maximized to its full potential to enable the world to meet its near-term climate targets.

3.3.1 Introduction

The fossil-fuel sector, covering oil and gas operations, as well as coal mining, including abandoned facilities, is the second largest contributor to anthropogenic methane, accounting for roughly one-third of global methane emissions[13]. The sector offers unparalleled potential for rapid, cost-effective abatement that should be maximized to enable the world to meet its near-term climate and methane-related targets, such as the GMP. While the agricultural and waste sectors are critical to longer-term methane mitigation, the fossil-fuel sector offers the most significant, achievable near-term reductions to reduce the current rate of warming (CCAC 2025a).

Emissions from the sector could be reduced by 78 per cent by 2030 compared to projected emissions in the same year under current legislation (or by 72 per cent under 2020 levels) using existing technologies and practices under full implementation of the MFTR scenario[14], aligned with the GMP target. Four groups of measures account for 85 per cent of the total mitigation potential –oxidation of ventilation air methane (VAM) and pre-mining degasification in the coal sector, as well as regular LDAR and addressing venting and flaring[15] for the oil and gas industry. These are often achievable at low cost with significant potential revenues for operators from captured gas if it can be monetized (IEA 2025).

Since the launch of the GMP, methane abatement policies in the oil and gas sector have become more innovative and widespread but they remain insufficient to achieve the 2030 targets. Expanding the adoption of new policies as well as strengthening enforcement of existing ones remains key in the next years. The coal sector, on the other hand, has not experienced the same level of policy growth. There is an urgent need for innovative approaches to overcome barriers, with particular attention to no-regrets policies such as pre-mining degasification, abandoned-mine methane capture, and mine-closure planning.

Despite the increased action on methane emissions in recent years, in particular from the oil and gas sector, barriers remain such as inconsistent enforcement, limited access to finance in emerging markets, uneven data transparency, and insufficient pricing of methane externalities. The rate of policy development and country participation still falls short of what is needed to achieve the 2030 targets. As of June 2025, 35 countries include explicit methane targets or measures for this sector in their current NDCs, including seven of the top 10 emitters, yet few translate those targets into enforceable rules.

This section reviews the status of progress on methane policies in the fossil-fuel sector (3.3.2) and then discusses barriers and innovative ways to overcome these (3.3.3). Finally, it lists a number of priority areas for bridging the gap on methane policies in the sector (3.3.4).

13 GAINS model 2030 estimates

14 GAINS model 2025 estimates

15 The GAINS model considers significantly increased recovery rates of associated petroleum gas and improved management of planned and accidental flare shut-downs through monitoring and swift response. Other mitigation measures with significant potential exist, such as component replacement and equipment upgrades, such as the replacement of compressor seals, the replacement with instrument air systems and electric motors/pumps, vapour recovery units for storage tanks, capture of blowdown gas, etc.

3.3.2 Global outlook of policies in the fossil-fuel sector

3.3.2.1 Oil and gas subsector

When the GMP was launched in late 2021, only a few jurisdictions—Canada, Colombia, Mexico, Nigeria, Norway, and the United States of America had enforceable methane rules. Over the past four years, momentum has spread to every producing region: Argentina, Brazil, China, the European Union, Ghana, Japan and Kazakhstan have all adopted, drafted or are in the process of developing dedicated plans and requirements. Several voluntary schemes have flourished as well – membership of OGMP 2.0 has more than doubled and now covers approximately 42 per cent of world output, while the Oil and Gas Decarbonization Charter (OGDC) unites companies responsible for approximately 40 per cent of the global oil and gas supply.

In the past four years momentum has reached every producing region. The European Union Methane Regulation introduced the world's first import standard, phasing in measurement, reporting and performance-based obligations between 2027 and 2030; the move is already prompting exporters to improve their practices. Nigeria became the first African producer with full scope LDAR and equipment standards, deliberately staged to build local service capacity. Canada published draft Oil and Gas Sector Greenhouse Gas Emissions Cap Regulations in November 2024, signalling a national cap and trade system that will reward companies that drive methane intensity below the sector cap[16]. In 2024, Brazil's National Energy Policy Council (CNPE) adopted guidelines that call for zero routine flaring and explicit measures to curb methane leaks across upstream operations[17]. In Central Asia, Kazakhstan is drafting rules to ban non-emergency venting, mandate LDAR and build a national MRV framework before 2030[18].

There are multiple additional forces that drive methane action within the fossil fuel sector today. Record high revenues from fossil fuels and a tight global gas market since 2022 have sharpened the business case for mitigation; the GAINS model shows that capturing methane could free up about 150 billion m^3 of saleable gas in 2030, bolstering energy security for both exporters and importers. Investor and customer scrutiny, amplified by high resolution satellite data, has turned large, unmitigated emissions into a potential reputational and capital access risk. At the same time, emerging economies seek technology transfer and concessional finance to bridge capacity gaps.

As discussed in Chapter 2 and the International Energy Agency (IEA) analysis (IEA 2023), it is important to note that the decarbonization of the energy system will lead to a reduction in methane emissions but will not reduce them fast enough without additional, immediate action on fossil-fuel production. Without a dual strategy of reducing methane and deep decarbonization it will not be possible to meet the Paris Agreement objective.

16 https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/oil-gas-emissions-cap.html

17 https://www.gov.br/planalto/en/latest-news/2024/08/president-launches-national-energy-transition-policy-expected-to-bring-brl-2-trillion-in-investment

18 https://www.ccacoalition.org/news/us-kazakhstan-joint-statement-accelerating-methane-mitigation-achieve-global-methane-pledge

Box 3.2: Oil and Gas Methane Partnership 2.0

The OGMP 2.0 is a voluntary industry measurement-based framework that helps oil and gas companies to replace generic emission factors with direct data, reconcile source- and site-level inventories, and report methane emissions across both operated and non-operated assets. Its rapid uptake by more than 150 companies has created a peer network that shares methods and accelerates learning. The detailed reporting aligns closely with emerging rules, most notably the new European Union Methane Regulation, so participation can smooth compliance and build confidence among investors, buyers, and regulators. While a number of gaps still exist in company coverage, the OGMP is making great efforts to improve this and bring in underrepresented regions, non-operated assets and joint ventures. Since the launch of the GMP, the OGMP 2.0 has more than doubled its membership – a reflection of the effect of the Pledge, regulations such as the European Union Methane Regulation, investor pressure and member-company pressure on joint ventures.

Full rollout of the European Union import standard could help increase the regulation of emissions considerably, as well as potentially augmenting importer standards in, for example, Japan and the Republic of Korea. Global scale-up of action across all actors in the sector, however, is urgently required to maximize the full abatement potential the oil and gas sector has to offer, which would bring the world significantly closer to meeting its near-term climate and methane-related targets.

3.3.2.2 Coal subsector

The IEA's Global Energy Review 2025 reported that global coal demand had risen by 1.4 per cent in 2024 and projects that it will peak by 2027. Coal demand is falling in advanced economies, but it remains high in Asia. While renewables will reduce demand for coal in the medium term, reducing methane emissions from coal mining using proven technologies is a rapid, near-term opportunity. Yet many coal-mine methane projects have stalled since the end of the Clean Development Mechanism (CDM).

Methane policy development and mitigation projects in the coal subsector lag far behind the oil and gas subsector due to several key factors including technical difficulty and cost. The coal industry also lacks coordinated, industry-led global initiatives to tackle methane emissions, leaving a policy vacuum that slows innovation and standard-setting.

Despite this lack of progress, several jurisdictions, including major coal producers and users such as China and Australia, have recently attempted to regulate methane emissions in the coal subsector either directly or through broader climate policies. The most comprehensive approach is that of the European Union which has regulated thermal coal methane and closed mines. Coal regulations, as the European Union regulations for oil and gas, start with improvements in data and monitoring then move to restrictions on flaring and venting.

Australia and California have both included coal methane as part of larger climate policies. Australia's Safeguard Mechanism will impact 59 of the largest mines and require emissions either to slowly decrease between now and 2030 or be offset with carbon credits. California has established methodologies to allow coal mine methane projects to be used as part of the California cap-and-trade programme.

Germany established the first Electricity Feed-In Act in 1991 to help drive renewable energy projects. The regulation was later revised to include abandoned-mine methane (AMM). Since 2002, project developers have developed AMM projects at several of the gassier coal-mine sites and more recent revisions have extended programme to include coal-mine methane (CMM)[19].

Box 3.3: Industry initiatives in the coal subsector

Even though there are no industry-led pledges in the subsector, industry plays a critical role in advancing CMM policy initiatives. This is especially true in the United States of America, where both compliance and voluntary markets are active. Private sector entities, for example, advocate for CMM incentives such as tax credits and renewable energy credits at the state level.

At the international level, private industry has promoted internationally accepted best practice and policies for CMM mitigation projects and policies through both the Global Methane Initiative and the United Nations Economic Commission for Europe's (UNECE) Group of Experts on Coal Mine Methane and Just Transition, both of which have been active for more than two decades. The industry is also engaged in UNEP IMEO's Steel Methane Programme, a new initiative aimed at tracking and mitigating methane emissions from metallurgical coal used in steel production (UNEP 2024).

Future policy and regulatory development for CMM mitigation should incorporate a combination of prescriptive, incentive and performance-based policy approaches. According to the IEA's Global Methane Tracker 2024, such a hybrid framework ensures deployment of proven technologies and incentivizes continuous improvement and innovation. Mandating the use of methane-drainage systems or regenerative thermal oxidizers at high-emitting mines, for instance, coupled with emissions-intensity targets or market-based mechanisms such as carbon pricing, encourages compliance and cost-effective solutions.

3.3.3 Barriers and solutions

Despite recent policy momentum, the fossil-fuel sector continues to face deep-rooted barriers that limit progress on methane mitigation. While technical solutions are readily available and cost effective, policy frameworks frequently fall short due to limited technical capacity, lack of data transparency, economic and financial constraints, and unclear ownership rights. This section describes these barriers and solutions to overcome them, as well as country case studies.

3.3.3.1 Technical capacity

Limited awareness, technical knowledge and institutional capacity continue to hinder the adoption of methane mitigation measures in the fossil-fuel sector (IEA 2021). Knowledge sharing between the public sector, civil society and the private sector is key to achieving deep methane reductions. Capacity programmes should include gender balanced training cohorts, outreach to women owned service small and medium-sized enterprises (SMEs) and workforce policies that enable women to access skilled jobs created by methane abatement. The CCAC plays a key role in supporting regulators through technical assistance and capacity building to overcome this awareness and knowledge gap.

19 https://www.iea.org/policies/12392-germanys-renewables-energy-act

Box 3.4: The Climate and Clean Air Coalition support for methane abatement in the fossil fuel sector

The CCAC is an active advocate for governments to prioritise methane and black carbon reductions from the fossil fuel sector. Through its Fossil Fuel Hub and project funding the CCAC supports the development and enforcement of regulatory approaches, training, the development of monitoring and reporting techniques, and knowledge and technology transfers.

As of June 2025, the CCAC is supporting nine projects with a combined investment of US$1.8 million. These include projects in Bosnia and Herzegovina, Colombia, Côte d'Ivoire, Gabon, Ghana, Iraq, Kazakhstan and Nigeria.

In 2024, the CCAC also launched the Fossil Fuel Regulatory Programme a streamlined effort to accelerate policy and regulatory support for fossil fuel methane reductions in up to 20 developing countries by 2027. The programme builds on a history of success in countries such as Colombia, Nigeria, and Iraq, with 3 countries already receiving support in a pilot phase (CCAC 2025b).

In Mexico, capacity building efforts were key to the finalization and implementation of the country's methane regulation in 2018. As part of this process, the Agencia de Seguridad, Energia y Ambiente (ASEA) of Mexico, in collaboration with CCAC, the Clean Air Task Force (CATF), and the Center for Clean Air Policy (CCAP), successfully launched a capacity building programme covering data management, LDAR, quantification best practice and third-party verification (CCAC 2022).

In 2022, Nigeria became the first country in Africa to regulate methane emissions from the oil and gas subsector. The country's regulations were built from best practice that other jurisdictions had incorporated in their regulations, such as frequent LDAR and specific equipment standards. They were based on a staged approach to build capacity in the country, recognizing that some of the knowledge, technologies, measurement, and mitigation service providers did not exist yet in the country. Only one LDAR survey, for example, was required in the first year, increasing to four surveys annually within five years.

3.3.3.2 Data transparency

Methane emissions data from the fossil-fuel sector have improved with advances in satellites and other detection and measurement technologies but remain scarce and uncertain (Binietoglou 2023). In the coal subsector, for example, many countries do not collect detailed gas-content and methane-flow data with regularly, or these data are not usually made publicly available, as they are considered proprietary information. Transparency is further hindered by fears of regulatory consequences, i.e., admitting to emissions may open companies to potential violations of existing policies or possibly to issues concerning royalty payments. Additionally, measurement protocols vary widely, complicating efforts on emissions data aggregation.

Developing measurement-based inventories and implementing robust MRV schemes will increase confidence in estimates of methane emissions and provide insights about main emissions sources and their typical sizes. Regulators do not need to wait for perfect data to act, and regulations can include flexibility for companies to modify mitigation plans if their company-specific inventories or measurements differ significantly from the national inventory based on generic emission factors. The European Union's rules on methane measurement and reporting, for example, builds on OGMP 2.0 to help identify the location and volume of methane emitted without relying on direct measurements (European Union Commission 2024). Another example is the state of Colorado, which focused first on establishing prescriptive work-practice standards to address emissions from equipment venting and leaks in 2014. Then in 2023, Colorado adopted its Intensity Verification Rule, which requires operators within the state to report methane intensity across their assets accurately.

3.3.3.4 *Economic and financial barriers*

Economic and financial constraints are major impediments to methane mitigation. The high upfront capital costs that are typical for large infrastructure projects can deter investment, particularly among small or financially constrained companies (CATF 2013). Even when financing for capital costs is available or capital costs are not high, ongoing operating costs can be difficult to justify for the operators, especially when competing with potential investment in additional oil and gas production. National oil companies often lack incentives to invest in mitigation solutions, as gains from improved operational efficiency and reductions in wasted gas are typically returned to the government. Coal-mine methane projects face additional hurdles, including variable methane flow rates, unfamiliarity among financiers, small project scale, and limited market outlets and possibilities for onsite use, all of which increase perceived risk and reduce investor interest (CATF 2013). Government-imposed price controls on natural gas or coal can artificially suppress market incentives for reducing emissions, weakening the economic case for action (CATF 2013).

International initiatives, such as the World Bank's Global Flaring and Methane Reduction Partnership, provide grant funding and finance mobilization to deploy flaring and oil and gas methane mitigation solutions. In addition, regulatory standards can help overcome economic barriers by requiring companies to budget for and invest in mitigation even when traditional returns on investment may fall short. Petróleos Mexicanos (PEMEX) the Mexican state-owned petroleum corporation, for example, included methane mitigation in its 2022 budget following the implementation Mexico's methane regulation[20]. The United States Environmental Protection Agency (USEPA) adopted regulations requiring the use of zero-bleed pneumatic controllers, with implementation required for existing facilities within five years of the rule's publication (Code of Federal Regulations 2025). This regulation pushed many companies to convert their entire fleets of natural gas-driven controllers to zero-bleed ones (Bart Cahir 2021; Code of Federal Regulations 2025).

3.3.3.5 *Structural and ownership barriers*

Corporate and contractual structures between different partners in oil and gas fields or coal mines can hinder methane management by creating split incentives, coordination challenges and legal barriers (USEPA 2019). In the oil and gas sector, production-sharing contracts or joint ventures, through which multiple companies hold financial stakes in both the assets that they do and do not operate, can obscure the responsibility for methane mitigation. Although companies profit from non-operated assets, they frequently exclude them from environmental reporting and sustainability commitments due to a perceived or actual lack of control over methane mitigation action at them (Feldman *et al.* 2025). In the coal sector, CMM projects are often further constrained by regulatory uncertainty, unclear ownership rights to use or destroy CMM released, and complex land-use arrangements and authorizations.

Regulations should account for unique structural/ownership issues in a country. All major operators should be part of policy development in advance of finalization through public consultation periods or industry workshops. In Mexico, for example, the Guidelines for the Prevention and Integral Control of Methane Emissions from the Hydrocarbon Sector was the outcome of extensive stakeholder collaboration and public consultation (GMI n.d.).

20 PEMEX allocated investment in methane mitigation, in compliance with the guidelines for the prevention and comprehensive control of methane emissions from the hydrocarbon sector, issued by the ASEA. This is reflected in their 2022 budget (see 2022 Annual Program (1st Quarter Update): https://www.pemex.com/procura/procedimientos-de-contratacion/Paginas/programas.aspxhttps://www.pemex.com/procura/procedimientos-de-contratacion/Paginas/programas.aspxhttps://www.pemex.com/procura/procedimientos-de-contratacion/Paginas/programas.aspx.)

3.3.4 Conclusion

Bridging the methane policy gap in the fossil fuel sector calls for strong implementation of existing policies, continuous capacity building, increased ambition from additional producing countries, a step change in the coal sector, ramped up technical support and innovative financial mechanisms to facilitate mitigation in developing countries. Key areas for attention include the following.

Enhancing MRV systems across all fossil fuel operations. Robust MRV is critical for understanding and addressing methane emissions. Many countries rely on high-level estimates or self-reported data without clear quantification guidelines, often underestimating emissions. Expanding the use of direct measurement protocols and corroborated satellite data could improve the accuracy and transparency of inventories.

Expanding LDAR in oil and gas. Leak detection and repair programmes offer a practical and cost-effective approach to cutting methane emissions. They not only help reduce leaks but also enhance data quality for inventories and enhance workplace safety and asset integrity.

Advancing methane mitigation in active underground and surface coal mines. Capturing and utilizing, or destroying methane offer clear abatement pathways, whether from underground drainage systems and ventilation shafts in active, underground mines or pre-mine drainage in surface mines. Setting clear utilization targets could complement broader mitigation efforts.

Ensuring proper sealing techniques during mine and well closure. Methane emissions from abandoned mines and wells can continue for decades after mining activities cease (Nazar 2020). Mines and wells must be properly closed and monitored, and, for coal mines, drainage systems put in place to capture and destroy or utilize methane.

Strengthening enforcement mechanisms. Enforcement plays a pivotal role in ensuring compliance with methane regulations. Establishing clear accountability structures, penalties for non-compliance and independent oversight can reinforce commitments.

Facilitating access to finance and capacity building. Financial and technical capacity constraints remain a barrier, particularly for smaller operators and emerging markets. Providing financial-support mechanisms for projects that are truly additional and technical assistance to less advanced players could help overcome these challenges.

Harnessing import standards as market leverage. Emerging import standards can serve as a de facto policy driver for exporters with minimal methane regulations. By conditioning market access on methane performance, major buyers create a clear incentive for producing countries to adopt stronger mitigation practices.

Leveraging international and bilateral frameworks for capacity and alignment. Global, regional and industrial partnerships, such as OGMP 2.0, can fill gaps where national policies are still emerging. Regional initiatives, such as the Japan-Republic of Korea CLEAN coalition for abatement of methane emissions from the liquified natural gas (LNG) supply chain, pair technical guidance, data-sharing and seed financing, helping governments craft and enforce robust methane rules in line with international best practice. Similarly, for coal-mine methane mitigation, the UNECE Group of Experts on Coal Mine Methane and Just Transition supports countries in developing effective MRV and mitigation systems and encourages the adoption of global standards.

By addressing these connected areas, governments can help close the existing policy gaps and support significant reductions in methane emissions from fossil fuel operations.

3.4 The waste sector

Key messages

- The waste sector is a significant source of anthropogenic methane emissions, contributing approximately 20 per cent of the global total anthropogenic methane emissions. Under current practices emissions from the waste sector are expected to rise to 80 Mt of methane per year by 2030.
- The solid waste subsector's immediate methane reduction potential of 8 Mt of methane per year by 2030 is modest. More substantial reductions, of 49 Mt of methane per year are, however, projected by 2050, contingent on near-term investment in landfill upgrades, and the large-scale diversion of organic waste from landfilling.
- Because methane emissions from waste can persist for decades, early action pre-2030 is critical to unlock long-term mitigation benefits.
- For the wastewater subsector, estimates suggest that the maximum annual mitigation potential is 5 Mt of methane per year by 2030 and 18 Mt of methane per year by 2050. Key measures to avoid methane releases from wastewater include preventing the formation of anaerobic conditions when possible, capturing methane in facilities using anaerobic processes, and minimizing leaks from the systems.
- Implementation of such technical measures should align with long-term decarbonization and circular-economy objectives, prioritizing upstream measures, such as mechanisms and incentives to prevent food loss and waste, together with mandatory source separation. Consistent treatment infrastructure for organic wastes and improved landfill engineering to ensure the sector would also contribute to meeting global methane abatement goals.
- Implementation of targeted methane mitigation measures would deliver important business and economic co-benefits, such as preventing pollution, improvements in public health, local economic development, social inclusion, renewable energy production and sustainable agriculture. Methane mitigation from waste is not a siloed climate action, but rather a catalytic investment in public wellbeing.
- Mitigating methane emissions from the waste subsector presents several cost-effective opportunities. Simple interventions, such as preventing food loss and waste, promoting household- and community-level composting, and enforcing basic operational standards at disposal sites, can yield immediate results with minimal investment.
- Over 150 countries include or acknowledge the sector in their NDC and 59 per cent have defined concrete and actionable measures in at least one subsector, but few have set quantified waste methane targets. To fully harness the climate mitigation potential of the sector, NDCs must explicitly incorporate waste methane mitigation targets, aligning them with long term decarbonization and circular-economy objectives.

- Economic instruments play a crucial role in promoting methane mitigation from waste, either by enabling adequate waste treatment infrastructures or rewarding low-emissions solutions.

- Effective mitigation of methane emissions from the waste sector demands systemic change supported by a comprehensive policy framework that combines regulatory measures, economic instruments and investment in infrastructure.

3.4.1 Introduction

The waste sector contributes approximately 20 per cent of global anthropogenic methane emissions, primarily from the anaerobic decomposition of organic matter in final disposal sites and from wastewater in lagoons, septic systems and latrines (IPCC 2021; UNEP 2022). Significant rises in emissions are expected for the sector by 2030 and 2050 driven by population and economic growth, as well as improvements in waste and wastewater collection and adequate disposal rates. These developments bring important health and environmental benefits but tend to increase methane emissions unless dedicated measures targeted at methane are introduced simultaneously.

Effective mitigation strategies either prevent its formation by reducing and diverting organic waste from final disposal sites through source segregation, composting, anaerobic digestion and thermal pre-treatment, or capture and use of landfill gas (European Commission 2018; USEPA 2023). Although landfill-gas capture and other technologies are well established, collection efficiencies are often influenced by landfill design, operational practices and aging infrastructure (Scheutz *et al.* 2009). Methane can also be emitted from mismanaged waste and wastewater treatment systems, particularly when aerobic processes shift to anaerobic conditions. While many countries have integrated waste methane reductions into their NDCs, widespread adoption of best practice remains uneven (UNEP 2022).

According to the GAINS model estimates presented in Chapter 2, the solid waste subsector has a maximum technical potential for reducing methane emissions of 8 Mt methane per year by 2030, relative to the CLE scenario. This potential is, however, constrained by legacy disposal practices, particularly the historic accumulation of organic waste in poorly managed landfills. An additional technically feasible reduction potential of 49 Mt of methane per year is projected for 2050, contingent on near-term investment in reducing food waste, the implementation of separate collection of (organic) waste, the valorisation of organic waste, and capturing and valorising methane emissions from existing and new landfills.

Since methane emissions from legacy waste persists for decades, early action before 2030 is essential to unlock these long-term mitigation benefits. Policy frameworks must therefore prioritize landfill gas capture or other strategies for limiting methane released from waste in existing disposal sites. At the same time, upstream interventions, such as mechanisms and incentives to prevent food loss and waste together with mandatory source separation, should be advanced. This action should be complemented by expanding infrastructure to valorise organic materials and improved landfill engineering, ensuring the waste subsector contributes meaningfully to global methane abatement goals (UNEP 2022).

For the wastewater subsector, estimates from Chapter 2 suggest that the maximum annual mitigation potential is 5 Mt of methane per year by 2030 and 18 Mt by 2050, when the remaining methane emissions are lower due to both prior abatement and structural shifts (e.g., better sewage systems, declining organic load in untreated wastewater, or replacement by less methane-intensive treatment technologies). Key measures to avoid methane releases in the subsector include preventing the formation of anaerobic conditions when possible, capturing methane in facilities using anaerobic processes and minimizing leaks from the systems. Septic tanks can be retrofitted or replaced with digesters that recover biogas.

Full deployment of methane targeted measures in the sector could reduce annual emissions by 16 per cent (13 Mt) by 2030 compared to projected levels this same year under current legislation. This potential could reach 66 Mt per year in 2050 provided that immediate investment and infrastructure development are initiated in the short term.

This section outlines the global outlook of policies in the waste sector, including recent trends in the policy landscape and commitments to action (3.4.2), barriers and solutions for the sector (3.4.3), and recommendations for moving forward. (3.4.4).

3.4.2 Global outlook of policies in the waste sector

Since the launch of the GMP at COP26, there has been growing global momentum to tackle methane emissions from waste. Over 150 countries include or acknowledge the sector in their NDCs, and 59 per cent (115) have defined concrete and actionable measures in at least one subsector. Many have emphasized upstream action such as food waste prevention, separate collection of organic waste and improved treatment infrastructure, reflecting a shift towards circularity and resource recovery.

Governments increasingly recognize the importance of appropriate waste collection, segregation and treatment hierarchies. Sweden, for example, has implemented investment aid policies since 2010 to support the market introduction of new biogas technologies, allocating significant funds to biogas projects to enhance production and profitability (IEA 2020). In India, the Sustainable Alternative Towards Affordable Transportation (SATAT) initiative aims to establish 5,000 compressed biogas plants by 2025, promoting the use of organic waste for energy production (World Biogas Association 2024a). Similarly, China's policies have supported the installation of household-scale digesters in rural areas to increase access to modern energy and clean cooking solutions (IEA 2020). In Brazil, the 2024 Fuel of the Future Law introduced a mandatory requirement for the gradual inclusion of biomethane in the natural-gas pipeline, starting at 1 per cent and rising to 10 per cent (World Biogas Association 2024b). These examples underline the global trend towards adopting suitable technologies as a means of reducing methane emissions and harnessing renewable energy.

The recognition of the waste sector as a significant source of methane emissions has driven a growing number of countries, sub-national governments and organizations to develop initiatives aimed at reducing these emissions. Among the most prominent are the GMP and the Lowering Organic Waste (LOW-Methane) Initiative. In addition to these flagship efforts, there are other initiatives designed to strengthen waste-management systems while simultaneously mitigating greenhouse gas emissions Including the Waste to Zero initiative, the Reducing Methane from Organic Waste Declaration (ROW), the Regional Cooperation Programme for Dumpsite Closure and Reduction of Methane Emissions from Organic Waste in Latin America and the Caribbean, the Inter-American Development Bank's (IADB) Too Good to Waste initiative, or the World Bank's Global Methane Reduction Platform for Development (CH4D).

Furthermore, there are several other regional and country initiatives aimed at reducing methane from the waste sector, encompassing different approaches and strategies to tackle this super pollutant. Policies such as France's food waste legislation reflect a shift toward prevention, recovery and circularity. Austria has implemented a comprehensive mandatory source-separation policy for biowaste, in place since 1995. The separated waste is directed to composting or anaerobic digestion facilities, enabling high-quality resource recovery. Robust monitoring, public engagement and bans on untreated biowaste in landfills have supported Austria's high capture rates (Ayandele *et al.* 2024). The Renewable Fuel Standard (RFS) in the United States of America incentivizes, through a market-driven approach, the capture and conversion of waste methane into renewable natural gas, which has a monetary value and can be sold to obligated parties, fuel refiners and importers, to meet their RFS quotas. The Food Policy of the Municipality of Milan recognizes anaerobic digestion as a key technology for the conversion of organic waste, food scraps and agricultural residues, into biogas and digestate, closing the loop in the food system.

Measures outlined in the NDCs for achieving methane mitigation targets in the waste subsector focus on improving waste management systems through circular-economy practices. These include strategies aimed at reducing food waste, source segregation, separate waste collection, the adoption of composting and waste-valorisation technologies such as anaerobic digestion, and the diversion of organic waste from landfills. Some also consider the closure and upgrade of existing disposal sites through the installation of gas-recovery systems for flaring or energy use. Furthermore, measures in the wastewater subsector include capturing methane from anaerobic treatment for energy purposes.

Examples showcasing good practice in defining measures to reduce methane emissions in the waste sector include the following.

- Cameroon: strengthening waste-management policies – by 2035, all major cities should have landfills with at least 70 per cent methane capture (UNFCCC 2021).

- Chile: Chile's 2021 National Organic Waste Strategy laid the groundwork for a special law currently under parliamentary review, targeting 66 per cent diversion of organic waste from landfills by 2040 and establishing a formal financing model for municipalities.

- Colombia: waste methane reduction fully integrated into national climate strategies.

- Mexico: targets for emission reductions for the waste sector by 28 per cent in 2030 and specifically for reducing landfill methane emissions by 25 per cent by 2030. Action is established in the General Law of Climate Change (LGCC) (Gobierno de México 2024).

- Nepal: by 2025, 380,000 m^3 of wastewater per day will be treated before being discharged, and 60,000 m^3 of faecal sludge will be managed per year. These two activities will reduce emissions of CO_2eq by more than 250,000 tonnes compared to BAU. (Government of Nepal 2020).

- Peru: a black-soldier-flies (BSFs) project aims to develop a plant for the transformation of organic waste from a food market in Lima into high value insect protein and additional saleable byproducts. This is noteworthy because food markets exist in almost every city/village in the Global South from which it is easier to collect waste than from households.

- Venezuela (Bolivarian Republic of): the National Sanitation Plan, which includes 35 landfills, recovery of final disposal sites nationwide and the control, capture and use of methane generated, and the National Plan for the Construction of two Sanitary Landfills for the control and capture of methane generated. The action is national, and it is estimated that if carried out, it will capture 17,134 tonnes of CO_2eq per year.

- Viet Nam: commitments to methane capture from wastewater treatment plants.

- United Arab Emirates (the): set landfill diversion targets, aiming for 50 per cent diversion by 2025 and 80 per cent by 2031 (GMP 2024).

- Uruguay: unconditional and conditional waste sector targets with a strong focus on methane mitigation and food systems. The country has committed to reducing food loss and waste by 50 per cent and implementing organic waste recovery and source-separation systems across all departments by 2035. It also mandates environmental upgrades and methane-reducing technologies for all household-waste disposal sites. Conditional targets include prioritizing food donations for surplus edible food and using remaining waste for animal feed, aligning with public health standards.

Integrating these targets into instruments such as National Waste Management Plans and transposing them into sub-national waste-management plans, alongside the development of clear implementation plans including on the local level, is essential to demonstrate national commitment and ensure alignment with broader NDC commitments.

3.4.3 Barriers and solutions

3.4.3.1 Financial incentives and barriers

Economic instruments play a crucial role in promoting waste methane mitigation, either by enabling adequate waste treatment infrastructure or by rewarding low-emissions solutions. Economic and financial instruments to support and leverage methane mitigation varies from grants, debt loans and equity, through fiscal and de-risking instruments, to revenue-enhancing mechanisms, including gate fees, user fees, pay-as-you-throw schemes, result-based schemes and carbon markets instruments. Adopting, for example, carbon-pricing mechanisms, such as taxes or cap-and-trade systems, has been effective tools for reducing emissions. High carbon pricing has been shown to lead to substantial reductions in methane emissions, making it a potent tool for climate policy (Pérez-Domínguez *et al.* 2021). Several financial barriers, however, hinder the implementation of methane mitigation projects, especially in low-to-middle income countries (Bufoni *et al.* 2016). Landfill gas (LFG) capture and use is particularly economic in medium to large landfills, in which economies of scale can be leveraged. Early LFG recovery using basic technologies can be deployed relatively quickly and at modest cost, making it an effective strategy for methane abatement (Scharff *et al.* 2023). High upfront investment costs for LFG systems and limited access to finance are significant challenges (Markgraf and Kaza 2016). Additionally, the lack of robust financial mechanisms and incentives can deter private sector investment in waste management infrastructure. The lack of effective and sufficient fee-collection systems coupled with undeveloped markets for byproducts and offtake volume for products coming out of waste valorisation infrastructure make waste projects seem high risk and low return.

3.4.3.2 Case studies from around the world

By optimizing anaerobic digestion in wastewater treatment plants, it is possible to enhance biogas production while minimizing methane emissions (Zueva *et al.* 2024; CCAC 2025). Germany has been a leader in implementing anaerobic digestion technologies for organic waste treatment. By integrating these technologies into municipal wastewater management systems, Germany has effectively reduced methane emissions from landfills. The digestate produced is used as a biofertilizer, promoting sustainable agricultural practices. This approach aligns with Germany's commitment under the GMP to lower methane emissions and transition to a circular economy (CATF 2025).

Brazil has several successful landfill gas-to-energy projects. The first CDM project, registered in 2004, planned to reduce emissions of methane from a landfill in the state of Rio de Janeiro by capturing methane to use it for generating electricity, aimed to mitigate about 31,000 tonnes of methane per year. More recently, the Fortaleza Renewable Natural Gas plant, inaugurated in 2018 at the Caucaia West Metropolitan Sanitary Landfill (ASMOC) in the Metropolitan Region of Fortaleza. It operates an advanced renewable natural gas treatment system and is the first plant in the region to inject biomethane into the local gas pipeline network. Another recent project, developed by Orizon, is designed to process up to 200,000 tonnes of waste per year, primarily municipal solid waste (MSW). It is upgrading of a former landfill in Paulínia, São Paulo, into an EcoPark, while focussing on converting waste into valuable biomethane.

By converting organic waste into high-quality protein and nutrient-rich frass[21] within about two weeks, BSF technology offers an environmentally friendly approach that supports organic-waste reduction, and therefore reduced methane emissions, agricultural sustainability and new business opportunities. This technology is versatile and scalable, making it suitable for a range of operations, from smallholder farms to large industrial facilities (CCAC 2025). While most BSF operations to date have been small to medium-sized, recent investments in larger BSF companies show considerable future potential. Entobel, a Singapore-based BSF company, has opened a BSF production facility in Viet Nam, which is described as one of the largest insect production facilities in Asia. In 2022, Entobel raised over US$30 million to build a commercial plant with the capacity to produce 10,000 tonnes of insect meal per year, creating 150 jobs in the region. A BSF factory of similar size was also completed in 2024 in Denmark by Enorm, with an investment of approximately US$50 million (CCAC 2025).

The Surabaya municipality in Indonesia has developed a community-based organic-waste diversion system that was initially supported by bilateral cooperation with Kitakyushu City, Japan, local non-governmental organizations (NGOs) and the private sector. Local NGOs played a crucial role in collecting organic waste from households, with residents being incentivized for their contributions. Over time, the system expanded to include waste banks and community-based composting centres, and further strengthening community engagement and waste-management capacity (CCAC 2025).

21 debris or excrement produced by insects

Composting is key to significantly reducing methane emissions by providing an aerobic alternative to anaerobic decomposition in landfills. From a cost-effectiveness standpoint, composting offers a budget-friendly approach to reducing methane emissions generated by landfills. Since composting can be carried out using simple, low-cost technology, particularly at the municipal scale, it presents a practical option for numerous communities. In Accra, Ghana, the government partnered with the Jospong Group[22] to expand composting capacity through blended finance. The model combines national budget allocations, private investment, grants from DFIs and debt financing. Investment of more than US$23 million has supported scaling, producing more than 240,000 tonnes of compost and creating over 1,000 jobs (CCAC 2025).

In Pakistan, the Lahore Composting Project's blended finance model combines private investment from Saif Group's[23] Lahore Compost Ltd. with donor support from the Energy Sector Management Assistance Program (ESMAP), managed by the World Bank. The private company invested equity and secured long-term debt to build a facility processing MSW into compost. ESMAP and the World Bank provided technical assistance and supported CDM registration, enabling the project to generate carbon credits based on verified methane reductions (CCAC 2025).

In Durban, South Africa, a city-led composting project diverts food waste from markets, reducing methane emissions and landfill costs of around US$93 per tonne. The city conducted a cost-benefit analysis projecting a net benefit of US$565,000 over 10 years, based on measurable outcomes including emissions reduction, job creation and municipal savings. These quantified results enabled reinvestment in the markets' infrastructure and demonstrate how data-driven impact projects can support future results-based finance opportunities (CCAC 2025).

Research by the Champions 12.3 coalition[24] across 17 countries and 700 companies on reducing food loss and waste indicates that there is a strong business case for private businesses to reduce food loss and waste (Flanagan *et al.* 2018). In many cases, the marginal benefits of eliminating losses outweigh the costs for interventions. Ninety-nine per cent of companies included in the analysis earned a positive return on their investments, with a median 14-fold financial return (Hansona and Mitchell 2017).

22 https://jospongroup.com/

23 https://saifgroup.com/

24 https://www.champions123.org/

Box 3.5: The Climate and Clean Air Coalition support for methane abatement in the waste sector

In the waste sector, the CCAC focuses its support toward cities and countries in the areas of planning and solutions mapping.

The CCAC is currently supporting four countries – Argentina, Brazil, Iraq and Senegal – to develop policies and/or regulations following requests for assistance. The targeted outcome for Argentina is the endorsement of policy to enable the use of byproducts of organic-waste valorisation by the end of the project or soon thereafter. At the subnational level in Brazil agencies aim to adopt new waste-management practices based on the Methane Strategy, and at the national level, the federal government is incorporating the Methane Strategy into relevant policies on reducing methane emissions. The Government of Iraq is including short-lived climate pollutant (SLCP) mitigation into its Municipal Solid Waste Management Law. The Government of Senegal is adopting an enhanced regulatory framework for SLCPs in organic waste management. Previously, the CCAC has assisted with the development of sustainable waste-management laws in Brazil (Sao Paulo), Kenya (Nairobi), and Peru.

The Coalition also supports Costa Rica, Peru, Uganda, Nigeria, Panama and Paraguay on the development/implementation of tools, technologies and/or practices to reduce methane from organic waste.

Overall, 30 projects are ongoing in the waste sector, including support to 21 countries and CCAC investment of US$8.5 million.

3.4.4 Conclusion

By taking urgent, sustained integrated action, the waste sector has a significant opportunity to reduce its methane emissions. Early intervention is essential to prevent emissions and avoid long-term lock-ins as methane emissions from landfilled organic waste may persist for decades.

These interventions should align with the necessary sectoral transition from a take-make-dispose linear model to a more circular waste-as-resource management system, encompassing the ultimate ambition of a zero-waste approach, with relevant greenhouse gas- including methane – savings from upstream initiatives such as waste prevention, reuse and recycling practices (Wilson *et al.* 2024). Accelerating action now is vital to maximizing short-term results while securing deeper mitigation outcomes over the coming decades.

In many cases, significant emissions reductions can be achieved at low or even no net cost, particularly when factoring in the economic value of recovered materials, avoided health costs and improved environmental quality. Simple interventions, such as preventing food loss and waste, promoting household- and community-level composting, and enforcing basic operational standards at disposal sites, can yield immediate results with minimal investment. Without clear mandates and consistent enforcement, however, low-cost mitigation options, such as food-waste prevention, BSF farming, composting, anaerobic digestion, bio covers and landfill-gas recovery will remain underused (Scheutz *et al.* 2009).

The waste sector requires an integrated and forward-looking approach that starts by strengthening regulatory frameworks together with better data collection and monitoring systems. Key action includes mandating the separate collection of organic waste and establishing facilities to treat it, enforcing standards for engineered landfills and increasingly diverting untreated biodegradable waste from landfills, essential to curbing methane emissions at source (European Commission 2018; UNEP 2022; UNEP and ISWA 2024). National regulations should also provide the basis for scaling up composting and anaerobic digestion infrastructure, especially in urban and peri-urban settings. Sub-national governments can play a pivotal role in implementation and should be supported with adequate institutional capacity and enforcement tools.

In parallel, to fully harness the climate mitigation potential of the waste sector, countries should explicitly incorporate methane mitigation targets in their NDCs, aligning them with long-term decarbonization goals and circular-economy strategies. By adopting the MTFR pathway, countries can unlock the full mitigation potential offered by the sector beyond 2030 (CCAC 2025).

To operationalize these goals, governments should also prioritize the mobilization of sustainable and scalable financing, enabling policies and expanding economic incentives through fiscal policies, carbon pricing, methane credits, and concessional financing for biogas and organic-waste processing infrastructure (IEA 2020). Long-term strategies should go beyond end-of-pipe waste management and prioritize upstream interventions, that are not only environmentally and climate sound, but also socially, politically and economically attractive, especially for countries facing multiple development challenges. Such interventions demonstrate that mitigation of methane emissions from waste is not a siloed climate action, but rather a catalytic investment in public well-being.

Expanding public-private partnerships (PPPs) is also critical to accelerating innovation, expanding infrastructure, and scaling methane mitigation solutions across the waste sector. By leveraging the expertise, efficiency and investment capacity of the private sector, PPPs can facilitate the deployment of cutting-edge technologies, such as advanced composting systems, modular anaerobic digesters, landfill-gas capture solutions and digital monitoring platforms. To be effective, these partnerships require enabling regulatory environments, clear risk-sharing mechanisms, transparent procurement processes and predictable revenue streams that make waste sector investments bankable. Integrating methane-reduction targets into PPP contracts, concession agreements and tenders for infrastructure can help align private capital with public climate goals, while promoting innovation and accountability throughout the value chain.

Additionally, robust MRV systems are not just a technical necessity, they are a strategic enabler, needed to track progress compared to the baseline; improve emissions estimates, including legacy emissions; and attract finance (UNEP 2022). Robust MRV systems provide a structured framework for monitoring the implementation and effectiveness of methane mitigation measures and are a prerequisite for accessing performance-based climate finance.

Time is a decisive factor. As highlighted in this chapter, methane emissions from the waste sector are released gradually over time, which means that action taken before 2030 is essential to unlock full mitigation benefits by 2040 and 2050. Methane mitigation in the waste sector remains one of the fastest and most cost-effective ways of reducing near-term warming and delaying action will narrow the window of opportunity. Without decisive and immediate action, the sector’s contribution to the GMP and broader climate goals will remain unrealized.

Solutions are available, affordable and already being implemented in many parts of the world, but require strategic investment, political commitment and coordinated action to be scaled up and replicated. Decisions made today could significantly mitigate methane emissions, reduce to effects of pollution, protect public health, create (green) jobs and make meaningful progress towards global climate targets. The opportunity is relevant and urgent, but still entirely within reach.

3.5 The agriculture sector

Key messages

- Agriculture is the largest source of global anthropogenic methane emissions, accounting for almost 42 per cent in 2020, with livestock and rice cultivation as the primary drivers. Without additional mitigation, emissions are expected to rise by 8 per cent by 2030 and 17 per cent by 2050, compared to 2020 levels, mainly due to increases in livestock populations in Africa and Latin America.

- Mitigation ambition in agriculture has increased, but current NDCs and MAPs lack specificity. Only 4 per cent of NDCs include quantified, time-bound agricultural methane reduction targets, and current plans achieve just half of the sector's full cost-effective mitigation potential.

- Low-cost mitigation options exist, including improved rice cultivation and bans on agricultural waste burning, especially in Africa and South-East Asia. Livestock-related options, though costlier, offer significant potential in the Americas and Western Europe.

- Building climate-resilient livestock systems in smallholder and pastoralist settings can deliver multiple benefits – improving productivity while reducing emissions.

- Policy coverage remains limited and uneven, with only 2–18 per cent of GMP participating countries having policies directly targeting key sources such as enteric fermentation, rice cultivation, or manure management.

- Holistic, equity-based policies are needed to avoid unintended consequences, such as shifting emissions to unregulated sources, or increasing food insecurity and rural poverty.

- Financial, institutional, and technical barriers persist, but redirecting a small share of harmful agricultural subsidies and improving MRV systems could unlock progress and link mitigation to development co-benefits.

3.5.1 Introduction

This section provides a brief overview of agricultural methane emission trends and mitigation opportunities, and then examines the global outlook for policies, illustrating their evolution and coverage of key emission sources over time, the stringency of these policies, potential unintended consequences, and their context within global food security. The section then considers barriers and solutions and makes recommendations for the future.

Box 3.6: Integrated Agriculture and Food Systems Assessment

The upcoming UNEP and Food and Agriculture Organization (FAO) Integrated Agriculture and Food Systems Assessment will be the first sector-focused integrated assessment produced by the CCAC. It will explore pathways that address climate change while supporting the development of agriculture and food systems.

The Assessment will identify and evaluate the links, synergies, trade-offs and multiple-benefits of SLCP-focused policies, action and measures in agriculture and food systems. This information will inform a roadmap for implementing relevant mitigation measures, consistent with the GMP target and 1.5°C climate scenarios, to maximize synergies for socio-economic development and food security while minimizing trade-offs.

Set for publication in 2026, the Assessment will explore mitigation options, including on-farm measures, action across broader food systems, and demand-side measures addressing food waste and diet. These will then be evaluated, using new modelling, to quantify the multiple benefits and potential trade-offs from implementing different combinations of measures. The modelling will assess both the short- and medium-term, outlining how emissions can be reduced within NDC and long-term strategy horizons, as well as assessing the long-term transformations needed to sustain reductions through to 2100.

3.5.1.1 Agricultural methane emissions: status, trends and mitigation opportunities

In 2020, agriculture was the largest source of global biogenic methane emissions, responsible for 146 Mt per year or almost 42 per cent of the global total, slightly ahead of the energy sector. Livestock and rice cultivation dominate these emissions, contributing 76 per cent and 21 per cent respectively, while agricultural waste burning accounts for the remaining 3 per cent.

Emissions vary significantly across regions. The G20+ accounts for more than 60 per cent of global agricultural methane emissions, led by India, China, Brazil, the United States of America, and the European Union. Non-G20+ countries, particularly in Africa and South-East Asia, contribute around 45 per cent of their total methane emissions from agriculture.

Without additional mitigation policies beyond those in place as of December 2024, emissions from agriculture are projected to rise by 7.8 per cent by 2030 and 17 per cent by 2050 compared to 2020 levels. Growth will be primarily driven by expanding livestock herds, especially in Africa and Latin America.

Under NDCs and MAPs, agricultural methane emissions are projected to stabilize at 2020 levels by 2030, due to the expansion of livestock herds outweighing reductions from rice cultivation and waste burning.

The GAINS model estimates that fully deploying low-cost mitigation technologies, those costing less than US$1,000 per tonne of methane or US$36 per tonne CO_2eq, could reduce agricultural methane emissions by 15 per cent by 2030 compared to projected emissions for the sector under current legislation in the same year. Despite agriculture's relatively modest role in global methane mitigation potential, around 24 Mt per year, several interventions offer substantial benefits at low or negative costs.

Key opportunities include improved rice cultivation, for example, improved water management and sulphate use, which could reduce emissions by 9.8 Mt per year at negative cost by 2030, and banning the open burning of agricultural waste, which lower emissions by a further 4.7 Mt per year at zero cost, by 2030. Geographically, the highest potentials are in South-East Asia, Africa, and the Americas.

In the livestock sector, cost-effective strategies such as reducing enteric fermentation and improved manure management are available, but implementation is often limited by higher costs and social factors. In low-income regions, co-benefits, such as improved animal health and climate resilience through veterinary care feed storage and gender-inclusive programmes, make mitigation more attractive.

Beyond technical solutions, shifts in food systems, such as adopting healthy diets and halving food waste, would bring additional cuts to global methane emissions which are needed to stay on a pathway consistent with internationally agreed climate goals by 2050. These changes, along with measures including anaerobic digestion and intermittent rice irrigation, could also yield reductions in other greenhouse gases, such as CO_2 and nitrous oxide (N_2O), amplifying climate benefits.

In summary, while agriculture is a major and growing source of methane emissions, multiple cost-effective and socially beneficial mitigation options exist. Urgent and ambitious action is needed to close the gap between current policy ambition and the sector's full mitigation potential.

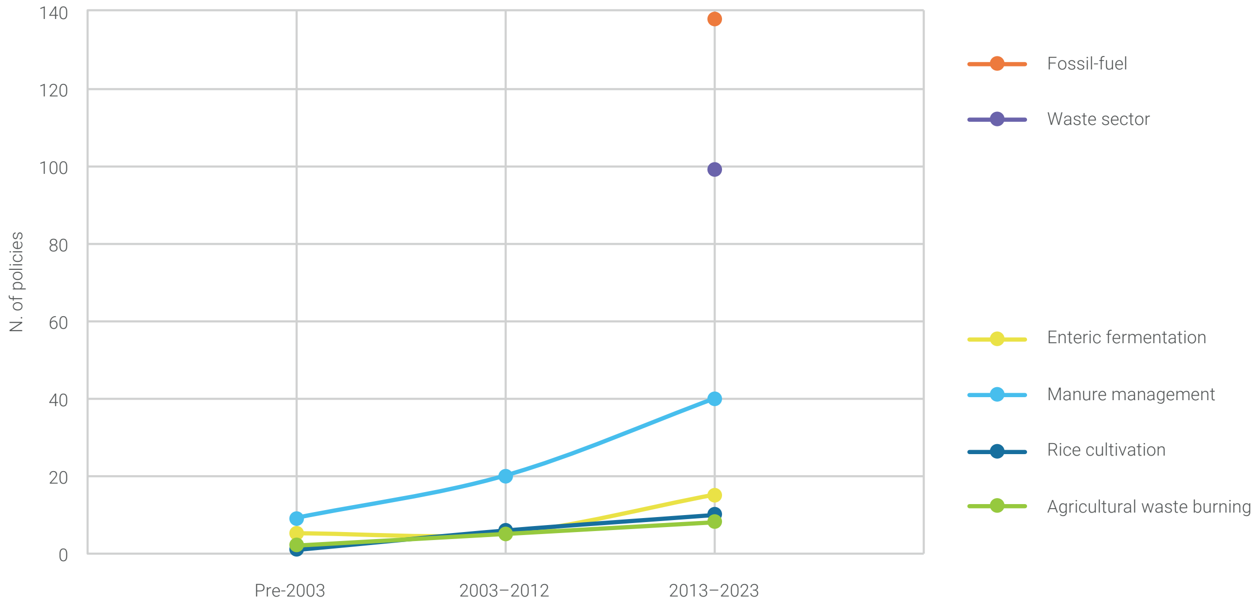
3.5.2 Global trends in national policies since the Global Methane Pledge

3.5.2.1 Evolution of agricultural methane reduction policies

Since the GMP, there has been a rise in the inclusion of agricultural methane reduction in national climate policies. As of June 2025, 85 countries, compared to 45 countries pre-2020, have identified policies and measures that address agricultural sources of methane in their latest NDCs, representing a growth of 89 per cent. Even when action in these methane emitting sectors is identified, however, quantitative targets for methane reductions or and timelines for the implementation of action are often not specified. Indeed, the FAO finds that only 4 per cent of the latest NDCs submitted identify quantified and time-bound methane-specific reduction targets in the agricultural sector, none of which are aligned with or comparable to the GMP target and base year. Furthermore, many of the world's largest methane emitting countries have not identified national action to reduce their emissions. A comparative analysis by the FAO of national methane emission sources from agriculture against methane mitigation measures included in the NDCs illustrates a policy coverage gap equivalent to 61 per cent of methane emissions in the sector (Crumpler *et al.* 2025). It is thus evident that the pledged methane emission reductions stated in the NDCs and MAPs are insufficient for achieving the GMP, and the political commitments stated within them will only achieve half of the sector's maximum technical reduction potential.

A global review of national policies in force as of 2023 found that only 13 per cent of global methane emissions are currently covered and that the agricultural sector, compared to energy and waste, is the least represented – constituting just 17 per cent of all policies identified (Olczak *et al.* 2023). Overall, there is a generally positive trajectory in the increase of agricultural methane reduction policies observed over the last decade compared to the previous one (Figure 3.3), driven primarily by three regions - Europe, Asia Pacific and North America, with far fewer policies adopted in the Middle East and Central and South America.

Figure 3.3: **Growing agricultural methane policy coverage, number of policies in force targeting specific agricultural methane emission sources, pre-2003, 2003–2012 and 2013–2023.**



Source: *Olzcak et al. 2023*

Policymakers designing agricultural methane policies more often choose economic, 35 per cent, and complementary, 25 per cent, instruments or mixes of policy tools, 20 per cent, over other types of policies, such as regulatory, 14 per cent, and information, 6 per cent, instruments (Figure 3.4). Over the last decade, however, policies have shifted towards more regulatory and informational instruments, consistent with the global shift towards financing through carbon markets (Schmidt *et al.* 2018; Eskander *et al.* 2020; Nascimento *et al.* 2022; Olzcak *et al.* 2023) and perhaps the recognition of the need to drive behavioural change through greater awareness and capacity building amongst agricultural communities, addressing an underlying barrier to many mitigation solutions in the sector.

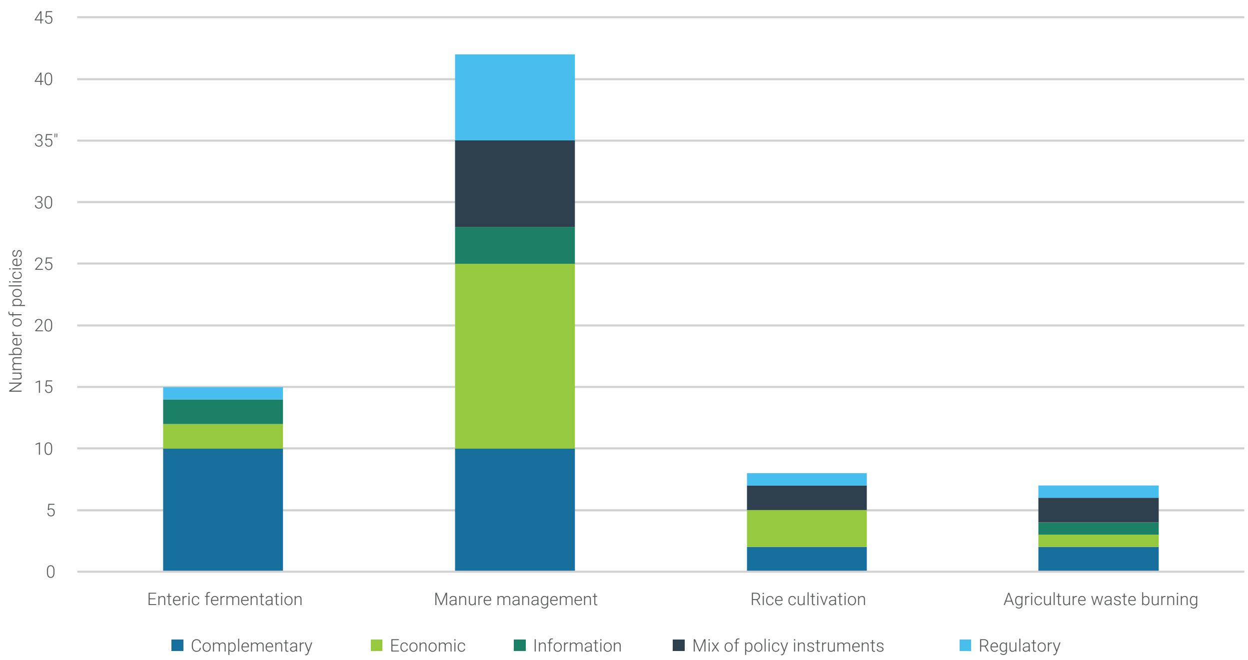
Compared to the fossil-fuel sector for which regulations are more common, policies in the agricultural sector are predominantly economic in nature, such as fiscal and financial incentives. The Brazilian Low Carbon Emission in Agriculture (ABC+) Plan (2020–2030), for example, provides government-backed loans and improved access to credit and financing to promote sustainable agriculture, including manure management. Tax credits for biogas in the United States of America are also used, for example, the Renewable Fuels Production Tax Credit, as are tax exemptions in China for biogas companies supplying rural clean energy from manure, as stated in the 14th Five Year Plan on Modern Energy System Planning in 2022. Denmark has also established a methane tax through the Agreement on a Green Denmark Policy. Some countries, including Australia, Canada and the United States of America, have integrated livestock and/or rice methane in their carbon trading schemes

(Olzcak *et al.* 2023; Zhu *et al.* 2024). Canada's draft Reducing Enteric Methane Emissions from Beef Cattle (REME) Protocol, for example, aims to reduce methane from confined beef-cattle feeding operations by providing offset credits generated through improved animal diets, management practices and the use of feed additives.

Complementary policies, such as research and development (R&D) subsidies and voluntary programmes, are also more common in the agricultural sector than others. The Brazilian Agricultural Research Corporation, for example, provides targeted funding for development and the creation of markets for new methane-reduction technologies (Lucchese-Cheung *et al.* 2022). Many countries, including Australia, Brazil, Canada, Ireland, the Netherlands, New Zealand, and the United States of America, provide R&D funding and supporting international research initiatives, such as the Global Research Alliance on Agricultural Greenhouse Gases. Voluntary agreements between governments and the private sector, such as the one between the Norwegian government and agricultural organizations to reduce emissions between 2021 and 2030, can also complement more stringent regulatory instruments. Mixes of different policies, such as a combination of a regulation, financial incentives and awareness-raising campaigns to address the burning of crop waste, are more commonly used than in the fossil-fuel sector (Olzcak *et al.* 2023).

Regulations often mandate improved manure management, for example in China and the Republic of Korea, and incentivize biogas production, as in China, Denmark, France, Germany and Italy. Regulations can also play a role in introducing new technologies and changing farming practice, such as by endorsing the system of rice intensification in Viet Nam, or, as in India, by regulating agricultural residue burning. Lastly, information instruments are critical for improving awareness of emissions and mitigation options among different stakeholders and can be developed in cooperation between the public and private sector, such as the Carbon-Neutral Brazilian Beef certification launched by the Brazilian Agricultural Research Corporation (Olzcak *et al.* 2023).

Figure 3.4: **Typologies of national agricultural methane policies adopted by governments between 1974–2024, number of policies.**

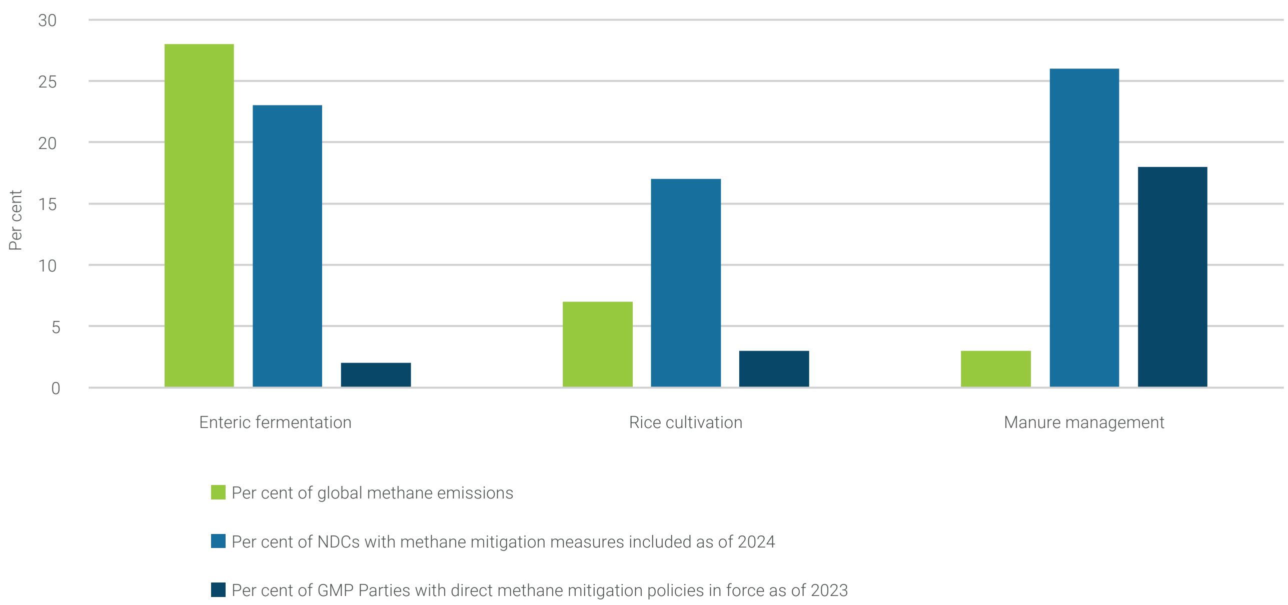


Source: Olzcak et al. 2023

3.5.2.2 *Agricultural methane policy coverage*

Amongst GMP participating countries, however, only 2 per cent, 3 per cent, and 18 per cent of members have national policies in force directly addressing enteric fermentation, rice cultivation, and manure management, respectively (Figure 3.5). This suggests that, despite political commitments in the NDCs and amongst GMP participating countries, there is limited translation and integration of agricultural methane reduction measures into actionable policies, strategies and implementation instruments at the national and sectoral levels.

Figure 3.5: Global agricultural methane emissions and direct methane mitigation policies in force/proposed by specific emission sources, per cent.



Source: Global agricultural methane emissions, FAOSTAT 2025 (FAO 2023); NDCs with agricultural methane measures, Crumpler et al. 2025; GMP participating countries with methane policies, Olzcak et al. 2023

In agriculture, policies most often target emissions from livestock manure, which is a smaller source of methane emissions globally than enteric fermentation (Figure 3.5). This may be explained by the wide availability of technologies that use manure for energy production, for instance, anaerobic digestion, due to policy support for this renewable source of energy through, for example, feed-in tariffs for biogas production (Olzcak *et al.* 2023). On the other hand, strategies to mitigate enteric fermentation emissions, such as animal and feed management, diet formulation, and rumen manipulation, are not widely used, and the barriers to their widescale adoption are not well understood (Nabuurs *et al.* 2022). As a result, emissions from enteric fermentation are rarely targeted by policy despite constituting the largest source of methane emissions from agriculture. A recent FAO livestock methane policy analysis, based on data on methane emissions from national greenhouse gas inventories submitted to the UNFCCC and other national policy documents, found that only about one-third of the 28 countries responsible for over 80 per cent of global livestock methane emissions have dedicated methane policy instruments to address livestock methane mitigation. Most countries have included livestock methane measures in their national policy frameworks, such as climate policies, agricultural development, and low-emission development strategies, yet nearly all omit livestock-specific methane reduction targets.

In the crop subsector, effective policies targeting rice cultivation and the burning of rice paddy straw and other crop residues are absent in selected regions, particularly in China, Japan, the Republic of Korea, South Asia (especially India) and South-East Asia, which together account for over 85 per cent of emissions from rice cultivation (Saunois *et al.* 2020; Olzcak *et al.* 2023). While open-field burning has declined globally, it is increasing in densely populated agricultural areas in China and India (Shyamsundar *et al.* 2019; Olzcak *et al.* 2023) as well as in Africa and the Americas (Lin and Begho, 2022; Deshpande *et al.* 2023).

A comparative review of methane policies in two of the world's top-emitting countries, China and the United States of America, found that both have paid the least attention to livestock enteric fermentation and rice cultivation, compared to other sectors. Policy coverage is highest with respect to manure management, largely due to concerns around manure as a major source of pollution in rural areas and its potential to provide low-cost clean energy to rural households. Both countries use a combination of laws, regulations, and tax credits to regulate manure management and incentivize investment in the development of biogas production (Zhu *et al.* 2024).

3.5.2.3 Agricultural methane policy stringency, effectiveness, unintended consequences and equity

Agricultural methane policies are generally less stringent (Olczak *et al.*, 2023) than those in the waste or oil and gas sectors, partly due to concerns over food security, rural livelihoods and international competitiveness. Evidence on their effectiveness and the cost of their implementation remains limited, highlighting the need for further research to guide future policymaking (Melvin *et al.*, 2016; Olczak *et al.*, 2023; Zhu *et al.*, 2024).

Poorly designed policies can lead to unintended consequences, such as increasing emissions of other greenhouse gases, raising food prices, or promoting more emission-intensive production through subsidies or offset schemes, for example, in the case of switching from maize to more greenhouse gas intensive rice production (Nabuurs *et al.* 2022; Olzcak *et al.* 2023).

Holistic, well-integrated approaches are essential to avoid such trade-offs and align methane mitigation with broader sustainability goals (Nabuurs *et al.* 2022; Olzcak *et al.* 2023). Importantly, mitigation in agriculture must consider equity: smallholder farmers and rural communities, who are most vulnerable to climate impacts, often bear the highest burden but are rarely explicitly acknowledged in agricultural climate mitigation plans (Crumpler *et al.* 2024). The IPCC and FAO emphasize the need for policy frameworks that evaluate methane reduction strategies through both effectiveness and equity lenses to ensure they support food security and poverty reduction (Nabuurs *et al.* 2022; Crumpler *et al.* 2024).

3.5.3 Barriers and solutions

While many mitigation options technically exist in the agricultural sector, implementing these often proves challenging due to divergent national government priorities, needs and capacities to act. In the agricultural sector, common barriers include a lack of financing, insufficient awareness and capacity, the need to change production methods or technologies, the absence of adequate policies and regulations, and challenges in changing consumption behaviour (UNEP and CCAC 2024). Overall, addressing these barriers requires the careful design of regulatory, economic, information-based and complementary policy instruments and mechanisms to facilitate and incentivize implementation (Olczak *et al.* 2023).

3.5.3.1 Socioeconomic barriers and opportunities

Lack of finance and investment: despite the widespread recognition of the role of the agricultural sector in achieving the temperature goal of the Paris Agreement, limited access to and scalability of finance represents a major barrier to the implementation of mitigation in the sector (Nabuurs *et al.* 2022). According to the Climate Policy Initiative (CPI), an estimated US$16.5 billion per year is needed in methane abatement finance in the agricultural, forestry and land-use (AFOLU) sector by 2030 (de Aragão Fernandes *et al.* 2023). While undoubtedly large, this amount pales in comparison to the often inefficient and harmful explicit subsidies in the sector, which available data suggests are at least US$635 billion per year but likely in excess of US$1 trillion (Damania *et al.* 2023). Repurposing even a small fraction of these resources could go a long way to addressing investment needs. Compared to current flows, methane abatement finance gaps are most significant in the fossil-fuel and AFOLU sectors, with the AFOLU financing gap estimated to be US$9 billion per year (de Aragão Fernandes *et al.* 2023). An FAO analysis reveals that livestock systems received just 2 per cent of total climate-related finance to agrifood systems between 2013 and 2022 (Galbiati and Bernoux 2024). The private sector currently provides 84 per cent of climate finance for methane abatement in the AFOLU sector for 2021/22 amounting to US$6.34 billion, while only US$1.17 billion, comes from public sources (de Aragão Fernandes *et al.* 2023).

There is potential for blended finance models to scale methane mitigation efforts at the farm level by leveraging concessional public finance to mobilize additional private investment. To this end, strategic partnerships between multilateral development banks (MDBs) and agricultural public development banks (AgriPDBs) could play a critical role, for example, through the World Bank's Global Methane Reduction Platform for Development. The active engagement of farmers and farmer organizations in the development of adequate financial instruments can ensure that funding mechanisms respond to their operational realities, risk profiles and investment capacities, creating incentives that are both effective and equitable.

De-risking private sector investments could release finance for agricultural methane mitigation. Under the International Livestock Research Institute (ILRI)-CCAC Accelerating Methane Reductions In Rice Production Systems Through Market-based Mechanisms project, for example, the enabling environment is being strengthened for private sector investment in carbon credits and market development for low-emission rice in South-East Asia.

Upfront investment risk and uncertainty: shifting to new or improved technologies that can reduce methane emissions, especially in agriculture, may require significant time or upfront financial investment by agricultural stakeholders. Adoption rates are often low due to risk aversion among agricultural stakeholders (Nabuurs *et al.* 2022). Finance and economic incentive mechanisms, such as subsidies, tax exemptions and financial benefits, can, however, smooth over risks associated with upfront investment costs, especially among poor rural communities. Government-backed loans, improved access to credit and financing are, for instance, key incentives in Brazil's ABC+ Plan promoting improved manure management.

Entrenched socio-cultural norms and resistance to change: agriculture is deeply tied to long-standing cultural traditions and heritage, often going back for generations. Evidence shows that barriers to adoption are strongest where emissions are tied to tradition. Where regulatory approaches or taxes face resistance, information programmes and awareness raising around how technologies can improve agricultural yields, reduce costs or improve rural livelihoods can prove powerful in facilitating behavioural change (Nabuurs *et al.* 2022).

3.5.3.2 Institutional barriers and opportunities

Fragmented institutional capacities and regulatory regimes: lack of institutional capacity to plan and coordinate mitigation programmes for agricultural methane across institutions and at different scales represents a recurring barrier to implementation. This is often compounded by lack of data to understand the sources of agricultural methane emissions and the capacity to plan and monitor them, which can also impede access to carbon markets. Some promising technologies may be impeded by regulatory processes, such as approval process for chemically synthesized enteric fermentation inhibitors, and administration in pasture-based systems can also be challenging. Further, the adoption of mitigation practices is limited in areas with unclear property rights (Nabuurs *et al.* 2022).

3.5.3.3 Ecological barriers and opportunities

Soil conditions, water availability and interactions with other greenhouse gases: some solutions for reducing methane emissions from agriculture may face on-site ecological barriers. Limitations on improving rice management, for example, can include soil type, percolation and seepage rates or fluctuations in precipitation, water canal or irrigation infrastructure, paddy surface levels and rice-field size, combined with social factors such as pump ownership and challenges in synchronizing water management between neighbours and pumping stations. Additionally, trade-offs between methane and nitrous oxide mitigation occur when water management enhances N_2O emissions due to alternating wet and dry conditions, potentially offsetting some methane mitigation benefits. Similarly, in the livestock sector, increased nitrous oxide emissions may occur from the application of manure to poorly drained or wet soils, while fugitive emissions may reduce the potential mitigation benefits of biogas production in some circumstances (Nabuurs *et al.* 2022). Hence, a careful assessment of the impact of methane policies on other greenhouse gases is necessary.

3.5.3.4 Technological barriers and opportunities

Limited access to innovation: access to innovative ways of reducing agricultural methane emissions, such as the use of perennial legumes or animals that produce less methane, and the technical assistance required to adopt new practices also represent significant barriers to implementation, particularly among marginalized communities, such as pastoralists, and low-income segments of the agricultural population. Addressing this barrier requires tailored policies and programmes to develop and disseminate innovations, often in partnership with research institutions, civil society and the private sector.

Uneven data and monitoring, reporting and verification systems: the coverage and granularity of agricultural methane emission quantification within national methane-emission inventories are essential to understand from where methane comes, formulate data-driven policies and measures, and track progress. A review of national greenhouse gas inventories since the establishment of the GMP (Section 3.2.2) demonstrates a substantial increase in the number of countries quantifying methane emissions from agriculture overall and, particularly a shift from the less granular Tier 1 estimations to more specific Tiers 2 and 3[25] estimations in non-Annex I countries since the GMP. Upper tier enteric fermentation and manure management estimates are, for instance, available in nearly all Annex I countries and have nearly doubled to 47 per cent of non-Annex I ones. However, FAO analysis, based on data on methane emissions from national greenhouse gas inventories submitted to the UNFCCC and other national policy documents, finds that only 11 of the 28 countries responsible for over 80 per cent of global livestock methane emissions use the more advanced Tier 2 for national GHG inventories. Additionally, methane emissions from inland waters, including aquaculture ponds, may be overlooked in global and national inventories (Malerba *et al.* 2022; Zhang *et al.* 2024). Further, the majority of developing countries have insufficient capacity to address research, requirements and MRV needs, compromising transparency, accuracy, completeness, consistency and comparability (Nabuurs *et al.* 2022). Transitions to more granular, Tier-2 based emission estimates and strengthened institutional arrangements are needed to facilitate effective policy design and tracking of implementation and progress with robust MRV systems in the agriculture sector, which are also crucial for accessing carbon markets. In Kenya and Uruguay, with the support of the CCAC and Livestock Data for Decisions (LD4D), for example, improvements in livestock data ecosystems and MRV capacities are unlocking access to climate finance, carbon markets and results-based financing mechanisms. Further, working collaboratively with the private sector using digital extension tools, such as the CCAC Technology and Economic Assessment Panel report (CCAC 2024) can help to bridge the data capacity gap.

25 According to the IPCC, a tier represents a level of methodological complexity. Usually, three tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 the most demanding in terms of complexity and data requirements.https://www.ipcc.ch/site/assets/uploads/2019/12/19R_V0_01_Overview.pdf

3.5.4 Leveraging the co-benefits of mitigation action as drivers of change

Tackling the barriers to agricultural methane mitigation requires leveraging co-benefits for sustainable development outcomes as drivers of change. The uptake of agricultural methane-reduction policies is strongest when mitigation objectives are linked to other policy objectives, such as enhancing agricultural productivity and food security, preventing soil erosion and land degradation, or reducing pollution and improving air quality and addressing gender gaps (Nabuurs *et al.* 2022). Methane policies in China and the United States of America, for instance, are primarily driven by efforts to reduce pollution from animal waste and reuse it as an energy source in rural areas (Zhu *et al.* 2024). As a good example, the Digital Services for Methane Management Solutions Group under the CCAC aims to ensure that digital agriculture technologies deliver on their promise of reducing the intensity of livestock emissions while supporting farmer productivity and food security in low and middle-income countries. More CCAC projects can be found in Box 3.7. Similarly, addressing systemic issues which constrain women's participation in agrifood systems, such as unequal access to land, credit, or extension services can deliver methane mitigation while boosting productivity and wages.

Box 3.7: The Climate and Clean Air Coalition support for methane abatement in the agriculture sector

Through 26 projects and the investment of US$7 million, the CCAC provides support to the agricultural sector in 26 countries.

Current projects cover, amongst others, methane mitigation tools, practices and technologies, including projects creating an open-source framework for estimating methane emissions from rice cultivation and implementing measures to reduce methane emissions intensity from livestock. Six are aimed at enhancing NDCs to include mitigation of methane emissions from agriculture.

One project in Viet Nam is developing an open-source framework for estimating methane emissions from rice cultivation using remote sensing products. Another is training 3,000 farmers in Brazil on the implementation of measures to reduce methane emissions from the livestock sector.

Previous CCAC work included enhancing ambition in the agriculture sector in NDCs for 26 countries and the adoption of 280 climate-smart technologies and practices.

3.5.5 Conclusion

Based on the analysis, six actions are recommended to strengthen the mitigation of methane from agriculture.

- First, countries should implement low- and no-cost mitigation options that offer immediate benefits with minimal financial burden.
- Second, the granularity and specificity of methane targets in NDCs should be improved, including quantified, time-bound objectives and detailed sectoral measures.
- Third, while many GMP participating countries express political commitment, few have translated this into actionable national policies; stronger integration into regulatory, financial, and voluntary frameworks is needed to leverage co-benefits for, and avoid trade-offs with, food security, rural development and the conservation of ecosystems.
- Fourth, scaling up targeted incentives and financial support, particularly for smallholder farmers, is essential to unlock broader adoption.
- Fifth, enhancing greenhouse gas inventories and national MRV systems will help improve transparency and policy accountability.
- Sixth, more research is needed on underexplored sources, such as aquaculture, barriers to livestock mitigation adoption, and the role of demand-side strategies such as dietary shifts and reduced food waste.

3.6 Conclusion

Global momentum to reduce methane emissions has grown significantly, with increasing integration of methane policies into national climate plans, especially among UNFCCC Non-Annex I countries, since the launch of the GMP. While progress is encouraging and cost-effective mitigation opportunities abound, efforts remain uneven across sectors and regions. Notably, policy innovation is advancing rapidly in oil and gas subsector, but coal lags behind. Similarly, the waste sector has seen rising attention, though adoption of best practice is still patchy. The agricultural sector suffers from limited policy coverage and a lack of quantified targets. Across all major emitting sectors, immediate implementation of targeted measures – embedded in equitable, system-wide transformation – remains critical. Only a handful of countries have, however, adopted comprehensive, timebound methane targets aligned with the 2030 GMP goal, underlining a gap between high-level commitments and actionable strategies. Moving forward, overcoming barriers to development, enforcement and implementation of effective policy frameworks, strengthening monitoring systems, and unlocking appropriate financing mechanisms will be essential to fully realizing the climate and health benefits of methane mitigation. Bridging these gaps now will determine whether the global community can harness this near-term opportunity to bend the curve on climate change and air pollution.

Photo: 994yellow/Adobe Stock

04 Observed Emissions and the Role of Empirical Data

Key messages

- Technically feasible mitigation options are readily available across sectors, and their implementation need not wait for perfect data. Measurement-based data are essential for effectively targeting and thus accelerating mitigation efforts, and for assessing targeted reductions.

- As industries and governments implement ambitious mitigation targets, accurately tracking changes in emissions over time becomes more central. Assessing progress towards goals requires transparent and reliable data. Readily available measurement-based approaches, when deployed frequently and with representative coverage, can effectively capture changes in emissions resulting from shifts in practices and operations.

- Recent regional studies with dense, near-source measurements consistently find underreported methane emissions in the fossil-fuel sector. Verifying and determining the magnitude of this underreporting across the world is needed to guide more effective mitigation and track mitigation progress. This requires additional regional measurements, leveraging new satellite-based measurements, and augmenting global ground and airborne-based observation systems. Reconciling any differences in sectoral attribution between regional and global approaches, including gap analyses, is important to enhance confidence in these measurements and improving emission inventories.

- Existing tools can be applied to different sectors to enhance the effectiveness of mitigation and tracking accuracy. As successful implementation in the fossil-fuel sector demonstrates, the use of existing direct measurement tools is feasible for most sources of anthropogenic methane and should be applied more widely.

- Robust testing and validation of emissions quantification methods are important to ensure the accuracy and credibility of measurement-based data and must be expanded as a core quality assurance tool.

- Ensuring that industries and regulators understand where and how to make the most of these measurement tools is also key, as is making the data useful for stakeholders and regulators alike.

4.1 Introduction

Measurement-based monitoring technologies are now actively deployed across sectors to detect, quantify and characterize methane emissions with increasing accuracy. These technologies collect data at a range of spatial scales: from the smallest point sources, such as individual pieces of equipment or animals, to entire oil and gas production regions. These technologies include *in situ* sensors, satellite-based and other airborne-based monitoring technologies – drones and aircraft.

Sensors are important for collecting real-time data. Scientific advancements have led to the development of high-precision sensors that measure methane concentrations to parts per billion (ppb) using off-the-shelf instrumentation. There are reliable methods to convert such measurements into emission rates, such as tonnes of methane emitted per hour, and these data are essential for accelerating mitigation and tracking emission reductions.

Satellites provide an important platform for measurement-based sources of data on methane emissions. The advent of satellite remote sensing and the availability of airborne-based monitoring technologies have provided data from previously inaccessible places. These technologies also allow more frequent monitoring with increasingly automated data-processing capabilities.

The availability of accurate, measurement-based methane data has had a material impact on methane mitigation policies, with, for example, some governments and industries shifting towards measurement-based standards (European Union regulation EU/2024/1787).

As industries, for example, through the OGDC, and governments, for example by way of the GMP, commit to implementing ambitious mitigation targets, there is an increased need to accurately track emissions over time. Transparent and reliable data are critical for assessing progress and ensuring accountability. When deployed consistently with representative coverage, readily available measurement-based approaches can effectively capture changes in emissions resulting from shifts in practices and operations as mitigation policies are implemented.

This chapter discusses the importance of observed emissions in support of effective methane abatement policies. It looks at available empirical data and analyses the growth of multiscale data and measurement-based approaches (Section 4.2). It presents examples of the successful use of empirical data for methane abatement policymaking (Section 4.3), assesses gaps (Section 4.4), the importance of validating monitoring technologies (Section 4.5), the opportunities for improving national inventories (Section 4.6), and the global budget knowledge gap (Section 4.7). It concludes with key recommendations to advance methane abatement through the use of empirical data (Section 4.8).

4.2 Global outlook of observed emissions and the use of empirical data

4.2.1 Global atmospheric methane concentrations

Atmospheric methane concentrations have shown a steady increase since 1985, except for a period of stabilization between 2000 and 2007 (Michel 2024). Despite variations in the atmospheric sink and uncertainties in contributions from natural sources, there is general agreement on a global increase in emissions from the three main anthropogenic sectors between 1985 and 2023: agriculture, including enteric fermentation and rice cultivation; fossil fuels, from production to distribution; and waste, degradation of solid waste and wastewater (Jackson *et al.* 2024). The current best estimate of the methane budget from anthropogenic sources is shown in Table 4.1.

Table 4.1: **Best bottom-up estimates of annual sectoral methane emissions, 2020, million tonnes.** Current best estimate of sectoral methane emissions from bottom-up estimates (i.e., inventory-based) for 2020, range shown represents minimums and maximums from literature values within Saunois et al. (2025). Global top-down estimates (i.e., measurement-based) are not available at this level of sectoral granularity.

Major anthropogenic source	2030 methane emissions Mt/yr
Livestock and manure	117 [114–124]
Rice	32 [29–37]
Landfills and Wastewater	71 [60–84]
Coal mining	41 [38–43]
Oil and gas	74 [67–80]
Biomass and biofuel burning	27 [20–41]

Source: Saunois et al. 2025

4.2.2 Growing multi-scale data and measurement-based approaches

Over the past decade, significant progress has been made in characterizing the magnitude and location of methane emissions from different sources. This work has developed effective measurement-based estimation approaches that reduce uncertainty, improve inventories and guide targeted mitigation. Emission inventories for the oil and gas industry, for example, have historically relied on generic emission factors that often underestimate or mischaracterize stochastic unpredictable leaks and dispersed emission sources. Current detection and quantification methods, such as optical cameras and handheld samplers, can pinpoint such sources and measure whole facilities or regions using vehicles, drones, aircraft, satellites or fixed mounts as platforms for sensors.

While technically feasible mitigation options are readily available across sectors, measurement-based data are essential for effective targeting, thus accelerating mitigation efforts, and for assessing whether targeted reductions are occurring. If policy instruments, such as a performance standard or methane fee per tonne emitted, require emissions quantification, then accurate emission measurements are key because generic emission factors are insufficient.

While uncertainties and challenges in the implementation of measurement-based approaches remain, progress continues with sensor miniaturization and the improvement in remote sensing technologies. Dedicated studies addressing key uncertainties, including wind fields and surface variability (Gorroño *et al.* 2023; Scheutz *et al.* 2025) and plume quantification algorithms (Jacob *et al.* 2022), aim to drive down uncertainty. Blind controlled-release experiments are key to demonstrating progress and to validation of methods (e.g., Chen *et al.* 2024; Bell *et al.* 2023; Chen *et al.* 2024; Sherwin *et al.* 2024). Ensuring that measurement capabilities have sufficient precision and accuracy to track mitigation efforts meaningfully determines whether the existing suite of methodologies is fit for purpose in the medium to long term.

4.3 Successful implementation of measurement-based monitoring

4.3.1 The International Methane Emissions Observatory's Methane Alert and Response System

Satellites provide an important measurement-based source of data on methane emissions. While point mappers quantify only the largest emission sources, these data are valuable for quickly identifying major emitters. This enables stakeholders to prioritize mitigation efforts and track progress in reducing methane emissions from super-emitting facilities. UNEP's IMEO operates the Methane Alert and Response System (MARS)[26], the first global platform integrating data from more than a dozen satellite sensors and providing actionable information on major methane emission events directly to stakeholders.

The MARS was launched in a pilot phase at the beginning of 2023 and has been fully operational since January 2024. Since its launch, it has detected more than 10,000 methane plumes across various sectors and issued in excess of 2,500 notifications of detections in the oil and gas subsector. To date, 23 countries have designated official focal points to engage directly with IMEO and partners on response, alongside more than 150 members of the OGMP 2.0. The response rates for MARS notifications have grown nearly tenfold since the end of 2024, reflecting growing engagement and action based on satellite data. In 2024, IMEO highlighted a landmark case in Hassi Messaoud, Algeria, where a long-standing methane leak, one of the oldest continuously emitting sources ever recorded, was successfully eliminated. The leak had released an estimated 27,500 tonnes of methane annually, underscoring the transformative potential of satellite-driven climate action.

26 https://methanedata.unep.org

4.3.2 Reducing uncertainty in the magnitude and location of methane emissions from oil and gas production in Mexico

As part of IMEO's methane science studies, multi-scale measurements in Mexico's oil and gas production regions revealed major discrepancies between measurement-based estimates and both industry and national inventory reporting (Shen *et al.* 2021; Zavala-Araiza *et al.* 2021).

While the vast majority of Mexican oil and gas production takes place from offshore fields, aircraft and satellite measurements revealed that offshore methane emissions were more than ten times lower than those reported in Mexico's national greenhouse gas inventory. In contrast, onshore emissions were over ten times higher than the official inventory estimates. The findings suggest that offshore-associated gas is transported onshore, where it is often flared or vented, resulting in significant emissions. This highlights substantial opportunities for methane capture and utilization.

By integrating two years of satellite data, for example, from TROPOMI[27], it was possible to assess that, in aggregate, total oil and gas methane emissions in the country were about twice those reported in the national inventory and by the operator. Furthermore, the measurement-based estimates identified a specific onshore region in the states of Veracruz and Tabasco in which roughly half the national oil and gas methane emissions were concentrated, indicating a priority region with significant mitigation potential.

These studies in Mexico illustrate the importance of measurement-based monitoring in efficiently guiding mitigation strategies. Based on current reporting and inventories, it would have been easy to assume that offshore platforms, from which most production takes place, were the major source of emissions. While reducing emissions from those platforms is still desirable, the main sources of emissions occur in the onshore production regions. These studies also demonstrate how integrating satellite data over time can provide useful information to improve inventories and track progress on mitigation.

4.3.3 How monitoring has improved emission estimation at the Hail Creek open-cut coal mine, Queensland, Australia

The IMEO coordinated research, in collaboration with the University of Bremen and Airborne Research Australia, in 2022 and 2023 to investigate methane emission rates from the Hail Creek open-cut coal mine located in the Bowen Basin, Queensland, Australia (Borchardt *et al.* 2025).

The study found that emissions measured during May–June 2022 and September 2023 were substantially higher than those reported by the operator for 2023 – those were based on state-wide emission factors under Australia's National Greenhouse and Energy Reporting (NGER) Scheme. In April 2025, the Hail Creek operator submitted an updated, higher emissions estimate for 2024 under Australia's Safeguard Mechanism reporting framework, which qualitatively aligns with the elevated emissions indicated by the aircraft measurements. Nonetheless, the aircraft-based estimates remain, on average, approximately twice as high as those reported using bottom-up NGER methodologies, highlighting the need for further efforts to reconcile emission factor and measurement-based approaches.

27 https://www.tropomi.eu/

In 2023, the Australian government announced a review of current NGER methodologies used to estimate methane emissions from open-cut coal mines – a decision partly driven by growing measurement-based evidence suggesting that existing reporting methods may not fully capture all methane emissions from these operations (Palmer *et al.* 2021; Sadavarte *et al.* 2021). This action reflects a broader effort to ensure the quality of Australia's methane emissions reporting and maintenance of its status as a country with effective state-of–the-art reporting of emissions from the coal sector.

4.3.4 Characterizing high-emitting landfills with remote sensing data

In 2023, Carbon Mapper presented pilot case studies from their airborne methane surveys, conducted between 2016 and 2022, to demonstrate how plume detection data at several California landfills were used first notify landfill operators and then to assist with on-the-ground repairs (Cusworth *et al.* 2024). Subsequent campaigns at these same facilities confirmed a reduction in emissions and/or absence of detections. The same capabilities are now available using some satellites with the goal of detecting, notifying, fixing and verifying for the largest emission sources, though this is more complex for landfills and agricultural emission sources than for oil and gas production. By combining finer spatial resolution and higher observation frequency, satellites should be able to better assist in locating and remediating landfill emissions where clear plumes can be identified.

4.4 Measurement gaps and monitoring needs

4.4.1 Oil and gas

Measurement-based estimates of oil and gas emissions are significantly higher than those from emission factor-based approaches (Schwietzke *et al.* 2016; Saunois *et al.* 2020; UNEP 2024). Expanding measurement-based monitoring at the regional and facility scales is essential to resolving this.

A substantial body of research covers atmospheric measurements from North American production areas (Alvarez *et al.* 2018). Elsewhere, studies remain limited, and many major production regions lack comparable coverage, making satellites an important data source.

Advanced satellite-based instruments detect and quantify high-emitting point and dispersed sources, with measurements possible every few days (Jacob *et al.* 2022). Satellite data from, for example, TROPOMI, MethaneSAT[28] and GOSAT-GW[29], can estimate total oil and gas emissions over large areas, characterize spatial patterns and benchmark performance between regions (Shen *et al.* 2022; Chen *et al.* 2023; Lu *et al.* 2023; Naus *et al.* 2023). Satellite data from, for example, IMEO's MARS, GHGSat[30] and Carbon Mapper[31], can also identify emissions from individual high-emitters (Irakulis-Loitxate *et al.* 2022; Lauvaux *et al.* 2022; Schuit *et al.* 2023; Guanter *et al.* 2024).

28 https://www.methanesat.org/

29 https://www.satnavi.jaxa.jp/files/project/gosat-gw/en/

30 https://www.ghgsat.com/en/?utm_id=Pmax&utm_term=&utm_campaign=GHGSAT-Pmax&utm_source=google&utm_medium=cpc&utm_content=ad_group_1&hsa_acc=9115351264&hsa_cam=22153456687&hsa_grp=&hsa_ad=&hsa_src=x&hsa_tgt=&hsa_kw=&hsa_mt=&hsa_net=adwords&hsa_ver=3&gad_source=1&gad_campaignid=22243654680&gclid=Cj0KCQjwqqDFBhDhARIsAIHTlkuBl9yYxZfsbk6xjS2N6DUQiqf7G3HNMY8tFB4TWd6_U9PqNV9cdvlaAilZEALw_wcB

31 https://carbonmapper.org/

To enable effective mitigation, however, all sources, large and small, require characterization and quantification. A recent study indicated that smaller emissions below the reliable detection limits of many satellite-based measurements could account for a large proportion of total emissions (Williams *et al.* 2025). As such, integrating multi-scale data is critical to quantify, track and reduce overall emissions. Recent success has been seen in Canada using a hybrid bottom-up, top-down emissions inventory approach that integrates measurements with inventories (Chan *et al.* 2024).

Emissions from abandoned oil and gas infrastructure are highly uncertain with estimates varying from 6–49 per cent of oil and gas production methane emissions in the United States of America and there is complete lack of empirical emission data beyond a few western countries (Williams *et al.* 2021; Riddick *et al.* 2024).

Monitoring and analysis need to be available and transparent to ensure measurement insights are up-to-date and can be acted on. Cost effectiveness and scalability are key to drive the uptake of improved methods by industry, regulators, and other groups. Ensuring measurement methods enable attribution at the scale needed for mitigation is crucial and the validation of quantification accuracy is important for trusted outputs. Data are increasingly available through online platforms within weeks of collection[32], allowing open access to measurement insights for regulators and other stakeholders. Empirical data are also becoming an increasingly important feature of industry reporting on commitments, as evidenced through the growth of initiatives such as OGMP 2.0. As mitigation policies advance, capturing changes in emissions over time will remain a top priority.

4.4.2 Coal

On the global scale, estimates of methane emissions using atmospheric inversions for the coal subsector are lower than corresponding inventory data (Tibrewal *et al.* 2024) in contrast to other sectors that potentially over rather than under report. In the United States of America, ongoing airborne research is considering the effectiveness of inventory-based calculations to accurately estimate emissions. While there is broad consistency between different inventories, this is likely due to a limited range of emission factors and associated assumptions being applied to the same production data. Further research is needed to better align global atmospheric inversions and global emission inventories.

Compared to the oil and gas, there is a paucity of atmospheric quantifications at the facility scale for the coal subsector. Fine-scale data are needed to better understand emission dynamics from coal mines, both underground and on the surface. A clearer understanding of the magnitude and temporal variability of CMM emissions can be obtained through ground and airborne approaches (Förster *et al.* 2025). The IMEO has funded measurement campaigns in Poland's Upper Silesia Coal Basin to determine the effectiveness of in-mine, ground and airborne (drone, helicopter, airplane) measurement platforms to asses emissions from coal-mine ventilation shafts, the primary source of methane from the coal subsector (Necki *et al.* 2025).

32 E.g., IMEO's Eye on methane: https://methanedata.unep.org/, Carbon Mapper: https://carbonmapper.org/data, and MethaneSAT: https://www.methanesat.org/data

A recent study comparing in-mine data with simultaneous quantification, using the PRISMA satellite platform[33], found good comparability between in-mine and satellite measurements and illustrated the influence of mitigation efforts at the mine studied in the United States of America (Karacan *et al.* 2025). More validation studies are, however, required to understand the ability of different satellite-based approaches. Satellite quantifications have the potential to improve emission estimates, but controlled release studies and more comparative analysis with high quality and time resolved in-mine data are needed. At present comparative analysis, as opposed to annual emission inventory data, is highly uncertain given the unknown temporal variability of emissions from the coal sector.

For underground mining, one-off atmospheric estimates may not be representative of annual emission rates. By contrast, when atmospheric-based approaches are directly time synchronized and compared with in-mine data within ventilation shafts, there can be good agreement (Förster *et al.* 2025). For ventilation shafts, well positioned and high-frequency in-mine measurements are a sound basis for greenhouse gas reporting. Emission estimates for underground coal mines should, however, also include drainage stations. There are few atmospheric-based estimates of emissions from drainage stations but measurements in Poland indicate these are far higher than expected from inventories and of comparable magnitude to those from ventilation shafts (Förster *et al.* 2025).

For surface mining, the problem of a mixture of diffuse and point sources of methane is analogous to landfills. There is a lack of information on what proportion of emissions comes from different contributing sources considered diffuse rather than point sources. To capture open-pit coal mine emissions, downwind aircraft mass balance is a well-established method (Borchardt *et al.* 2025), but it is only a snapshot and may miss temporal variability. Downwind ground-based tall towers and in-mine sensor arrays may have potential but have not yet been applied for surface mining. Analysis of TROPOMI satellite data has been applied to surface mines, but due to TROPOMI's large pixel (5.5 x 7 km) it can often not separate emissions from different coal mines (Sadavarte *et al.* 2021). The reported mismatch between surface-mining inventory data and atmospheric-based estimates in Australia shows the need for measurement-based reconciliation (Sadavarte *et al.* 2021; Borchardt *et al.* 2025).

4.4.3 Waste

Methane emissions from landfills occur as a result of anaerobic decomposition within the waste mass. These emissions are released at or near ground level, are moisture-saturated with approximately 50 per cent CO_2, and escape either diffusely across the surface or through localized leaks, such as soil cracks or leachate systems. Additionally, landfill methane plumes are influenced by surface features, atmospheric and meteorological conditions, seasonality, and operational practices, leading to complex and variable emission patterns. These distinctions underscore the need for landfill-specific monitoring as methods used for oil and gas are directly transferable.

Detecting, locating and quantifying waste-sector emissions, particularly from landfills, presents unique challenges compared to the oil and gas subsector. These emissions are dispersed over large areas, released near ground level, and moisture saturated, complicating their localization and quantification. The industry gold standard for whole site measurement for landfill emissions quantification is the tracer correlation method (Mønster *et al.* 2019), but this should be augmented with walk-over or drone surveys to identify and target hotspots.

33 https://www.asi.it/en/earth-science/prisma/

Even once identified, remediation relies heavily on the installation of infrastructure, such as gas wells, extraction systems and effective cover technologies, though there is increasing promise of biological capture systems. Many regions, particularly in developing countries, lack access to these capital-intensive systems, resulting in persistent large-scale methane emissions from landfills. It has, however, been demonstrated in the United States of America that the main sources of emissions are from the active landfill face and especially those with gas capture systems (Scarpelli *et al.* 2024) – indicating that ineffective gas capture at such sites is a potential target for systemic mitigation. The implementation of such solutions needs to be combined with frequent monitoring, leak detection and repair. Thus, long-term solutions lie in waste management practices, shifting to regarding organic waste as a resource. Methane generation from organic waste should be restricted to biogas plants designed for the purpose of producing gas, or composting plants, which implies upstream waste segregation.

4.4.4 Agriculture

Quantifying emissions from the agricultural sector is challenging. There are often numerous and overlapping sources – sources, such as cattle or manure, not in fixed positions and producing varying quantities. Quantifying emissions from a mixture of point sources located together can present methodological difficulties.

Methodologies for making representative in situ farm scale measurements are in early adoption, borrowing from landfills or oil and gas applications. A variety of techniques using dual-tracers, drones (Vinković *et al.* 2022), vehicle-mounted instruments, light aircraft or combinations thereof have shown success (Moyes *et al.* 2025), and tracer correlation methods (Section 4.4.3) have been utilized effectively in Denmark, resulting in measured emissions 35 per cent greater than inventory values (Vechi, Mellqvist and Scheutz 2022). Isotopic and co-tracer, such as ethane, techniques can distinguish co-located emissions from, for example, ruminants and gas leaks (Menoud *et al.* 2022).

Rice paddies supply half the global population with staple food, but also account for approximately half of greenhouse gas emissions from croplands (Qian *et al.* 2023), with significant opportunities for mitigation (Zhou *et al.* 2024). Estimates of emissions from rice paddies rely on either small-scale chamber measurements (~1 m^2) with upscaling or tower-based eddy covariance measurements that cover a larger area (~1 km^2). The use of eddy covariance for rice fields gives better spatial coverage, does not interfere with gas exchange and permits continuous data collection, allowing longitudinal studies across seasons (Alberto *et al.* 2014). Advances in modelling improve quantification and guide mitigation efforts (Guo *et al.* 2023). Emissions from very large rice fields on a basin scale have been estimated using satellite measurements (Liang *et al.* 2024) and additional work is needed to validate these approaches and ensure full characterization.

4.5 The role of validation of monitoring technologies

The robust testing and validation of methodologies being used to report emissions quantification is critical as the primary tool for quality assurance. Methodologies need to be robust to meet future policy requirements for measurement-based emission quantification. There are two main focuses of method validation: (1) the ability to detect and localize methane emissions – especially important for oil and gas facilities with many potential sources, enabling rapid mitigation; and (2) the ability to quantify emissions accurately so that emissions can be reported, tracked and used to evaluate mitigation efforts over time.

The evaluation centres at the Methane Emissions Technology Evaluation Centre (METEC) and Stanford University have tested methods from ground-based sensors to satellites (Ravikumar *et al.* 2019; Bell *et al.* 2023; El Abbadi *et al.* 2024; Ilonze *et al.* 2024; Sherwin *et al.* 2024), with improvements observed across methodologies (Zimmerle *et al.* 2025).

The advancement of validation through the development of more complex systems, such as the landfill simulator SIMFLEX[34]; conducting experiments in varied environments, such as offshore and complex terrain; and challenge experiments involving controlled releases at operational sites, are important steps in understanding true performance across methodologies. Further details are available in the Technical Annex.

4.6 Opportunities for improvement of national inventories

Although there are growing efforts to integrate large-scale measurements in inventories, as in Switzerland and the United Kingdom of Great Britain and Northern Ireland, direct, individual source-level measurements have been the easiest to integrate into national inventories, which are primarily based on bottom-up approaches. Even these measurements, however, can be challenging because of the lack of activity data at the corresponding source/component level or a mismatch between levels, such as wellhead and surface-casing vent emissions (Bowman *et al.* 2023)). There is also the alternative approach of directly creating a hybrid inventory by combining measurements with bottom-up estimates (Johnson *et al.* 2023).

Nevertheless, with close collaboration between national inventory compilers in measurement design, there are many opportunities to maximize the impact measurements can have on national inventories, especially by helping countries develop locally-specific emission factors where possible.

Global repeated observations of atmospheric methane with the TROPOMI satellite instrument at 5.5 x 7 km^2 pixel resolution (Lorente *et al.* 2023) combined with higher resolution aircraft or in situ data offer powerful information to evaluate and improve national emission inventories using inverse methods (Lunt *et al.* 2021; Nesser *et al.* 2024; Hancock *et al.* 2025). An implementation of this approach is the open-access cloud-based Integrated Methane Inversion (IMI) available through Integral Earth[35] (Estrada *et al.* 2025), designed

34 https://fluxlab.ca/simflex/https://fluxlab.ca/simflex/

35 https://integralearth.github.io/https://integralearth.github.io/

to provide a stakeholder-friendly analytical inversion tool for exploiting TROPOMI and other satellite data. The IMI has been applied extensively to optimize emissions on national scales and evaluate the bottom-up inventories reported by individual countries to the UNFCCC (Chen *et al.* 2023; Nesser *et al.* 2024; Hancock *et al.* 2025).

A new generation of area-mapping satellites, such as, Sentinel-5[36], GOSAT-GW[37], CO_2M[38] and MethaneSAT[39], will further contribute to the improvement of inventories in the near future.

4.7 Global budget knowledge gaps

The extent of natural source emissions remains highly uncertain, predominantly from wetlands and inland waters, with estimates of 130–280 Mt of methane per year in 2019–2020 from bottom-up approaches (Bloom *et al.* 2024), and constrained by inverse modelling approaches to 190–240 Mt of methane per year (Qu *et al.* 2021; Yu *et al.* 2023; Saunois *et al.* 2025). As many of the indicators of recent increases in methane emissions suggest a climatic feedback effect of increased tropical wetland methane emissions (Nisbet *et al.* 2023), it is critical to better understand the climate-driven impacts on natural methane emissions.

The role of variability of methane sinks in the budget, mainly the hydroxyl radical, and hydroxide (OH), as well as soil uptake and atmospheric chlorine, is not fully constrained. There is significant debate over the variability of atmospheric radical concentrations and their impact on methane lifetimes (Zhao *et al.* 2020; Thompson *et al.* 2024) .

There is overwhelming evidence of underestimation of methane emissions in inventories from the fossil-fuel sector, mainly from the oil and gas industry. In the oil and gas upstream/production subsector, measurement campaigns in numerous basins around the world, including in the United States of America (Alvarez *et al.* 2018; Lu *et al.* 2022), Canada (Chan *et al.* 2020), Mexico (Zavala-Araiza *et al.* 2021), the southern North Sea (Pühl *et al.* 2024), Romania (Stavropoulou *et al.* 2023), and Algeria (Naus *et al.* 2023), suggest that methane emissions exceed national inventory estimates. These measurement campaigns used ground-based, aerial and satellite platforms. Cases in which independent empirical data confirm national inventories are rare for oil and gas production (Foulds *et al.* 2022).

In the coal subsector, empirical data are limited, with available examples showing mixed patterns: confirmation of emission estimates using in-mine data for underground mines in Poland (Fiehn *et al.* 2020), but significant underreporting in an Australian surface mine (Borchardt *et al.* 2025). The potential for under or over reporting of emissions from underground mining is an on-going research consideration. Further research is also assessing the applicability of the findings of Borchardt *et al.* (2025) to other surface mines.

Overall, this widespread empirical evidence of underreported methane emissions at a regional scale, from studies with a high density of data, i.e., a high sampling rate near sources for ground-based and airborne measurements in regions where differentiating between fossil and non-fossil sources is not an issue, is inconsistent with global-scale

36 https://sentinels.copernicus.eu/missions/sentinel-5

37 https://www.satnavi.jaxa.jp/files/project/gosat-gw/en/

38 https://www.eumetsat.int/co2m

39 https://www.methanesat.org/

atmospheric inverse modelling, which largely confirms or reduces inventories (Saunois *et al.* 2025). A possible explanation is that current global observation systems are spatially under-constrained for attributing several natural and anthropogenic sources. Further work is needed to reconcile global and regional results, starting with integration of both approaches, including a gap analysis comparing global inversion results, disaggregated at a continental or regional scale, with regional estimates from measurement campaigns and the growing availability of satellite-based, country-level methane quantification.

4.8 Conclusion and recommendations

Monitoring and assessing emissions through measurements combined with high-resolution bottom-up inventory data are now feasible and worthwhile for most anthropogenic methane sources. Ensuring that industries and regulators understand where and how to use measurement tools is key, as is making the data useful for stakeholders and regulators alike. The oil and gas industry has the most developed reporting pathways through OGMP 2.0, and other sectors should learn from their experiences, applying available technologies to assist in both methane mitigation and emissions tracking, while developing sector-specific reporting pathways combining measurement systems with refined emission factors for constant sources and better accounting for variable sources.

Data integration is essential for accelerating methane mitigation efforts, particularly in, but not limited to, the oil and gas sector. Even though cost-effective mitigation opportunities exist, they require accurate understanding and tracking. Despite a dramatic increase in available data from such sources as satellites, ground and airborne-based monitoring, and industry and regulatory reports, widespread data fragmentation remains a critical hurdle. This fragmentation exists across different scales, source, site and regional; technologies, in situ and remote sensing; and reporting frameworks, such as OGMP2.0 or government programmes leading to inconsistencies, masking variations in data quality and scope, creating apparent conflicts and providing a skewed view of the full range of emitters, particularly by overlooking numerous smaller emitters that may make up a large share of total emissions (Williams *et al.* 2025).

This fragmented approach obscures the true picture of emissions, potentially leading to misinformed strategies, false confidence and partial mitigation strategies that focus only on super-emitters, while ignoring most total emissions. Integrated methane data is key to identifying from where the emissions are released, how much is being emitted, and how those emissions are changing over time. This enables policymakers and industry leaders to target interventions, monitor progress, and drive accountability. To facilitate this, norms and guardrails for data integration are needed, ensuring that data contributors and data aggregators follow clear structures and quality assurance requirements so data can support future methane mitigation efforts.

Bringing together and integrating methane emissions data from diverse sources – satellites, ground and airborne-based monitoring, inventories and industry-based reporting – is essential to identify from where the emissions are released, how much is being emitted and how those emissions are changing over time. It is also important for aggregating data along value chains to derive product related emission-performance data, such as required under European Union Methane Regulation[40]. As industries and countries raise their ambitions to reduce methane emissions and implement mitigation strategies, providing reliable and transparent data to answer these questions becomes increasingly critical.

40 https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/methane-emissions_en

Photo: sawitreelyaon/Adobe Stock

05 Financing Methane Abatement

Key messages

- Methane finance has increased in recent years. Data limitations complicate precise, comprehensive tracking of global investment in methane mitigation, but CPI analysis found that tracked methane finance increased by 18 per cent to US$13.7 billion per year on average in 2021 and 2020.

- Tracked methane finance falls substantially short of estimated 2030 costs to implement technical abatement measures and achieve emissions reductions in line with the GMP. The scale of resources needed is not, however, out of reach. Annual costs to implement the MTFR scenario are estimated at US$127 billion per year in 2030.

- Resource needs are varied and closing the methane finance investment gap will require action from a wide range of sources.

- Inability to access sufficient or affordable capital is not always the primary barrier to greater action on methane. Other factors, including inadequate policy incentives, data, institutional capacity or viable projects often must be addressed in parallel.

- Developing economies may require public sector or philanthropic support to undertake the necessary technical assistance, capacity building and project preparation. This kind of upfront investment can be highly catalytic – with a supportive policy environment, many mitigation measures can prove cost effective, be private sector led, and secure commercial or private sector development finance.

- Development finance institutions are a critical but still limited source of methane finance, at around US$3 billion per year in 2021–2022, compared to their roughly US$2.5 trillion in collective annual investment. Methane abatement advances other core development priorities, including increased productivity and resilience and improved health outcomes, and as such, these investments align well with development bank missions.

- Private sector actors, including corporations and financial institutions and investors, are also emerging as critical sources of methane finance. They, too, have critical roles to play in helping scale methane finance, including investing in methane mitigation in their own operations and supply chains and considering methane in their procurement and carbon credit purchasing strategies.

5.1 Existing investment in methane mitigation

The GMP has clearly helped underscore the urgent need to scale investment in methane mitigation. There has been important progress since its launch and, while nowhere near sufficient, successful early cases, discussed in greater detail in Section 5.3, have the potential to demonstrate replicable and scalable models and incentivize greater action, particularly as they reinforce the many economic, social and health benefits associated with these investments.

There is no comprehensive, real-time source of data tracking investment in methane mitigation across sectors and sources. Broadly accepted reporting standards for public and private climate finance are lacking, and the reporting processes that do exist do not include dedicated methane mitigation markers. As a result, there are substantial gaps in available data, and identifying methane-related finance flows in the data that does exist is complex. The CPI has, however, established a valuable baseline through the use of data science and key-word search methods to track and analyse methane finance, which it defines as primary, project-level investment in targeted and additional measures that contribute to reducing methane emissions (Rosane 2022). That analysis shows that tracked methane finance was US$13.7 billion per year on average in 2021 and 2022, representing an 18 per cent increase over 2019 and 2020, when average annual finance stood at US$11.6 billion (de Aragao 2023).

5.1.1 Investment by sector

Analysis by the CPI found that data is particularly limited for domestic and overseas investment by private sector actors in the energy sector, hindering accurate assessment of progress in the sector using tracked financial flows. It identified only US$10.6 million per year on average invested in 2021 and 2022 (de Aragao 2023). In the agricultural sector, US$7.5 billion per year was invested over the same period. Of that total, US$2.9 billion per year was invested in the livestock subsector, marking a significant increase over the previous two-year period, when average annual investment stood at US$1.6 billion. Most livestock investment supported manure-to-energy and manure-management projects. Projects promoting animal health and productivity received far less support in 2021 and 2022, US$0.41 billion per year, but were the most common type of livestock investment in 2019 and 2020, receiving US$1.3 billion per year. Enteric fermentation accounted for investments of just US$20 million per year in 2021 and 2022. Additionally, rice paddy abatement solutions received just US$10 million per year in the same period, primarily to support small-scale pilot projects (de Aragao 2023).

The waste sector received the second largest volume with US$4.1 billion per year in investment in 2021 and 2022. Most investment in the waste sector, 94 per cent, however, supported projects involving waste incineration, with three-quarters of that investment coming from the private sector. A much smaller amount, US$223 million, was invested by MDBs and governments in targeted waste management solutions, such as landfill-gas capture and food-waste anaerobic digestion, and just US$22 million was invested in organic-waste management projects. Wastewater projects in the same period attracted US$2 billion in annual investment, nearly all of which, US$1.9 billion, supported improved wastewater management practices. Nearly three-quarters of that investment came from bilateral and multilateral development finance institutions (DFIs) in the form of concessional and non-concessional debt. Advanced wastewater treatment facilities and wastewater-to-energy projects attracted just US$900 million in 2021 and 2022 (de Aragao 2023).

5.1.2 Investment by source

Private sector financial institutions and investors, corporations, development finance institutions, governments, state-owned enterprises and philanthropy are all emerging as important sources of methane finance, with variability across sectors and intervention types in the key sources of finance. In the CPI's analysis, private sector sources contributed around 60 per cent of tracked methane finance in 2019 and 2020 and 70 per cent in 2021 and 2022, with most private sector finance coming from commercial banks and corporations. Finance from corporations and commercial banks was concentrated in the agricultural sector in, for example, residue and biomass burning and livestock, particularly in East Asia, North America and Western Europe.

Public sector sources contributed a smaller share of all tracked methane finance, but data on public sector funding deployed domestically are a significant gap. The largest sectoral recipient of public finance was waste, mainly in wastewater management and solid waste to energy. Additionally, nearly 70 per cent of tracked public finance in 2019–2020 and 2021–2022 came from DFIs, including multilateral, bilateral, and national development banks, with MDBs delivering the largest share. Although public development banks contributed most of the tracked public finance, their contributions of between US$2.7–3 billion in each year from 2019–2022 remain limited relative to their total financing capacity, estimated at roughly US$2.5 trillion per year (Finance in Common 2025). State-owned enterprises and state-backed financial institutions are also important sources of public investment, contributing 23–25 per cent of public finance in those years (CPI 2023).

In addition to the CPI's analysis on sources of finance, there is also evidence that philanthropic funders are placing increased emphasis on methane. Specifically, of all philanthropic funding for climate mitigation, efforts to reduce super pollutants, particularly methane, saw the fastest growth of any sector from 2019 to 2023 (Esmaeili 2025). Growing philanthropic support for methane mitigation is critical, since philanthropy can offer uniquely flexible, highly concessional resources for high-impact activities.

5.2 Methane mitigation investment needs

The IIASA's GAINS model offers unit abatement cost data, annualized over the equipment lifetime, broken down by upfront investment and operations and maintenance (O&M) costs, and accounting for estimated electricity and gas savings. According to GAINS estimates, 2030 annual costs to implement NDCs and MAPs measures are around US$29 billion per year. As discussed in Chapter 2, that level of action, however, falls far short of the GMP goal. Costs in 2030 to implement the MTFR scenario, excluding measures with average abatement cost exceeding US$15,000 per tonne of methane, are estimated at US$127 billion per year (Table 5.1).

Table 5.1: **Tracked methane finance and 2030 cost and energy savings estimates, billion United States dollars.** Numbers rounded to two significant digits.

billion US$ per year	Annual average tracked methane finance (2021≠2022)	Annual cost 2030 (NDCs and MAPs scenario)	Annual cost 2030 (MTFR scenario)	Annual investment cost 2030 (MTFR scenario)	Annual O&M cost 2030 (MTFR scenario)	Annual electricity or gas savings 2030 (MTFR scenario)
Total	14	29	127	122	101	-96
Energy	0.11	12	98	96	42	-40
Agriculture	7.6	17	38	13	54	-29
Waste	6.1	0	-9	13	5	-27

Source: *Tracked methane finance, CPI; IIASA-GAINS 2025*

While undoubtedly significant, the estimated annual cost to fully implement these technical measures and achieve emissions reductions consistent with the GMP goal represents just 6 per cent of global climate finance flows in 2023. Additionally, for 2022–2023, global climate finance increased by US$252 billion, nearly double the estimated annual costs to implement the maximum feasible reduction (Naran 2025).

Energy sector measures have the highest annual costs in 2030, at nearly US$98 billion, and the required investments are capital intensive, requiring about US$96 billion per year in upfront investment. Of these totals, coal sector measures entail US$11 billion in annual costs and an upfront investment of US$3 billion per year. Upstream oil and gas interventions have estimated annual costs of US$6.6 billion and capital costs of US$6.5 billion per year, while midstream and downstream measures have annual costs of US$80 billion and upstream capital costs of US$87 billion. Relative to MTFR 2030 mitigation potential, upstream oil and gas measures are extremely cost-effective at US$0.12 billion per million tonnes of methane emissions reduced. The IEA provides alternative, lower estimates suggesting that around US$43 billion in total annual spending and around US$35 billion in new capital expenditure is needed annually for 2025–2030 to reduce energy sector methane emissions by 75 per cent (IEA 2025). Primary responsibility for investing in methane mitigation lies with fossil-fuel companies, and the varying estimates of annual costs represent just 2–4 per cent of the sector's US$2.4 trillion in net income in 2023 (IEA 2024).

According to GAINS, agricultural sector measures have the second largest annual costs at US$38.3 billion/year in 2030. Operations and maintenance costs contribute substantially to total costs in the sector. Alternative analysis from the United States Environmental Protection Agency (USEPA) estimates comparable costs but with higher mitigation potential (UNEP and CCAC 2021). According to GAINS estimates, implementing MTFR potential requires in the order of a five-fold increase in investment in the sector compared to tracked 2021–22 levels. Even so, 2030 annual cost estimates pale in comparison to the often inefficient and harmful explicit subsides in the sector, which available data suggests are at least US$635 billion per year but likely in excess of US$1 trillion (Damania *et al.* 2023). Repurposing even a small fraction of these resources could go a long way towards addressing investment needs.

Accounting for potential gas savings, estimated annual costs to implement measures in the waste sector are net negative, while estimated upfront investment costs are US$13 billion per year and O&M costs are US$5 billion per year. It is important to note that other available analyses estimate higher abatement costs for comparable mitigation potential in the sector. Cost estimates from the USEPA, for example, are positive when considering the full range of mitigation measures in the sector and only net negative when limited to the lowest-cost interventions (UNEP and CCAC 2021). Recognizing uncertainty in aggregate investment needs, investment in the sector will have to scale and shift towards critical measures, such as landfill gas capture and advanced wastewater treatment facilities. Over half of tracked finance in these sectors in 2021 and 2022 came from private sector sources, but private investment was concentrated in waste-to-energy projects. The nature of the related infrastructure and service provision as a public good means that governments, especially municipal governments, have a critical role to play in scaling up investment in these sectors.

5.3 Addressing priority investment gaps

Methane abatement projects face many challenges in securing financing, including lack of awareness of investment opportunities, viable projects, policy incentives, high perceived risks, reluctance on the part of some financial institutions to finance oil and gas or coal projects, or investors requiring larger transaction sizes (CPI 2023). It is therefore critical to identify the specific barriers at play accurately and strategically deploy limited public resources where they are most needed. This section considers the varying types of support needed and uses real-world examples to draw lessons on how to address potential barriers to investment and scale methane finance. Going forward, additional data identifying and disaggregating investment needs is required to support strategic planning and resource allocation.

5.3.1 Investing in enabling conditions

For any intervention, even the most cost effective, policy and regulatory gaps, capacity constraints and the lack of a pipeline of investable projects can hinder investment and require public sector technical and financial support. Support for the investment enabling environment – such as filling data gaps, designing and implementing training programmes and other extension services, analysing policy options or supporting sectoral planning – often requires budgetary resources or grant-based donor finance, including from bilateral development agencies, philanthropy or dedicated climate funds. Canada's 2021–2026 climate finance commitment, for example, provided grant funding to support landfill measurement techniques in Ecuador, implement waste management clinics for municipalities in India, analyse policy options for the oil-and-gas sector in Nigeria, and support biogas capacity building in Côte d'Ivoire.

This type of dedicated, country-specific support can be highly catalytic but challenging to scale. Certain gaps, however, are widespread and could be most efficiently tackled at a global level with sufficient donor support. In particular, the lack of data is systemic across much of the developing world, directly impacting policy planning, project development and service delivery. While a comprehensive emissions inventory and a fully functioning MRV system are not always required for all prescriptive abatement measures, a coherent effort to invest in high-quality, open-access data resources could accelerate action and enable use of a wider array of financial instruments. Similarly, coordinated efforts to develop high-quality sectoral reporting frameworks and standards, such as OGMP 2.0, can also support the investment enabling environment.

5.3.2 Supporting project preparation

Similarly, project development activities, including stakeholder engagement, technical and economic feasibility assessments, and the design of financing mechanisms and contract terms, can prove challenging without public backing, given the high risk during early project stages. Donor governments can support project preparation by DFIs. With a small amount of donor funding, the World Bank's CH4D is, for example, incorporating methane mitigation measures into a portfolio of World Bank projects across 15 countries.

Additionally, some multilateral climate and environment funds have dedicated project preparation resources. In 2022, for instance, the Green Climate Fund (GCF), International Fund for Agricultural Development (IFAD), the FAO and the Global Dairy Platform jointly provided US$3.5 million to support the development of a regional programme to reduce dairy sector methane emissions in East Africa. The funds establish emissions baselines, assess market and policy conditions, analyse emissions reduction pathways, design social and environmental management frameworks, and conduct various other assessments, all necessary for programme design (Green Climate Fund 2022). That support enabled the development of the US$358 million Dairy Interventions for Mitigation and Adaptation (DaIMA) project, which the GCF board recently approved (GCF 2025).

The Inter-American Development Bank (IADB), with support from the Global Methane Hub, ran a competitive call for proposals to allocate funding of up to US$200,000 per proposal to support the studies required in the development of high-quality waste methane projects. The IADB selected 14 proposals, including projects to reduce food loss and waste, organic waste recovery projects, and initiatives for emissions monitoring. The IADB received 230 proposals from 20 countries seeking more than US$35 million, highlighting the huge demand for resources for these upfront costs (IADB 2025).

5.3.3 Incentivizing cost-effective projects

Some methane mitigation measures have the potential to improve the resilience and profitability of the underlying economic activity. These measures are consistent with economic objectives and can prove cost effective without the need for subsidized finance. In such cases, dedicating the necessary resources to address policy or capacity gaps and support project development activities has the potential to leverage much larger-scale investment, including private investment and non-concessional development finance.

Other interventions may reduce emissions and deliver valuable environmental or social co-benefits, without creating a direct economic incentive for adoption. In these cases, policy interventions, in form of regulatory mandates or market-based mechanisms, are likely to be needed for progress at-scale. Alternative wetting and drying (AWD) in rice cultivation, rather than continuously flooding fields, for instance, can substantially cut emissions and water use without reducing yield. In many cases, however, if individual farmers do not pay for water inputs by volume and do not earn a premium for low-carbon rice, they will have no incentive to change practices.

In a recent project, the World Bank used its Program-for-Results financing instrument to support comprehensive agricultural water pricing reform, alongside carbon trading pilots at the county level, to address the mismatch of incentives and promote adoption of AWD. The programme paired the policy intervention with training and extension services to support farmers to apply new techniques (World Bank 2023). Large corporates in the food sector can also adopt procurement strategies to incentivize emissions reductions in their supply chains by committing to purchase low-methane products.

5.3.4 Unlocking capital-intensive projects

Some measures, such as addressing venting and flaring of associated gas, refurbishing existing gas pipelines or upgrading gas distribution networks, involve high upfront costs. In such cases, even for investments with the potential to produce attractive returns, funding constraints, competing demands for resources, inability to access affordable or sufficiently long-term capital, misaligned incentives or lack of awareness may still deter investment, especially for resource-constrained companies.

In some cases, getting these projects off the ground requires external support. The World Bank's Global Flaring and Methane Reduction Partnership, for example, is demonstrating the importance of working with industry clients to develop internal capacity and build portfolios of investable projects. Development finance may also be needed to mobilize the necessary capital. The Asian Development Bank (ADB), for example, recently approved a US$125 million loan package to support rehabilitation of gas distribution networks in 10 cities. The ADB's support was needed for the project to access longer-term loans not otherwise available from local banks. Additionally, because of ADB's role in the project, the loan was pre-certified as green, with funds earmarked for measurable methane-leakage reduction and improvements in network integrity, and the loan agreement requires periodic reporting on the emissions reductions achieved (ADB 2024).

Debt instruments that explicitly encourage methane mitigation could prove valuable if carefully designed. Sustainable debt instruments, such as transition, use-of-proceeds or sustainability linked bonds, could be well suited to this context (Howell 2024). The Methane Finance Working Group, a coalition of financial institutions, environmental organizations and industry leaders, recently launched technical guidance on the structuring of debt instruments for methane abatement in the oil-and-gas sector (Methane Finance Working Group 2025). Measures to promote cost sharing and recovery of initial investment costs among joint operating companies in the oil-and-gas sector would also enable operators to bring in additional private finance to support specific investment.

5.3.5 Covering ongoing project costs

Infrastructure investments also require sufficient funding to cover ongoing O&M costs. These costs are significant in some cases and ensuring that projects generate sufficient revenue to cover them can prove challenging. Targeted efforts to diversify revenue streams can help improve the long-term sustainability of such projects. In Indonesia, the World Bank is supporting the construction of new waste-treatment facilities and upgrades to improve collection and the sorting of organic waste. To improve system-wide sustainability, the programme includes support for the development of new business lines and sustainable products, including compost, refuse-derived fuel to replace low-grade fuel in cement plants, recyclables, and black soldier fly larvae for chicken and fish feed and organic fertilizer, as well as support efforts to enhance the financial, institutional, planning and operational capacities of local governments for improved solid-waste management.

Additionally, high-integrity carbon credits can mobilize private capital and supplement project revenue, but ensuring quality requires robust MRV and methodologies aligned with the best available science. While corporate buyers may not have traditionally prioritized methane mitigation projects, high quality methane credits represent an opportunity to support large-scale emissions reductions alongside the many economic and social co-benefits associated with such projects.

5.3.6 Supporting innovation

Although most methane abatement can be achieved using solutions that exist today, there is a need for funding to support the development and commercialization of new and innovative technologies. Governments in advanced economies, philanthropy and the private sector can all play a role. In 2023, for example, a group of governments, philanthropies and a private corporation jointly launched the Enteric Fermentation Research and Development Accelerator with more than US$200 million in funding to support innovation in the livestock sector (Global Methane Hub 2023). Large food-sector companies have also supported research and invested in emerging methane abatement technologies.

5.4 Conclusion and recommendations

While significant data limitations hinder precise tracking investment in methane mitigation, the best available estimates of recent flows, along with modelled estimates of 2030 mitigation costs, suggest that delivering on the GMP requires methane finance to increase by many multiples – in the order of a nine-fold increase – over 2022 levels. More investment is needed, at all levels, to address data and tracking gaps including e.g. sex-disaggregated results in funded projects. Additionally, resource needs are highly varied and closing the investment gap requires action from bilateral and philanthropic donors to private sector financial institutions, investors and everything in between.

Sources of scarce grants and highly concessional donor funding, including governments and philanthropy, should continue to scale available funding. They should work together to limit fragmentation of those resources by pooling funding whenever possible. Finally, they should coordinate efforts to fill critical gaps and help scale approaches demonstrating results. Concessional donor funding is particularly valuable in addressing policy and capacity gaps and creating pipelines of viable projects.

Development finance institutions must also continue to increase attention on methane in their operations. There are opportunities to boost the methane mitigation potential of projects in the waste and agricultural sectors that are primarily motivated by unrelated development aims. National and bilateral DFIs remain relatively untapped sources, and MDBs should also continue to scale available resources. The World Bank and IADB have taken important early steps and are beginning to demonstrate successful approaches that should be replicated and scaled. Additionally, development banks and their shareholders should ensure they support high-impact methane mitigation projects in the energy sector that would otherwise not happen without public backing.

Private sector actors, including corporations, financial institutions and investors, can help scale available finance in a variety of ways. Besides direct investment to reduce methane in their own operations, which is critical, corporations can adopt procurement policies that incentivize emissions reductions in their supply chains and commit to purchasing low-methane products. Corporate buyers of carbon credits can seek to partner with developers of high impact methane reduction projects and prioritize these in their credit purchasing strategies. Investors can engage and support portfolio companies on plans to reduce methane emissions and continue to support the development of well-designed sustainable debt instruments.

Photo: JKLoma/Adobe Stock

06 Conclusion

Since the launch of the GMP in 2021, global awareness and political momentum around methane mitigation have grown markedly. The number of countries participating in the GMP has reached 159, demonstrating widespread political support. Significant strides have been made, particularly in policy development, improved emissions inventories and voluntary industry-led initiatives, especially in the energy sector. 65 per cent countries who are Parties to the Paris Agreement have now integrated methane into their NDCs, indicating growing recognition of its critical role in achieving climate and clean air objectives.

Despite this momentum, global anthropogenic methane emissions have continued to rise. Since 2020, emissions have increased by approximately 2 per cent, are projected to grow by 5 per cent by 2030 and 21 per cent by 2050 unless additional action is taken. This trajectory places the world far off course from meeting the GMP goal of at least a 30 per cent reduction from 2020 levels by 2030, and from pathways consistent with limiting warming to 1.5°C.

While current legislation and action under existing national policies have reduced the expected growth in methane emissions compared to older projections, they remain insufficient to reverse the upward trend. Progress made since the launch of the GMP is encouraging. Fully implementing the mitigation pledges in current NDCs could drive emissions reductions of up to 8 per cent by 2030, potentially representing the largest and most enduring decline in anthropogenic methane emissions in recorded human history, yet still short of the GMP target.

Sectoral analysis reveals that the energy sector offers the greatest potential for rapid and cost-effective methane mitigation, accounting for 72 per cent of abatement opportunities by 2030. Tackling venting, flaring and fugitive emissions in the oil, gas and coal industries, especially using existing cost-effective technologies, are high-impact, readily available opportunities.

The waste sector is receiving increased policy attention, though it accounts for a smaller share of emissions; early investments made before 2030 are essential to unlocking reductions in the coming decades.

The agricultural sector remains under addressed. Despite many measures targeting enteric fermentation, manure management and rice cultivation potentially providing net cost savings, policy coverage remains limited.

Meeting the GMP target requires significantly increased ambition and action through the full uptake of methane control measures to reach the maximum technically feasible reduction across all emitting sectors. If implemented fully and swiftly, these measures have the potential to reduce global anthropogenic methane emissions by 32 per cent by 2030.

Financially, methane abatement is not only feasible, but also cost-effective. The cost of implementing these MTFR measures is far outweighed by the associated benefits. These are not just economic, full implementation of MTFRs could prevent more than 180,000 premature deaths annually by 2030. Health benefits also include more than half a million avoided asthma-related emergency-room visits per year and tens of billions of avoided lost hours of labour for outdoor workers. Agriculture would similarly benefit, with nearly 19 billion tonnes of crop losses avoided annually by 2030. These outcomes demonstrate that methane abatement is essential not only for meeting internationally agreed climate goals but for public health, food security and global productivity.

The path forward, however, is not without challenges. While technological solutions are available and effective, policy gaps remain, particularly in turning commitments into enforceable action with measurable results. As of June 2025, only six countries have quantified methane reduction targets aligned with the GMP goal.

Monitoring, reporting and verification systems should be significantly improved to ensure policies deliver as promised. Recent near-source measurement studies have revealed substantial underreporting of methane emissions, particularly in the fossil-fuel sector. Reliable and transparent MRV, from both satellite-based systems and ground-based monitoring, is necessary not only to track progress but also to guide effective mitigation efforts and build public trust. Robust validation and cross-verification of methodologies need to be scaled up to ensure the credibility of data, particularly as more countries incorporate methane mitigation into their climate strategies.

Methane finance has grown in recent years, reaching an average of US$13.7 billion per year in 2021 and 2022, but it still falls well short of the estimated US$127 billion annually needed to fully implement the maximum technically feasible reductions by 2030. This funding gap, however, is not insurmountable. The required investment represents just 6 per cent of total global climate finance in 2023 and a mere fraction of the revenue of the fossil-fuel industry and of the subsidies currently allocated to harmful practices in the agricultural sector. Development finance institutions, private sector actors and philanthropic organizations all have critical roles to play. In many cases, policy clarity, institutional capacity and pipeline development are greater obstacles to mobilizing finance than capital availability.

Moving forward, methane mitigation must be embedded within broader climate strategies. Simultaneous efforts to decarbonize the energy system, reduce food waste and promote sustainable consumption patterns, such as dietary shifts, are essential to achieving long-term reductions. Full implementation of methane control measures, combined with energy system transformations and demand-side changes, can deliver a 53 per cent reduction in methane emissions by 2050. This would be consistent with 1.5°C-aligned pathways and contribute to avoiding up to 0.36°C of warming between 2040 and 2070.

Ultimately, the scientific, economic and moral imperatives to act on methane are overwhelming. The technologies exist, the benefits are clear, and momentum is building. Achieving deep, sustained reductions in methane emissions, however, requires scaling up ambition, accelerating implementation and closing the gaps in finance, data and policy enforcement. As the world continues to confront escalating impacts of climate change, addressing methane is not only a fast and effective lever, it is an essential one.

Now is the time to elevate methane mitigation to the highest levels of national and international climate priorities. Through collective leadership, smart policy and strategic investment, a safer, healthier and more sustainable future can be unlocked while delivering the most significant near-term climate win available today.

Photo: briday/Adobe Stock

References

Chapter 2

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L. *et al.* (2011) Cost-effective control of air quality and greenhouse gases in Europe: Modelling and policy applications, *Environmental Modeling and Software*. 26, 1489-1501

CCAC. 2025. CCAC NDC Tracking Database_MasterData_Jan2025. Paris: Climate and Clean Air Coalition

Crippa, M., Guizzardi, D., Pagani, F., Banja, M., Muntean, M., Schaaf, E.*et al.* (2024) GHG emissions of all world countries. Luxembourg: Publications Office of the European Union. doi:10.2760/4002897, JRC138862

Crumpler, K., Wybieralska, A., Roffredi, L., Tanganelli, E., Angioni, C., Prosperi, P. *et al.* (2025). Agrifood Systems in NDCs and NAPs, v1.0, last updated January 1, 2025. Rome: Food and Agricultural Organization of the United Nations

EC. (2021). Fit for 55: Delivering on the Proposals. Brussels: European Commission. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en

FAO. (2018). *The future of food and agriculture – Alternative pathways to 2050*. Rome: Food and Agriculture Organization of the United Nations

GoI MC. (2020). *Ministry of Coal Annual Report 2020, Chapter 12: International Cooperation*. Minister of Coal and Mines. New Dehli: Government of India, Ministry of Coal.

GoI MC. (2024). Methane emissions from coal mining. Unstarred question No.681 to be answered on 02 Dec. 2024 by Minister of Coal and Mines. New Delhi: Government of India, Ministry of Coal

GoI MIB. (2025). Transforming India's Agricultural and Dairy Sectors – Recent policy decisions and budgetary provisions. Posted on 20 March 2025. New Delhi: Government of India, Ministry of Information and Broadcasting. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2113351

GoI MNRE. (2022). *Administrative approval for implementation of Biogas Programme under the Umbrella scheme of National Bio Energy Programme for FY 2021-22 to 2025-26 (Phase-I) regarding. No.300/2/2020 -Waste to Energy*. New Delhi: Government of India, Ministry of New and Renewable Energy (Biogas Division).

Gomez-Sanabria, A., Höglund-Isaksson, L., Rafaj, P. and Schöpp, W. (2018). Carbon in global waste and wastewater flows – its potential as energy source under alternative future waste management regimes, *Advances in Geosciences*. 45, 105-113

Gomez-Sanabria, A., Kiesewetter, G., Kilmont, Z., Schöpp, W. and Habert, H. (2022). Potentials for future reductions of global GHG and air pollutant emissions from circular municipal waste management systems. *Nature Communications.* 13, 106. 10.1038/s41467-021-27624-7

Harmsen, M., Tabak, C., Höglund-Isaksson, L., Humpenöder, F., Purohit, P. and van Vuuren, D. (2023). Uncertainty in non-CO_2 greenhouse gas mitigation contributes to ambiguity in global climate policy feasibility. *Nature Communications*. 14, 2949. https://www.nature.com/articles/s41467-023-38577-4

Hoesly, R., Smith, S.J., Prime, N., Ahsan, H., Suchyta, H., O'Rourke, P. *et al.* (2024). CEDS v_2024_07_08 Release Emission Data (v_2024_07_08) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.12803197

Höglund-Isaksson, L. (2012). Global anthropogenic methane emissions 2005–2030: technical mitigation potentials and costs. *Atmospheric Chemistry and Physics.* 12, 9079-9096

Höglund-Isaksson, L. (2017) Bottom-up simulations of methane and ethane from global oil and gas systems. *Environmental Research Letters.* 12, 024007. http://iopscience.iop.org/article/10.1088/1748-9326/aa583e

Höglund-Isaksson, L., Gómez-Sanabria, A., Klimont, Z., Rafaj, P. and Schöpp, W. (2020). Technical potentials and costs for reducing global anthropogenic methane emissions in a 2050 timeframe. *Environmental Research Communications.* 2(2). https://iopscience.iop.org/article/10.1088/2515-7620/ab7457

Höglund-Isaksson, L., Purohit, P., Gómez-Sanabria, A., Kaltenegger, K., Pauls, A. Rafaj, P. *et al.* (2023). *Non-CO2 greenhouse gas emissions in the EU27 from 2005 to 2070 with technical mitigation potentials and costs -results from the GAINS model. Methodology* report. Produced by IIASA for the European Commission DG-CLIMA. Laxenburg: International Institute for Applied Systems Analysis. https://pure.iiasa.ac.at/id/eprint/19546/1/GAINS_Methodology_nonCO2_EU27_10oct2023_Final.pdf

IPCC. (2022). *Sixth Assessment Report Working Group III, Climate change 2022: Mitigation of Climate Change*. Cambridge: Cambridge University Press. doi: 10.1017/9781009157926

Jones, M.W., Peters, G.P., Gasser, T., Andrew, R.M., Schwingshackl, C., Gütschow, J. *et al.* (2023). National contributions to climate change due to historical emissions of carbon dioxide, methane, and nitrous oxide since 1850. *Scientific Data.* 10. 1. https://www.nature.com/articles/s41597-023-02041-1

Kanter, D.R., Winiwarter, W., Bodirsky, B.L., Bouwman, L., Boyer, E., Buckle, S. *et al.* (2020). Nitrogen futures in the shared socioeconomic pathways. *Global Environmental Change.* 61: e102029. DOI:10.1016/j.gloenvcha.2019.102029

Kleinen T., Gromov S., Steil B. and Brovkin V. (2021) Atmospheric methane underestimated in future climate projections, *Environ. Res.* Lett. 16(9): 094006. https://dx.doi.org/10.1088/1748-9326/ac1814

Kotz, M., Levermann, A. and Wenz, L. (2024). The Economic Commitment of Climate Change. Nature, 628. 551–557. https://www.nature.com/articles/s41586-024-07219-0

Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S. *et al.* (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global Environ. Change. 42. 153-168

Rogelj, J. and Lamboll, R.D. (2024). Substantial reductions in non-CO_2 greenhouse gas emissions reductions implied by IPCC estimates of the remaining carbon budget. *Communications Earth & Environment.* 5. 35. https://www.nature.com/articles/s43247-023-01168-8

Saunois, M., Martinez, A., Poulter, B., Zhang, Z., Raymond, P.A., Regnier, P. *et al.* (2025). Global Methane Budget 2000–2020. *Earth System Science Data.* 17.5. 1873-1958. https://essd.copernicus.org/articles/17/1873/2025/

Shen, L., Peng, S., Zhang Z., Tong, C., Lin, T., Zhong, H. *et al.* (2025). The large role of declining atmospheric sulfate deposition and rising CO_2 concentrations in stimulating future wetland CH_4 emissions, *Science Adv*. 11. 6. https://www.science.org/doi/10.1126/sciadv.adn1056

Shindell D., Sadavarte, P., Aben, I., de Oliveira Bredatiot, T., Dreyfus, G., Höglund-Isaksson, L. *et al.* (2024). The methane imperative. *Front. Sci*. 2 https://www.frontiersin.org/journals/science/articles/10.3389/fsci.2024.1349770/full

Springmann, M., Wiebe, K., Mason-D'Croz, D., Sulser, T.B., Rayner, M. and Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: A global modelling analysis with country-level detail. *Lancet Planetary Health.* 2. 10. E451–E461. https://www.thelancet.com/journals/lanpla/article/PIIS2542-5196(18)30206-7/fulltext

Tamire, M., Mor, S.M., Baylis, M. and Kaba, M. (2025). Perceived impacts of climate change in pastoralist regions of Ethiopia: A qualitative study applying the concept of One Health. International Journal of *Environmental Research and Public Health*. 22. 2. 257. https://doi.org/10.3390/ijerph22020257

Udo, H.M.J., Aklilu, H.A., Phong, L.T., Bosma, R.H., Budisatria, I.G.S., Patil, B.R. *et al.* (2011). Impact of intensification of different types of livestock production in smallholder crop-livestock systems. *Livestock Science.* 139:22-29. https://doi.org/10.1016/j.livsci.2011.03.020

UNEP. (2021). *Food Waste Index Report 2021*. Nairobi: United Nations Environment Programme

UNEP. (2021). *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions.* Nairobi: United Nations Environment Programme. https://pure.iiasa.ac.at/id/eprint/17202/

UNEP. (2024). *Global Nitrous Oxide Assessment.* Nairobi: United Nations Environment Programme. https://www.unep.org/resources/report/global-nitrous-oxide-assessment

UNEP and CCAC (2022). *Global Methane Assessment: 2030 Baseline Report.* Nairobi: United Nations Environment Programme and Climate and Clean Air Coalition. https://www.unep.org/resources/report/global-methane-assessment-2030-baseline-report

UNFCCC. (2024). National Inventory Submissions 2024. New York: United Nations Framework Convention on Climate Change.

USEPA, (2019) *Global Non-CO2 Greenhouse Gas Emission Projections & Marginal Abatement Cost Analysis: Methodology Documentation.* EPA-430-R-19-012. Washington D.C.: U.S. Environmental Protection Agency, RTI International, Abt Associates, Inc. and ICF. https://www.epa.gov/sites/default/files/2019-09/documents/nonco2_methodology_report.pdf.

USEPA. (2025). *Non-CO2 Greenhouse Gas Emission Projections & Mitigation.* Washington, D.C.: U.S. Environmental Protection Agency. https://www.epa.gov/global-mitigation-non-co2-greenhouse-gases

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S. *et al.* (2019). Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *The Lancet.* Volume 393, Issue 10170, p.447-492. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)31788-4/abstract

Zhang, Z., Poulter, B., Melton, J.R., Riley, W.J., Allen, G.H., Beerling, D.J. *et al.* (2025). Ensemble estimates of global wetland methane emissions over 2000–2020. *Biogeosciences.* 22(1): 305–21. https://bg.copernicus.org/articles/22/305/2025/

Chapter 3

Section 3.2

de Aragão Fernandes, F., Naran, B., Alberti, C., Wignarajah, D., Connolly, K. and Zhang, T. (2023). *Landscape of Methane Abatement Finance 2023*. San Francisco: Climate Policy Initiative. https://www.climatepolicyinitiative.org/publication/landscape-of-methane-abatement-finance-2023/

CCAC (2025). *Transforming Organic Waste with Black Soldier Flies: A Guide for Decision-Makers, Entrepreneurs, and Implementers to Unlock the Organic Waste Potential of Black Soldier Fly Systems.* Paris: Climate and Clean Air Coalition https://www.ccacoalition.org/resources/ccac-teap-report-transforming-organic-waste-black-soldier-flies-guide-decision-makers-entrepreneurs-and-implementers-unlock-organic-waste-potential-black-soldier-fly-systems

Crumpler, K., Wybieralska, A., Roffredi, L., Tanganelli, E., Angioni, C., Prosperi, P. *et al.* (2025). *Agrifood systems in nationally determined contributions: Global analysis.* Rome, Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd6284en

Damania, R., Balseca, E., de Fontaubert, C., Gill, J., Kim, K., Rentschler, J. *et al.* (2023). *Detox Development: Repurposing Environmentally Harmful Subsidies.* Washington DC: World Bank. http://hdl.handle.net/10986/39423

Deshpande, M.V., Kumar, N., Pillai, D., Krishna, V.V. and Jain, U. (2023). Greenhouse gas emissions from agricultural residue burning have increased by 75% since 2011 across India. *Science of the Total Environment.* 904. https://www.sciencedirect.com/science/article/pii/S0048969723055699

Eskander, S.M.S.U., and Fankhauser, S. (2020). Reduction in green- house gas emissions from national climate legislation. *Nat. Clim. Chang.* 10, 750–756. https://doi.org/10.1038/s41558-020-0831-z

Food and Agriculture Organization of the United Nations (2025). FAOSTAT agriculture sector emissions in 2022. https://www.fao.org/faostat/en/#data/GT [Accessed July 2025]

Galbiati, G.M. and Bernoux, M. (2024). *Climate-related development finance to agrifood systems, 2024 update.* Rome: Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/items/64e63441-6646-4bc5-8153-52153677e8b1

Lin, M, and Begho, T. (2022). Crop residue burning in South Asia: A review of the scale, effect, and solutions with a focus on reducing reactive nitrogen losses. *Journal of Environmental Management.* 314. https://www.sciencedirect.com/science/article/pii/S0301479722006776

Lucchese-Cheung, T., de Aguiar, L.K., de Lima, L.C., Spers, E.E., Quevedo-Silva, F., Alves, F.V. *et al.* (2022). Brazilian carbon neutral beef as an innovative product: consumption perspectives based on intentions' framework. *J. Food Prod. Market.* 27, 384–398. https://doi.org/10.1080/10454446.2022.2033663

Malerba, M.E., de Kluyver, T., Wright, N., Schuster, L. and Macreadie, P.L. (2022). Methane emissions from agricultural ponds are underestimated in national greenhouse gas inventories. *Communications Earth & Environment.* 3, 306. https://doi.org/10.1038/s43247-022-00638-9

Melvin, A.M., Sarofim, M.C. and Crimmins, A.R. (2016). Climate benefits of U.S. EPA programs and policies that reduced methane emissions 1993–2013. *Environmental Science & Technology.* 50(13), 6873–6881. https://doi.org/10.1021/acs.est.6b00367

Nabuurs, G-J., Mrabet, R., Abu Hatab, A., Bustamante, M., Clark, H., Havlík, P. *et al.* (2022). Agriculture, Forestry and Other Land Uses (AFOLU). In Intergovernmental Panel on Climate Change (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter07.pdf

Nascimento, L., Kuramochi, T., Iacobuta, G., den Elzen, M., Fekete, H., Weishaupt, M. *et al.* (2022). Twenty years of climate policy: G20 coverage and gaps. *Clim. Pol.* 22, 158–174. https://newclimate.org/sites/default/files/2022-03/twenty_years_of_climate_policy.pdf

Olczak, M., Piebalgs, A. and Balcombe, P. (2023). A global review of methane policies reveals that only 13% of emissions are covered with unclear effectiveness. *One Earth.* 6, 519-535. https://doi.org/10.1016/j.oneear.2023.04.009

Saunois, M., Stavert, A.R., Poulter, B., Bousquet, P., Canadell, J.G., Jackson, R.B. *et al.* (2020). The global methane budget 2000–2017. *Earth Syst. Sci. Data.* 12, 1561–1623. https://doi.org/10.5194/essd-12-1561-2020

Schmidt, N.M., and Fleig, A. (2018). Global patterns of national climate policies: analyzing 171 country portfolios on climate policy integration. *Environ. Sci. Pol.* 84, 177–185. http://dx.doi.org/10.1016/j.envsci.2018.03.003

Shyamsundar, P., Springer, N.P., Tallis, H., Polasky, S., Jat, M.L., Sidhu, H.S., *et al.* (2019). Fields on fire: alternatives to crop residue burning in India. Science. 365, 536–538. https://doi.org/10.1126/science.aaw4085

UNEP-Convened Climate and Clean Air Coalition (2024). *Leveraging the Benefits of non-CO_2 Pollutants and Air Quality in NDC 3.0: Guidance on Including Methane in Nationally Determined Contributions.* https://www.ccacoalition.org/sites/default/files/resources/files/Guidance%20on%20Including%20Methane%20in%20NDC%203.0_17%20Oct_0.pdf

Zhang, L., Wang, X., Huang, L., Wang, C., Goa, Y., Pang, S. *et al.* (2024). Inventory of methane and nitrous oxide emissions from freshwater aquaculture in China. *Commun Earth Environ.* 5, 531. https://doi.org/10.1038/s43247-024-01699-8

Zhu, M., Smith, S.J., Chen, M., Evans, M., Chai, Q., Teng, F. *et al.* (2024). A comparative review of methane policies of the United States and China in the context of US-China climate cooperation. *Climate Policy.* 25(2), 171–189. https://doi.org/10.1080/14693062.2024.2366902

Section 3.3

Agri-PDB Platform. (2023). Working group of the Agricultural Public Development Banks: *What tools for financing adaptation to climate change?* Rome: International Fund for Agricultural Development https://www.agri-pdb.org/wp-content/uploads/2024/04/en-concept-notes-what-tools-for-financing-adaption-to-cc.pdf

Ahmed, S., Kumar, V., Uz Zaman, A., Dewan, M.R., Khatun, A., Hossain, K. *et al.* (2025). Dry direct-seeded and broadcast rice: A profitable and climate-smart alternative to puddled transplanted aus rice in Bangladesh. *Field Crops Research.* 322. https://doi.org/10.1016/j.fcr.2025.109739

Ayandele, E., Frankiewicz, T. and Wu, Y. (2024). A Playbook for Municipal Solid Waste Methane Mitigation: Recommendations Based on Global Waste Management Archetypes. Basalt, CO: RMI. https://rmi.org/wp-content/uploads/dlm_uploads/2024/03/wastemap_global_strategy_playbook.pdf

Beauchemin, K.A., Ungerfeld, E.M., Abdalla, A.L., Álvarez, C., Arndt, C., Becquet, P., *et al.* (2022). Invited review: current enteric methane mitigation options. *Journal of Dairy Science.* 105(12), 9297-9326. https://doi.org/10.3168/jds.2022-22091

Binietoglou, I., Turitto, J. and Tzompa Sosa, Z. (2023). *A guide to monitoring and quantifying methane emissions from the oil and gas sector.* Boston, MA: Clean Air Task Force. https://www.catf.us/2023/02/guide-monitoring-quantifying-methane-emissions-oil-gas-sector/

Borchardt, J., Harris, H.J., Hacker, J.M., Lunt, M., Krautwurst, S., Bai, M. *et al.* (2025). Insights into Elevated Methane Emissions from an Australian Open-Cut Coal Mine Using Two Independent Airborne Techniques. *Environmental Science & Technology Letters*, 12(4). https://pubs.acs.org/doi/10.1021/acs.estlett.4c01063

Bufoni, A.L., Oliveira, L.B. and Rosa, L.P. (2016). The declared barriers of the large developing countries waste management projects: The STAR model. *Waste Management.* Volume 9787. https://pubmed.ncbi.nlm.nih.gov/27020343/

Cahir, b. (2021), Why ExxonMobil's Permian net zero plan by 2030 matters. Huston, TX: ExxonMobil. https://corporate.exxonmobil.com/news/viewpoints/why-exxonmobils-permian-net-zero-plan-by-2030-matters#:~:text=Equipment%20upgrades%3A%20We've%20already,air%2C%20which%20eliminates%20methane%20emissions

California Air Resources Board. (2025). Cap-and-Trade Program. Sacramento, CA: California Air Resources Board. https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program

California Air Resources Board. (2025). Mine Methane Capture (MMC) Projects. Sacramento: California Air Resources Board. https://ww2.arb.ca.gov/our-work/programs/compliance-offset-program/compliance-offset-protocols/mine-methane-capture-projects

Carbon Limits. (2025). Methane Emissions Inventory for your company. Oslo: Carbon Limits https://www.mist.carbonlimits.no/

CATF. (2013). Methane Emissions from the Oil and Gas Sector: *Barriers to abatement and technologies for emission reductions.* Boston, MA: Clean Air Task Force. https://cdn.catf.us/wp-content/uploads/2019/02/21093826/CATF_Pub_BarriersOpportunitiesOilGasSector.pdf

CCAC. (2022). Reducing methane emissions from Mexico's oil and gas sector. Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/projects/reducing-methane-emissions-mexicos-oil-and-gas-sector

CCAC. (2023). Lowering Organic Waste Methane (LOW-Methane). Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/content/low-methane

CCAC. (2025a). Benefits and Costs of Mitigating Methane Emissions. [Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/content/benefits-and-costs-mitigating-methane-emissions

CCAC. (2025b). Fossil Fuel Regulatory Programme (FFRP). Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/content/fossil-fuel-regulatory-programme-ffrp

Chen, G., Bai, J., Bi, C., Wang, Y. and Cui, B. (2023). Global greenhouse gas emissions from aquaculture: a bibliometric analysis. *Agriculture, Ecosystems and Environment.* 348. https://doi.org/10.1016/j.agee.2023.108405

Climate Change Authority. (2023). 2023 *review of the National Greenhouse and Energy Reporting legislation.* Canberra: Climate Change Authority

Code of Federal Regulations. (2025). 60.5390b What GHG and VOC standards apply to process controller affected facilities? https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-60/subpart-OOOOb/section-60.5390b

Crumpler, K., Wybieralska, A., Roffredi, L., Tanganelli, E., Angioni, C., Prosperi, P. (2025). *Agrifood systems in Nationally Determined Contributions: Global Analysis.* Rome: Food and Agriculture Organization of the United Nations

Datta, A., Das, S., Manjunath, K.R. and Adhya, T.K. (2012). Comparison of two methods for the estimation of greenhouse gas flux from rice ecosystems in India. *Greenhouse Gas Measurement and Management.* 2(1), 43–49. https://doi.org/10.1080/20430779.2012.699771

DCCEEW. (2024). *Safeguard Mechanism.* Department of Climate Change, Energy, the Environment and Water, Australian Government. https://www.dcceew.gov.au/sites/default/files/documents/safeguard-mechanism-reforms-factsheet-2023.pdf?utm_source=chatgpt.com

de Aragao P., Naran B., Alberti C., Wignarajah D., Connolly J. and Zhang T. (2023). *Landscape of Methane Abatement Finance 2023.* San Francisco, CA: Climate Policy Initiative. https://www.climatepolicyinitiative.org/publication/landscape-of-methane-abatement-finance-2023/

Estrada, L.A., Varon, D.J., Sulprizio, M., Nesser, H., Chen, Z., Balasus, N. *et al.* (2024). Integrated Methane Inversion (IMI) 2.0: an improved research and stakeholder tool for monitoring total methane emissions with high resolution worldwide using TROPOMI satellite observations, *EGUsphere [preprint].* https://doi.org/10.5194/egusphere-2024-2700

EU. (2024). Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on the reduction of methane emissions in the energy sector and amending Regulation (EU) 2019/942 (Text with EEA relevance). Brussels: European Union. http://data.europa.eu/eli/reg/2024/1787/oj

European Commission. (2018). *Directive (EU) 2018/850 on the landfill of waste.* Brussels: European Union. https://eur-lex.europa.eu/eli/dir/2018/850/oj/eng

European Commission. (2024). Methane Emissions. Brussels: European Union. https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/methane-emissions_en#eu-methane-strategy

FAO. (2023a). FAOSTAT Climate Change: Agrifood systems emissions, Emissions Totals. Rome: Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat/en/#data/GT

FAO. (2024). Food Systems-Based Dietary Guidelines: Na Overview. Rome: Food and Agriculture Organization of the United Nations. https://openknowledge.

Feldman, L., Turitto, J. and Patel, H. (2025). Hidden flares: How joint ventures can obscure accountability for dirty assets. Boston, MA: Clean Air Task Force. https://www.catf.us/2025/03/hidden-flares-joint-ventures-obscure-accountability-dirty-assets/

Gaihre, Y.K., Islam, S.M.M. and Singh, U. (2025). Managing rice soils for mitigating greenhouse gases emissions. In: Kumar, S. and Meena, R.S. (eds.). *Agriculture Toward Net Zero Emissions.* Cambridge, MA: Academic Press. https://doi.org/10.1016/B978-0-443-13985-7.00021-X

Galbiati, G.M. and Bernoux, M. 2024. *Climate-related development finance to agrifood systems, 2024 update.* Rome: Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/items/64e63441-6646-4bc5-8153-52153677e8b1

GMI. (2024). Global Methane Initiative (GMI): Leading methane action since 2004. Geneva: Global Methane Initiative. https://www.globalmethane.org/

GMI. (2025). Global Methane Initiative. Geneva: Global Methane Initiative. https://www.globalmethane.org/index.aspx

GMI. (n.d.) Final Regulation Guidelines for the Prevention and Integral Control of Methane Emissions from the Hydrocarbon Sector. Geneva: Global Methane Initiative. https://globalmethane.org/challenge/mexico.html

GMP. (2022). Global Methane Pledge Waste Pathway. Paris: Climate and Clean Air Coalition. https://www.globalmethanepledge.org/annual-report/waste-pathway

GMP. (2024). Factsheet: 2024 Global Methane Pledge Ministerial. Paris: Climate and Clean Air Coalition. https://www.globalmethanepledge.org/news/factsheet-2024-global-methane-pledge-ministerial

Gobierno de México. (2024). *Primer Informe Bienal de Transparencia ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático.* Mexico City: Government of Mexico. https://unfccc.int/sites/default/files/resource/IBT1_libro_29ENE2025.pdf?download

Government of Nepal. (2020). Second Nationally Determined Contribution (NDC). Kathmandu: Government of Nepal. http://climate.mohp.gov.np/attachments/article/167/Second%20Nationally%20Determined%20Contribution%20(NDC)%20-%202020.pdf

Habib, M.A., Islam, S.M.M., Haque, M.A., Hassan, L., Ali, M.Z., Nayak, S. *et al.* (2023). Effects of Irrigation Regimes and Rice Varieties on Methane Emissions and Yield of Dry Season Rice in Bangladesh. *Soil Syst.* 7. https://doi.org/10.3390/soilsystems7020041

IDB. (2023). Too good to waste: Initiative to mitigate methane emissions from waste in LAC. Washington, D.C.: Inter-American Development Bank. https://www.iadb.org/en/project/RG-T4317

IEA. (2020). *Outlook for biogas and biomethane: Prospects for organic growth.* Paris: International Energy Agency. https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth

IEA. (2021). *Driving Down Methane Leaks from the Oil and Gas Industry.* Paris: International Energy Agency. https://www.iea.org/reports/driving-down-methane-leaks-from-the-oil-and-gas-industry

IEA. (2023). *The imperatives of cutting methane from fossil fuels.* Paris: International Energy Agency. https://www.iea.org/reports/the-imperative-of-cutting-methane-from-fossil-fuels

IEA. (2025). *Global Methane Tracker 2025.* Paris: International Energy Agency. https://www.iea.org/reports/global-methane-tracker-2025

IPCC. (2007). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC.* Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar4/wg3/

IPCC. (2021). Climate Change 2021: *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC.* Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/

Islam, S.M.M., Gaihre, Y.K., Islam, M.R., Akter, M., Mahmud, A.A., Singh, U. *et al.* (2020). Effects of water management on greenhouse gas emissions from farmers' rice fields in Bangladesh. *Science of The Total Environment.* 734, doi.org/10.1016/j.scitotenv.2020.139382

Islam, S.M.M., Gaihre, Y.K., Islam, M.R., Ahmed, M.N., Akter, M., Singh, U. *et al.* (2022). Mitigating greenhouse gas emissions from irrigated rice cultivation through improved fertilizer and water management. *Journal of Environmental Management.* 307. doi.org/10.1016/j.jenvman.2022.114520

Islam, S.M.M., Gaihre, Y.K., Islam, M.N., Jahan, A., Sarkar, M.A.R., Singh, U. *et al.* (2024). Effects of integrated nutrient management and urea deep placement on rice yield, nitrogen use efficiency, farm profits and greenhouse gas emissions in saline soils of Bangladesh. *Science of The Total Environment.* 909. https://doi.org/10.1016/j.scitotenv.2023.168660

Ivanovich, C.C., Sun, T., Gordon, D.R. and Ocko, I.B. (2023). Future warming from global food consumption. *Nature Climate Change,* 13, 297–302.

Jacob, D.J., Varon, D.J., Cusworth, D.H., Dennison, P.E., Frankenberg, C., Gautam, R. *et al.* (2022). Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane, *Atmos. Chem. Phys.* 22 (14), 9617-9646. https://acp.copernicus.org/articles/22/9617/2022/

Jahangir, M.M.R., Bell, R.W., Uddin, S., Ferdous, J., Nasreen, S.S., Haque, M.E. *et al.* (2022). Conservation Agriculture With Optimum Fertilizer Nitrogen Rate Reduces GWP for Rice Cultivation in Floodplain Soils. *Front Environ Sci.* 10. https://doi.org/10.3389/fenvs.2022.853655

Kaur, M., Dheri, G.S., Brar, A.S. and Kalia, A. (2024). Methane and nitrous oxide emissions in rice fields influenced with duration of cultivars and irrigation regimes. *Agric Ecosyst Environ.* 365, 108923. https://doi.org/10.1016/j.agee.2024.108923

Kazakhstan. (2021) Environmental Code of the Republic of Kazakhstan (Code No. 400-VI ZRK of 2021). https://policy.asiapacificenergy.org/node/3706/portal?_gl=1*lf2zso*_ga*MTcyMzQ2MDM5MC4xNzQzNzAyMTQ1*_ga_NV2GF32X0C*MTc0MzcwMjE0NS4xLjEuMTc0MzcwMjE1OS4wLjAuMA..*_ga_SB1ZX36Y86*MTc0MzcwMjE0NS4xLjEuMTc0MzcwMjE1OS40Ni4wLjA

Kholod, N., Evans, M., Pilcher, R.C., Roshchanka, V., Ruiz, F., Coté, M. *et al.* (2020). Global methane emissions from coal mining to continue growing even with declining coal production, *Journal of Cleaner Production.* Volume 256, 120489. https://doi.org/10.1016/j.jclepro.2020.120489

Kosten, S., Almeida, R.M., Barbosa, I., Mendonça, R., Santos Muzitano, I., Sobreira Oliveira-Junior, E. *et al.* (2020). Better assessments of greenhouse gas emissions from global fish ponds needed to adequately evaluate aquaculture footprint. *Science of the Total Environment.* Vol. 748. https://doi.org/10.1016/j.scitotenv.2020.141247

Lauvaux, T., Giron, C., Mazzolini, M., D'Aspremont, A., Duren, R., Cusworth, D. *et al.* (2022). Global assessment of oil and gas methane ultra-emitters. *Science.* 375. https://doi.org/10.1126/science.abj4351

Malerba, M.E., de Kluyver, T., Wright, N., Schuster, L. and Macreadie, P.L. (2022). Methane emissions from agricultural ponds are underestimated in national greenhouse gas inventories. *Communications Earth & Environment.* 3:306. https://doi.org/10.1038/s43247-022-00638-9

Markgraf, C. and Kaza, S. (2016). *Financing Landfill Gas Projects in Developing Countries.* Washington D.C.: World Bank. https://documents1.worldbank.org/curated/en/591471490358551160/pdf/AUS106805-100p-financing-landfill-projects.pdf

MEU. (2023). Your guide to understanding the Safeguard Mechanism. Sydney: Mining and Energy Union. https://meu.org.au/your-guide-to-understanding-the-safeguard-mechanism/?utm_source=chatgpt.com

Palmer, P.I., Feng, L., Lunt, M.F., Parker, R.J., Bösch, H., Lan, X. *et al.* (2021). The added value of satellite observations of methane for understanding the contemporary methane budget. *Philosophical Transactions of the Royal Society A.* 379(2210), p.20210106. https://pmc.ncbi.nlm.nih.gov/articles/PMC8554821/

Pazhanivelan, S., Sudarmanian , N.S., Geethalakshmi, V. and Deiveegan M. (2024). Assessing Methane Emissions from Rice Fields in Large Irrigation Projects Using Satellite-Derived Land Surface Temperature and Agronomic Flooding: A Spatial Analysis. *Agriculture.* 14, 3. doi:10.3390/agriculture14030496

Pemex. (2025). *Programa anual, Programa anual de adquisiciones, arrendamientos, obras y servicios (PAC).* Mexico City: Pemex. https://www.pemex.com/procura/procedimientos-de-contratacion/Paginas/programas.aspx

Pérez-Domínguez, I., del Prado, A., Mittenzwei, K., Hristov, J., Frank, S., Tabeau, A. *et al.* (2021). Short- and long-term warming effects of methane may affect the cost-effectiveness of mitigation policies and benefits of low-meat diets. *Nature Food.* pp. 970-980. https://www.nature.com/articles/s43016-021-00385-8

Qian, H., Zhu, X., Huang, S., Linquist, B., Kuzyakov, Y., Wassmann, R. *et al.* 2023. Greenhouse gas emissions and mitigation in rice agriculture. *Nat Rev Earth Environ.* https://doi.org/10.1038/s43017-023-00482-1

Sadavarte, P., Pandey, S., Maasakkers, J.D., Lorente, A., Borsdorff, T., Denier van der Gon, H. *et al.* (2021). Methane emissions from superemitting coal mines in Australia quantified using TROPOMI satellite observations. *Environmental Science & Technology.* 55(24). https://pubs.acs.org/doi/10.1021/acs.est.1c03976

Scharff, H., Soon, H-Y., Taremwa, S.R., Zegers, D., Dick, B., Villas Bôas Zanon, T. *et al.* (2023). The impact of landfill management approaches on methane emissions. Waste Management & Research. 42(11), pp. 1052-1064. doi:10.1177/0734242X231200742Scheutz, C., Kjeldsen, P., Bogner, J.E., De Visscher, A., Gebert, J., Hilger, H.A. *et al.* (2009). Microbial methane oxidation processes and technologies for mitigation of landfill gas emissions. *Waste Management & Research.* 27(5), pp. 409-455. doi: 10.1177/0734242X09339325

Shen, L., Zavala-Araiza, D., Gautam, R., Omara, M., Scarpelli, T., Sheng, J. *et al.* (2021). Unravelling a large methane emission discrepancy in Mexico using satellite observations. *Remote Sensing of Environment,* 260, 112461. https://doi.org/10.1016/j.rse.2021.112461

UNECE. (2025). Group of Experts on Coal Mine Methane and Just Transition. Geneva: United Nations Economic Commission for Europe. https://unece.org/sustainable-energy/committee-sustainable-energy/group-experts-coal-mine-methane-and-just-transition

UNEP. (2022). *Global Methane Assessment: 2030 Baseline Report.* Nairobi: United Nations Environement Programme. https://www.unep.org/resources/report/global-methane-assessment-2030-baseline-report

UNEP. (2023). Urgent action to cut methane emissions from fossil fuel operations essential to achieve global climate targets. Nairobi: United Nations Environment Programme. https://www.unep.org/news-and-stories/press-release/urgent-action-cut-methane-emissions-fossil-fuel-operations-essential

UNEP-CCAC. (2024). *Leveraging the Benefits of non-CO_2 Pollutants and Air Quality in NDC 3.0: Guidance on Including Methane in Nationally Determined Contributions.* Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/sites/default/files/resources/files/Guidance%20on%20Including%20Methane%20in%20NDC%203.0_17%20Oct_0.pdf

UNEP and CCAC. (2021). *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions.* Nairobi: United Nations Environment Programme; Paris: Climate and Clean Air Coalition

UNEP and ISWA. (2024). *Global Waste Management Outlook 2024: Beyond an age of waste.* Nairobi: United Nations Environment Programme; Rotterdam: International Solid Waste Association. https://www.unep.org/resources/global-waste-management-outlook-2024

UNFCCC. (2021). *République du Cameroun Nationally Determined Contribution* - Updated. New York: United Nations Framework Convention on Climate Change. https://unfccc.int/sites/default/files/NDC/2022-06/CDN%20r%C3%A9vis%C3%A9e%20CMR%20finale%20sept%202021.pdf

USEPA. (2019). *Status of CMM Ownership and Policy Incentives in Key Countries: Considerations for Decision Makers.* Washington, D.C.: United States Environmental Protection Agency. https://globalmethane.org/documents/CMM-ownership-policy_march-2019.pdf

USEPA. (2023). Landfill Methane Outreach Program (LMOP): Basic Information. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/lmop/about-landfill-methane-outreach-program

USEPA. (2025). United States Environment Protection Agency, Subpart FF – Underground Coal Mines. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/ghgreporting/subpart-ff-underground-coal-mines

Varon, D.J., Jacob, D.J., Sulprizio, M., Estrada, L.A., Downs, W.B., Shen, L. *et al.* (2022). Integrated Methane Inversion (IMI 1.0): a user-friendly, cloud-based facility for inferring high-resolution methane emissions from TROPOMI satellite observations*. Geosci. Model Dev.* 15(14). https://doi.org/10.5194/gmd-15-5787-2022

Vaughn, T.L., Bell, C.S., Pickering, C.K., Schwietzke, S., Heath, G.A., Pétron, G. *et al.* (2018). Temporal variability largely explains topdown/bottom-up difference in methane emission estimates from a natural gas production region. *Proc. Natl. Acad. Sci*. 115, 11712–11717. https://doi.org/10.1073/pnas. 1805687115

Vo, T.B.T., Wassmann, R., Mai, V.T., Vu, D.Q., Bui, T.P.L., Vu, T.H. *et al.* (2020). Methane Emission Factors from Vietnamese Rice Production: Pooling Data of 36 Field Sites for Meta-Analysis. *Climate.* 8(6), 74 https://doi.org/10.3390/cli8060074

Vroom, R.J.E., Kosten, S., Almeida, R.M., Mendonça, R., Muzitano, I.S., Barbosa, I. *et al.* (2023). Widespread dominance of methane ebullition over diffusion in freshwater aquaculture ponds. *Frontiers in Water.* 5. https://doi.org/10.3389/frwa.2023.1256799

Wassmann, R., Alberto, M.C., Tirol-Padre, A., Hoang, N.T., Romasanta, R., Centeno, C.A. *et al.* (2018). Increasing sensitivity of methane emission measurements in rice through deployment of 'closed chambers' at nighttime. *PLoS ONE* 13(2): e0191352. https://doi.org/10.1371/journal.pone.0191352

Wilson, D.C., Paul, J., Ramola, A. and Silva Filho, C. (2024.) Unlocking the significant worldwide potential of better waste and resource management for climate mitigation: with particular focus on the Global South. *Waste Management & Research.* pp.1–13. https://doi.org/10.1177/0734242X241262717

World Bank. (2015). Zero Routine Flaring by 2030 (ZRF) Initiative. Washington, D.C.: World Bank. https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030

World Bank. (2025). Zero Routine Flaring by 2030 (ZRF) Initiative endorsers. Washington, D.C.: World Bank. https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030/endorsers

World Biogas Association. (2024a). *Policy and Market Briefing 2024*. London: World Biogas Association

World Biogas Association. (2024b). Brazil advances with a new regulatory framework for biofuels. London: World Biogas Association. https://www.worldbiogasassociation.org/brazil-advances-with-a-new-regulatory-framework-for-biofuels/

Yang, P., Tang, K.W., Yang, H., Tong, C., Zhang, L., Lai, D.Y.F. *et al.* (2023). Contrasting effects of aeration on methane (CH_4) and nitrous oxide (N_2O) emissions from subtropical aquaculture ponds and implications for global warming mitigation. *Journal of Hydrology.* 617. https://doi.org/10.1016/j.jhydrol.2022.128876

Zavala-Araiza, D., Omara, M., Gautam, R., Smith, M.L., Pandey, S., Aben, I. *et al.* (2021). A tale of two regions: Methane emissions from oil and gas production in offshore/onshore Mexico. *Environmental Research Letters*, 16(2). https://doi.org/10.1088/1748-9326/abceeb

Zhao, C., Qiu, R., Zhang, T., Luo, Y. and Agathokleous, E. (2024). Effects of Alternate Wetting and Drying Irrigation on Methane and Nitrous Oxide Emissions From Rice Fields: A Meta-Analysis. *Gob. Chang. Biol.* 30. https://onlinelibrary.wiley.com/doi/10.1111/gcb.17581

Zhang, L., Wang, X., Huang, L., Wang, C., Gao, Y., Peng, S. *et al.* (2024). Inventory of methane and nitrous oxide emissions from freshwater aquaculture in China. *Commun Earth Environ.* 5, 531. https://doi.org/10.1038/s43247-024-01699-8

Zhu, M., Behrendt, J., Cui, R., Hultman, N., Cheng, X., Li, W., Li, Y. *et al.* (2024). *Overview of methane mitigation policies in global key emitters beyond the United States and China.* College Park, MD: Center for Global Sustainability, University of Maryland. https://cgs.umd.edu/research-impact/publications/overview-methane-mitigation-policies-global-key-emitters-beyond-united

Zueva, S., Ferella, F., Corradini, V. and Vegliò, F. (2024). Review of Organic Waste-to-Energy (OWtE) Technologies as a Part of a Sustainable Circular Economy. *Energies.* 17(15:3797). https://doi.org/10.3390/en17153797

Section 3.4

Ayandele, E., Frankiewicz, T. and Wu, Y. (2024). *A Playbook for Municipal Solid Waste Methane Mitigation: Recommendations Based on Global Waste Management Archetypes.* Basalt, CO: RMI.

Bufoni, A.L., Oliveira, L.B. and Rosa, L.P. (2016). The declared barriers of the large developing countries waste management projects: The STAR model. *Waste Management.* Volume 9787. https://www.researchgate.net/publication/299210170_The_declared_barriers_of_the_large_developing_countries_waste_management_projects_The_STAR_model

CATF. (2025). *Four countries have effectively reduced their waste methane emissions through policy action. Here's what they have in common.* Boston, MA: Clean Air Task Force. https://www.catf.us/2025/05/four-countries-have-effectively-reduced-waste-methane-emissions-policy-action-heres-have-common/

CCAC. (2023). Lowering Organic Waste Methane (LOW-Methane). Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/content/low-methane

CCAC. (2025). Benefits and Costs of Mitigating Methane Emissions. Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/content/benefits-and-costs-mitigating-methane-emissions

European Commission. (2018). Directive (EU) 2018/850 on the landfill of waste. Brussels: European Union. https://eur-lex.europa.eu/eli/dir/2018/850/oj/eng

GMI. (2004). Global Methane Initiative (GMI): Leading methane action since 2004. Geneva: Global Methane Initiative. https://www.globalmethane.org/

GMP. (2022). Global Methane Pledge Waste Pathway. Paris: Climate and Clean Air Coalition. https://www.globalmethanepledge.org/annual-report/waste-pathway

GMP. (2024). Factsheet: 2024 Global Methane Pledge Ministerial. Paris: Climate and Clean Air Coalition. https://www.globalmethanepledge.org/news/factsheet-2024-global-methane-pledge-ministerial

Gobierno de México. (2024). *Primer Informe Bienal de Transparencia ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático.* Mexico City: Government of Mexico. https://unfccc.int/sites/default/files/resource/IBT1_libro_29ENE2025.pdf?download

Government of Nepal. (2020). Second Nationally Determined Contribution (NDC). Kathmandu: Government of Nepal. http://climate.mohp.gov.np/attachments/article/167/Second%20Nationally%20Determined%20Contribution%20(NDC)%20-%202020.pdf

IDB. (2023). Too good to waste: Initiative to mitigate methane emissions from waste in LAC. Washington, D.C.: Inter-American Development Bank. https://www.iadb.org/en/project/RG-T4317

IEA. (2020). *Outlook for biogas and biomethane: Prospects for organic growth.* Paris: International Energy Agency. https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth

IPCC. (2007). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC.* Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar4/wg3/

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC.* Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg1/

Markgraf, C. and Kaza, S. (2016). *Financing Landfill Gas Projects in Developing Countries.* Washington D.C.: World Bank. https://documents1.worldbank.org/curated/en/591471490358551160/pdf/AUS106805-100p-financing-landfill-projects.pdf

Pérez-Domínguez, I., del Prado, A., Mittenzwei, K., Hristov, J., Frank, S., Tabeau, A. *et al.* (2021). Short- and long-term warming effects of methane may affect the cost-effectiveness of mitigation policies and benefits of low-meat diets. *Nature Food.* pp. 970-980. https://www.nature.com/articles/s43016-021-00385-8

Scharff, H., Soon, H-Y., Taremwa, S.R., Zegers, D., Dick, B., Villas Bôas Zanon, T. *et al.* (2023). *The impact of landfill management approaches on methane emissions. Waste Management & Research.* 42(11), pp. 1052-1064. doi:10.1177/0734242X231200742

Scheutz, C., Kjeldsen, P., Bogner, J.E., De Visscher, A., Gebert, J., Hilger, H.A. *et al.* (2009). Microbial methane oxidation processes and technologies for mitigation of landfill gas emissions. *Waste Management & Research.* 27(5), pp. 409-455. doi: 10.1177/0734242X09339325

UNEP. (2022). *Global Methane Assessment: 2030 Baseline Report.* Nairobi: United Nations Environement Programme. https://www.unep.org/resources/report/global-methane-assessment-2030-baseline-report

UNEP and ISWA. (2024). *Global Waste Management Outlook 2024: Beyond an age of waste.* Nairobi: United Nations Environment Programme; Rotterdam: International Solid Waste Association. https://www.unep.org/resources/global-waste-management-outlook-2024

UNFCCC. (2021). *République du Cameroun Nationally Determined Contribution - Updated.* New York: United Nations Framework Convention on Climate Change. https://unfccc.int/sites/default/files/NDC/2022-06/CDN%20r%C3%A9vis%C3%A9e%20CMR%20finale%20sept%202021.pdf

USEPA. (2023). Landfill Methane Outreach Program (LMOP): Basic Information. Washington, D.C.: United States Environmental Protection Agency. https://www.epa.gov/lmop/about-landfill-methane-outreach-program

Wilson, D.C., Paul, J., Ramola, A. and Silva Filho, C. (2024.) Unlocking the significant worldwide potential of better waste and resource management for climate mitigation: with particular focus on the Global South. *Waste Management & Research.* pp.1–13. https://doi.org/10.1177/0734242X241262717

World Biogas Association. (2024a). *Policy and Market Briefing 2024.* London: World Biogas Association

World Biogas Association. (2024b). Brazil advances with a new regulatory framework for biofuels. London: World Biogas Association. https://www.worldbiogasassociation.org/brazil-advances-with-a-new-regulatory-framework-for-biofuels/

Zueva, S., Ferella, F., Corradini, V. and Vegliò, F. (2024). Review of Organic Waste-to-Energy (OWtE) Technologies as a Part of a Sustainable Circular Economy. *Energies.* 17(15:3797). https://doi.org/10.3390/en17153797

Section 3.5

Climate and Clean Air Coalition (2024). *Role of Digital (Extension) Services for Livestock on Tackling Methane Emissions.* Paris. https://www.ccacoalition.org/resources/ccac-teap-report-role-digital-extension-services-livestock-tackling-methane-emissions

Crumpler, K., Wybieralska, A., Roffredi, L., Tanganelli, E., Angioni, C., Prosperi, P. *et al.* (2025). Agrifood systems in nationally determined contributions: Global analysis. Rome, FAO. Olczak, M., Piebalgs, A. & Balcombe, P. 2023. A global review of methane policies reveals that only 13% of emissions are covered with unclear effectiveness. *One Earth.* 6, 519-535. https://doi.org/10.1016/j.oneear.2023.04.009

Damania, R., Balseca, E., de Fontaubert, C., Gill, J., Kim, K., Rentschler, J. *et al.* (2023). *Detox Development: Repurposing Environmentally Harmful Subsidies.* Washington, D.C.: World Bank. http://hdl.handle.net/10986/39423

de Aragao P., Naran B., Alberti C., Wignarajah D., Connolly J. and Zhang T. (2023). *Landscape of Methane Abatement Finance 2023.* San Francisco, CA: Climate Policy Initiative. https://www.climatepolicyinitiative.org/publication/landscape-of-methane-abatement-finance-2023/

Eskander, S.M.S.U. and Fankhauser, S. (2020). Reduction in greenhouse gas emissions from national climate legislation. *Nat. Clim. Chang.* 10, 750–756. https://doi.org/10.1038/s41558-020-0831-z

FAO. (2025). *Greenhouse gas emissions from agrifood systems: global, regional and country trends, 2000–2022.* Rome: Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/items/74bfebdb-3272-4e6a-98f4-ee36c7146d44

Galbiati, G.M. and Bernoux, M. (2024). *Climate-related development finance to agrifood systems, 2024 update.* Rome: Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/items/64e63441-6646-4bc5-8153-52153677e8b1

Lucchese-Cheung, T., de Aguiar, L.K., Lima, L.C.d., Spers, E.E., Quevedo-Silva, F., Alves, F.V. *et al.* (2022). Brazilian carbon neutral beef as an innovative product: consumption perspectives based on intentions' framework. *J. Food Prod. Market.* 27, 384–398. https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/1150393/1/Brazilian-carbon-neutral-beef-2021.pdf

Malerba, M.E., de Kluyver, T., Wright, N., Schuster, L. and Macreadie, P.L. (2022). Methane emissions from agricultural ponds are underestimated in national greenhouse gas inventories. *Communications Earth & Environment.* 3:306. https://doi.org/10.1038/s43247-022-00638-9

Melvin, A.M., Sarofim, M.C. and Crimmins, A.R. (2016). Climate benefits of U.S. EPA programs and policies that reduced methane emissions 1993–2013. *Environmental Science & Technology.* 50(13), 6873–6881. https://doi.org/10.1021/acs.est.6b00367

Deshpande, M.V., Kumar, N., Pillai, D., Krishna, V.V. and Jain, M. (2023), Greenhouse gas emissions from agricultural residue burning have increased by 75 % since 2011 across India. *Science of The Total Environment.* Volume 904, 166944. https://www.sciencedirect.com/science/article/pii/S0048969723055699?via%3Dihub

Lin, M. and Begho, T. (2022). Crop residue burning in South Asia: A review of the scale, effect, and solutions with a focus on reducing reactive nitrogen losses. *Journal of Environmental Management.* Volume 314, 115104. https://doi.org/10.1016/j.jenvman.2022.115104

Nascimento, L., Kuramochi, T., Iacobuta, G., den Elzen, M., Fekete, H., Weishaupt, M. *et al.* (2022). Twenty years of climate policy: G20 coverage and gaps. *Clim. Pol.* 22, 158–174. https://doi.org/10.1080/14693062.2021.1993776

Nabuurs, G-J., Mrabet, R., Abu Hatab, A., Bustamante, M., Clark, H., Havlík, P, *et al.* (2022). Agriculture, Forestry and Other Land Uses (AFOLU). In IPCC. (2022). *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf

Olczak, M., Piebalgs, A. and Balcombe, P. (2023). A global review of methane policies reveals that only 13% of emissions are covered with unclear effectiveness. *One Earth.* Volume 6, Issue 5, 19 May 2023, Pages 519-535. https://doi.org/10.1016/j.oneear.2023.04.009

Schmidt, N.M. and Fleig, A. (2018). Global patterns of national climate policies: analyzing 171 country portfolios on climate policy integration. *Environ. Sci.* Pol. 84, 177–185. https://doi.org/10.1016/j.envsci.2018.03.003

Saunois, M., Stavert, A.R., Poulter, B., Bousquet, P., Canadell, J.G., Jackson, R.B. *et al.* (2020). The global methane budget 2000–2017. *Earth Syst. Sci.* Data 12, 1561–1623. https://doi.org/10.5194/essd-12-1561-2020

Shyamsundar, P., Springer, N.P., Tallis, H., Polasky, S., Jat, M.L., Sidhu, H.S. *et al.* (2019). Fields on fire: alternatives to crop residue burning in India. *Science.* 365, 536–538. https://doi.org/10.1126/science.aaw4085

UNEP-CCAC. (2024a). *Leveraging the Benefits of non-CO_2 Pollutants and Air Quality in NDC 3.0.* Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/sites/default/files/resources/files/Guidance%20on%20Including%20Methane%20in%20NDC%203.0_17%20Oct_0.pdf

UNEP-CCAC. (2024b). *Guidance on Including Methane in Nationally Determined Contributions.* Paris: Climate and Clean Air Coalition. https://www.ccacoalition.org/sites/default/files/resources/files/Guidance%20on%20Including%20Methane%20in%20NDC%203.0_17%20Oct_0.pdf

Zhang, L., Wang, X., Huang, L., Wang, C., Gao, Y., Peng, S. *et al.* Inventory of methane and nitrous oxide emissions from freshwater aquaculture in China. *Commun Earth Environ 5*. 531 (2024). https://doi.org/10.1038/s43247-024-01699-8

Zhu, M., Smith, S.J., Chen, M., Evans, M., Chai, Q., Teng, F. *et al.* (2024): A comparative review of methane policies of the United States and China in the context of US – China climate cooperation. *Climate Policy.* 25(2). doi: 10.1080/14693062.2024.2366902
Section 3.6

UNECE. (2021). *Draft report on the review of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, as amended in 2012.* ECE/EB.AIR/WG.5/2022/3. Geneva: United Nations Economic Commission for Europe. https://unece.org/sites/default/files/2022-02/ECE_EB.AIR_WG.5_2022_3-2201159E.pdf

UNECE. (2022). *Hemispheric transport of air pollution. Report prepared by the Co-Chairs of the Task Force on Hemispheric Transport of Air Pollution.* ECE/EB.AIR/GE.1/2022/8–ECE/EB.AIR/WG.1/2022/19. Geneva: United Nations Economic Commission for Europe. https://unece.org/sites/default/files/2022-07/ECE_EB.AIR_GE.1_2022_8-2210410E.pdf

UNECE. (2025). UNECE Air Convention advances Gothenburg Protocol revision. Geneva: United Nations Economic Commission for Europe. https://unece.org/media/news/402715

Chapter 4

Alberto, M.C.R., Wassmann, R., Buresh, R.J., Quilty, J.R., Correa, T.Q., Sandro, J.M. *et al.* (2014). 'Measuring methane flux from irrigated rice fields by eddy covariance method using open-path gas analyzer'. *Field Crops Research.* 160, 12-21

Alvarez, R.A., Zavala-Araiza, D., Lyon, D.R., Allen, D.T., Barkley, Z.B., Brandt, A.R. *et al.* 2018. Assessment of methane emissions from the U.S. oil and gas supply chain'. *Science.* 361: 186-88.

Climate Change Authority. (2023). *2023 review of the National Greenhouse and Energy Reporting legislation.* Canberra: Climate Change Authority

Basu, S., Lan, X., Dlugokencky, E., Michel, S., Schwietzke, S., Miller, J.B., Bruhwiler, L. *et al.* (2022). Estimating emissions of methane consistent with atmospheric measurements of methane and δ13C of methane. Atmos. *Chem. Phys.* 22, 15351-77

Bell, C., Ilonze, C., Duggan, A. and Zimmerle, D. (2023). Performance of Continuous Emission Monitoring Solutions under a Single-Blind Controlled Testing Protocol. *Environmental Science & Technology.* 57, 5794-805

Bloom, A.A., Bowman, K.W., Lee, M., Turner, A.J., Schroeder, R., Worden, J.R. *et al.* (2024). *CMS: Global 0.5-deg Wetland Methane Emissions and Uncertainty (WetCHARTs v1.3.3) (Version 1.3.3).* Oak Redge, TN: Oak Ridge National Laboratory Distributed Active Archive Center. https://doi.org/10.3334/ORNLDAAC/2346

Borchardt, J., Harris, S.J., Hacker, J.M., Lunt, M., Krautwurst, S., Bai, M. *et al.* (2025). Insights into Elevated Methane Emissions from an Australian Open-Cut Coal Mine Using Two Independent Airborne Techniques. *Environmental Science & Technology Letters.* 12, 397-404

Bowman, L.V., El Hachem, K. and Kang, M. (2023). Methane Emissions from Abandoned Oil and Gas Wells in Alberta and Saskatchewan, Canada: The Role of Surface Casing Vent Flows. *Environmental Science & Technology.* 57, 19594-601

Buendia, E.C., Guendehou, S., Limmeechokchai, B., Pipatti, R., Rojas, Y., Sturgiss, R. *et al.* (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventory.* Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2019/05/01_2019rf_OverviewChapter.pdf

Chan, E., Vogel, F., Smyth, S., Barrigar, O., Ishizawa, M., Kim, J. *et al.* (2024). Hybrid bottom-up and top-down framework resolves discrepancies in Canada's oil and gas methane inventories. *Communications Earth & Environment.* 5, 566

Chen, Z., Jacob, D.J., Gautam, R., Omara, M., Stavins, R.N., Stowe, R.C. *et al.* (2023). Satellite quantification of methane emissions and oil–gas methane intensities from individual countries in the Middle East and North Africa: implications for climate action. *Atmos. Chem. Phys.* 23, 5945-67

Chen, Z., El Abbadi, S.H., Sherwin, E.D., Burdeau, P.M., Rutherford, J.S., Chen, Y. *et al.* (2024). Comparing Continuous Methane Monitoring Technologies for High-Volume Emissions: A Single-Blind Controlled Release Study. *ACS ES&T Air.* 1, 871-84

Cusworth, D.H., Duren, R.M., Ayasse, A.K., Jiorle, R., Howell, K.., Aubrey, A. *et al.* (2024). Quantifying methane emissions from United States landfills. *Science.* 383, 1499-504

Della Rosa, M.M., Jonker, A. and Waghorn, G.C. (2021). A review of technical variations and protocols used to measure methane emissions from ruminants using respiration chambers, SF6 tracer technique and GreenFeed, to facilitate global integration of published data. *Animal Feed Science and Technology.* 279, 115018

Duan, Z., Kjeldsen, P. and Scheutz, C. (2022). Efficiency of gas collection systems at Danish landfills and implications for regulations. *Waste Management.* 139, 269-78

El Abbadi, S.H., Chen, Z., Burdeau, P.M., Rutherford, J.S., Chen, Y., Zhang, Z. *et al.* (2024). Technological Maturity of Aircraft-Based Methane Sensing for Greenhouse Gas Mitigation. *Environmental Science & Technology.* 58, 9591-600

Estrada, L.A., Varon, D.J., Sulprizio, M., Nesser, H., Chen, Z., Balasus, N. *et al.* (2025). Integrated Methane Inversion (IMI) 2.0: an improved research and stakeholder tool for monitoring total methane emissions with high resolution worldwide using TROPOMI satellite observations. *Geosci. Model Dev.* 18, 3311-30

Fiehn, A., Kostinek, J., Eckl, M., Klausner, T., Gałkowski, M., Chen, J. *et al.* (2020). Estimating CH_4, CO_2 and CO emissions from coal mining and industrial activities in the Upper Silesian Coal Basin using an aircraft-based mass balance approach. *Atmos. Chem. Phys.* 20, 12675-95

Förster, E., Huntrieser, H., Lichtenstern, M., Pätzold, F., Bretschneider, L., Schlerf, A. *et al.* (2025). A helicopter-based mass balance approach for quantifying methane emissions from industrial activities, applied for coal mine ventilation shafts in Poland. *EGUsphere*. 2025, 1-26

Foulds, A., Allen, G., Shaw, J.T., Bateson, P., Barker, P.A., Huang, L. *et al.*(2022). Quantification and assessment of methane emissions from offshore oil and gas facilities on the Norwegian continental shelf. *Atmos. Chem. Phys*. 22, 4303-22

Gorroño, J., Varon, D.J., Irakulis-Loitxate, I. *and Guanter, L. (20*23). Understanding the potential of Sentinel-2 for monitoring methane point emissions. *Atmos. Meas. Tech.* 16, 89-107

Guanter, L., Roger, J., Sharma, S., Valverde, A., Irakulis-Loitxate, I., Gorroño, J. *et al.* (2024). 'Multisatellite Data Depicts a Record-Breaking Methane Leak from a Well Blowout. *Environmental Science & Technology Letters.* 11, 825-30

Guo, Y., Zhang, G., Abdalla, M., Kuhnert, M., Bao, H., Xu, H. *et al.* (2023). Modelling methane emissions and grain yields for a double-rice system in Southern China with DAYCENT and DNDC models. *Geoderma.* 431, 116364

Hancock, S.E., Jacob, D.J., Chen, Z., Nesser, H., Davitt, A., Varon, D.J. et al. (2025). Satellite quantification of methane emissions from South American countries: a high-resolution inversion of TROPOMI and GOSAT observations. *Atmos. Chem. Phys.* 25, 797-817

Ilonze, C., Wang, J., Ravikumar, A.P. and Zimmerle, D. (2024). Methane Quantification Performance of the Quantitative Optical Gas Imaging (QOGI) System Using Single-Blind Controlled Release Assessment. *Sensors*. 24, 4044

Irakulis-Loitxate, I., Guanter, L., Maasakkers, J.D., Zavala-Araiza, D. and Aben, I. (2022). Satellites Detect Abatable Super-Emissions in One of the World's Largest Methane Hotspot Regions. *Environmental Science & Technology.* 56, 2143-52

Jackson, R.B., Saunois, M., Martinez, A., Canadell, J.G., Yu, X., Li, M. *et al.* (2024). Human activities now fuel two-thirds of global methane emissions. *Environmental Research Letters.* 19, 101002

Jacob, D.J., Turner, A.J., Maasakkers, J.D., Sheng, J., Sun, K., Liu, X. *et al.* (2016). Satellite observations of atmospheric methane and their value for quantifying methane emissions. *Atmos. Chem. Phys.* 16, 14371-96

Jacob, D.J., Varon, D.J., Cusworth, D.H., Dennison, P.E., Frankenberg, C., Gautam, R. *et al.* (2022). Quantifying methane emissions from the global scale down to point sources using satellite observations of atmospheric methane. *Atmos. Chem. Phys.* 22, 9617-46

Johnson, M.R., Conrad, B.M. and Tyner, D.R. (2023). Creating measurement-based oil and gas sector methane inventories using source-resolved aerial surveys. *Communications Earth & Environment.* 4, 139

Kang, M., Christian, S., Celia, M.A., Mauzerall, D.L., Bill, M., Miller, A.R. (2016). Identification and characterization of high methane-emitting abandoned oil and gas wells. *Proceedings of the National Academy of Sciences.* 113, 13636-41

Karacan, C.Ö., Field, R.A., Olczak, M., Kasprzak, M., Ruiz, F.A. and Schwietzke, S. (2024). Mitigating climate change by abating coal mine methane: A critical review of status and opportunities. *International Journal of Coal Geology.* 295, 104623

Karacan, C.Ö., Irakulis-Loitxate, I., Field, R.A. and Warwick, P.D. (2025). Temporal and spatial comparison of coal mine ventilation methane emissions and mitigation quantified using PRISMA satellite data and on-site measurements. *Science of The Total Environment.* 975, 179268

Kholod, N., Evans, M., Pilcher, R.C., Roshchanka, V., Ruiz, F., Coté, M. *et al.* (2020). Global methane emissions from coal mining to continue growing even with declining coal production. *J Clean Prod.* 256, 120489

Krautwurst, S., Fruck, C., Wolff, S., Borchardt, J., Huhs, O., Gerilowski, K. *et al.* (2024). Identification and Quantification of CH_4 Emissions from Madrid Landfills using Airborne Imaging Spectrometry and Greenhouse Gas Lidar. *EGUsphere*. 2024, 1-52

Lauvaux, T., Giron, C., Mazzolini, M., d'Aspremont, A., Duren, R., Cusworth, D. *et al.* (2022). Global assessment of oil and gas methane ultra-emitters. *Science.* 375, 557-61

Liang, R., Zhang, Y., Hu, Q., Li, T., Li, S., Yuan, W. *et al.* (2024). Satellite-Based Monitoring of Methane Emissions from China's Rice Hub. *Environmental Science & Technology.* 58, 23127-37

Lin, G., Jiang, D., Zhang, W. and Fu, J. (2024). China should be wary of the methane emissions from mine closure. *The Innovation Energy.* 1, 100024

Liu, Q., Teng, F., Nielsen, C.P., Zhang, Y. and Wu, L. (2024). Large methane mitigation potential through prioritized closure of gas-rich coal mines. *Nature Climate Change.* 14, 652-58

Lorente, A., Borsdorff, T., Martinez-Velarte, M.C. and Landgraf, J. (2023). Accounting for surface reflectance spectral features in TROPOMI methane retrievals. *Atmos. Meas. Tech.* 16, 1597-608

Lu, X., Jacob, D.J., Zhang, Y., Shen, L., Sulprizio, M.P., Maasakkers, J.D. *et al.* (2023). Observation-derived 2010-2019 trends in methane emissions and intensities from US oil and gas fields tied to activity metrics. *Proceedings of the National Academy of Sciences.* 120, e2217900120

Lunt, M.F., Manning, A.J., Allen, G., Arnold, T., Bauguitte, S.J.B., Boesch, H. *et al.* (2021). Atmospheric observations consistent with reported decline in the UK's methane emissions (2013–2020). *Atmos. Chem. Phys.* 21, 16257-76

Maasakkers, J.D., Varon, D.J., Elfarsdóttir, A., McKeever, J., Jervis, D., Mahapatra, G. *et al.* (2022a). Using satellites to uncover large methane emissions from landfills. *Sci Adv.* 8, eabn9683

Maasakkers, J.D., Varon, D.J., Elfarsdóttir, A., McKeever, J., Jervis, D., Mahapatra, G. *et al.* (2022b). Using satellites to uncover large methane emissions from landfills. *Science Advances.* 8, eabn9683

McLinden, C.A., Griffin, D., Davis, Z., Hempel, C., Smith, J., Sioris, C. *et al.* (2024). An Independent Evaluation of GHGSat Methane Emissions: Performance Assessment. *Journal of Geophysical Research Atmospheres.* 129, e2023JD039906

Menoud, M., van der Veen, C., Lowry, D., Fernandez, J.M., Bakkaloglu, S., France, J.L. *et al.* (2022). New contributions of measurements in Europe to the global inventory of the stable isotopic composition of methane. *Earth Syst. Sci. Data.* 14, 4365-86

Michel, S.E., Lan, X., Miller, J., Tans, P., Clark, J.R., Schaefer, H. *et al.* (2024). Rapid shift in methane carbon isotopes suggests microbial emissions drove record high atmospheric methane growth in 2020–2022. *Proceedings of the National Academy of Sciences.* 121, e2411212121

Mønster, J., Kjeldsen, P. and Scheutz, C. (2019). Methodologies for measuring fugitive methane emissions from landfills – A review. *Waste Management.* 87, 835-59

Naus, S., Maasakkers, J.D., Gautam, R., Omara, M., Stikker, R., Veenstra, A.K. *et al.* (2023). Assessing the Relative Importance of Satellite-Detected Methane Superemitters in Quantifying Total Emissions for Oil and Gas Production Areas in Algeria. *Environmental Science & Technology*. 57, 19545-56

Necki, J.M., Bartyzel, J., Jagoda, P., Swolkień, J., Szlazak, N., Korzec, M. *et al.* (2025). *Evaluating Pellistor Sensors for Reporting of Methane Emission in Coal Mine Ventilation: Toward Low-Cost Reporting Solutions.* Preprint

Nesser, H., Jacob, D.J., Maasakkers, J.D., Lorente, A., Chen, Z., Lu, X. *et al.* (2024). High-resolution US methane emissions inferred from an inversion of 2019 TROPOMI satellite data: contributions from individual states, urban areas, and landfills. *Atmos. Chem. Phys*. 24, 5069-91

Nisbet, E.G., Manning, M.R., Dlugokencky, E.J., Michel, S.E., Lan, X., Röckmann, T. *et al.* (2023). Atmospheric Methane: Comparison Between Methane's Record in 2006–2022 and During Glacial Terminations. *Global Biogeochemical Cycles.* 37, e2023GB007875

Nisbet, E.G., Manning, M.R., Lowry, D., Fisher, R.E., Lan, X., Michel, S.E. *et al.* (2025). Practical paths towards quantifying and mitigating agricultural methane emissions. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences.* 481, 20240390

Palmer, P.I., Feng, L., Lunt, M.F., Parker, R.J., Bösch, H., Lan, X. *et al.* (2021). The added value of satellite observations of methane forunderstanding the contemporary methane budget. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences.* 379, 20210106

Qian, H., Zhu, X., Huang, S., Linquist, B., Kuzyakov, Y., Wassmann, R. *et al.* (2023). Greenhouse gas emissions and mitigation in rice agriculture. *Nature Reviews Earth & Environment.* 4, 716-32

Qu, Z., Jacob, D.J., Shen, L., Lu, X., Zhang, Y., Scarpelli, T.R. *et al.* (2021). Global distribution of methane emissions: a comparative inverse analysis of observations from the TROPOMI and GOSAT satellite instruments. *Atmos. Chem. Phys.* 21, 14159-75

Ravikumar, A.P., Sreedhara, S., Wang, J., Englander, J., Roda-Stuart, D., Bell, C. *et al.* (2019). Single-blind inter-comparison of methane detection technologies – results from the Stanford/EDF Mobile Monitoring Challenge. *Elementa: Science of the Anthropocene.* 7

Riddick, S.N., Mbua, M., Santos, A., Emerson, E.W., Cheptonui, F., Houlihan, C. *et al.* (2024). Methane emissions from abandoned oil and gas wells in Colorado. *Science of The Total Environment*. 922, 170990

Röckmann, T., Eyer, S., van der Veen, C., Popa, M.E., Tuzson, B., Monteil, G. *et al.* (2016). In situ observations of the isotopic composition of methane at the Cabauw tall tower site. *Atmos. Chem. Phys.* 16, 10469-87

Sadavarte, P., Pandey, S., Maasakkers, J.D., Lorente, A., Borsdorff, T., van der Gon, H.D. *et al.* (2021). Methane Emissions from Superemitting Coal Mines in Australia Quantified Using TROPOMI Satellite Observations. *Environmental Science & Technology.* 55, 16573-80

Saunois, M., Martinez, A., Poulter, B., Zhang, Z., Raymond, P.A., Regnier, P. *et al.* (2025). Global Methane Budget 2000–2020. *Earth Syst. Sci. Data*. 17, 1873-958

Scarpelli, T.R., Cusworth, D.H., Duren, R.M., Kim, J., Heckler, J. Asner, G.P. *et al.* (2024). Investigating Major Sources of Methane Emissions at US Landfills. *Environmental Science & Technology.* 58, 21545-56

Scheutz, C., Knudsen, J.E., Vechi, N.T. and Knudsen, J. (2025). Validation and demonstration of a drone-based method for quantifying fugitive methane emissions. *Journal of Environmental Management.* 373, 123467

Schuit, B.J., Maasakkers, J.D., Bijl, P., Mahapatra, G., van den Berg, A.W., Pandey, S. *et al.* (2023). Automated detection and monitoring of methane super-emitters using satellite data. *Atmos. Chem. Phys.* 23, 9071-98

Schwietzke, S., Sherwood, O. A., Bruhwiler, L. M. P., Miller, et al.: Upward revision of global fossil fuel methane emissions based on isotope database, Nature, 538, 88–91, https://doi.org/10.1038/nature19797, 2016.

Shaw, J.T., Shah, A., Yong, H. and Allen, G. (2021). Methods for quantifying methane emissions using unmanned aerial vehicles: a review. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 379, 20200450

Shen, L., Gautam, R., Omara, M., Zavala-Araiza, D., Maasakkers, J.D., Scarpelli, T.R. (2022). Satellite quantification of oil and natural gas methane emissions in the United States of America and Canada including contributions from individual basins. *Atmos. Chem. Phys.* 22, 11203-15

Shen, L., Zavala-Araiza, D., Gautam, R., Omara, M., Scarpelli, T., Sheng, J. *et al.* (2021). Unravelling a large methane emission discrepancy in Mexico using satellite observations. *Remote Sensing of Environment.* 260, 112461

Sherwin, E.D., El Abbadi, S.H., Burdeau, P.M., Zhang, Z., Chen, Z., Rutherford, J.S. *et al.* (2024). Single-blind test of nine methane-sensing satellite systems from three continents. *Atmos. Meas. Tech.* 17, 765-82

Thompson, R.L., Montzka, S.A., Vollmer, M.K., Arduini, J., Crotwell, M., Krummel, P.B. *et al.* (2024). Estimation of the atmospheric hydroxyl radical oxidative capacity using multiple hydrofluorocarbons (HFCs). *Atmos. Chem. Phys.* 24, 1415-27

Tibrewal, K., Ciais, P., Saunois, M., Martinez, A., Lin, X., Thanwerdas, J. *et al.* (2024). Assessment of methane emissions from oil, gas and coal sectors across inventories and atmospheric inversions. *Communications Earth & Environment.* 5, 26

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.* Nairobi: United Nations Environment Programme

Vechi, N.T., Mellqvist, J. and Scheutz, C. (2022). Quantification of methane emissions from cattle farms, using the tracer gas dispersion method. *Agriculture, Ecosystems & Environment.* 330, 107885

Vinković, K., Andersen, T., de Vries, M., Kers, B., van Heuven, S., Peters, W. *et al.* (2022). Evaluating the use of an Unmanned Aerial Vehicle (UAV)-based active AirCore system to quantify methane emissions from dairy cows. *Science of The Total Environment.* 831, 154898

Williams, J.P., Omara, M., Himmelberger, A., Zavala-Araiza, D., MacKay, K., Benmergui, J. *et al.* (2025). Small emission sources in aggregate disproportionately account for a large majority of total methane emissions from the United States of America oil and gas sector. *Atmos. Chem. Phys.* 25, 1513-32

Williams, J.P., Regehr, A. and Kang, M. (2021). Methane Emissions from Abandoned Oil and Gas Wells in Canada and the United States. *Environmental Science & Technology.* 55, 563-70.

Woolley Maisch, C.A., Fisher, R.F., France, J.L., Lowry, D., Lanoisellé, M., Bell, T.G. *et al.* (2023). Methane Source Attribution in the United Kingdom of Great Britain and Northern Ireland Using Multi-Year Records of CH_4 and δ13C. *Journal of Geophysical Research: Atmospheres.* 128; e2023JD039098

Worden, J., Green, P., Eldering, A. and Sherwin, E. (2025). *Common Practices for Quantifying Methane Emissions from Plumes Detected by Remote Sensing.* NIST Interagency Report, NIST IR 8575. Gaithersburg, MD: National Institute of Standards and Technology.

Yu, X., Millet, D.B., Henze, D.K., Turner, A.J., Delgado, A.L., Bloom, A.A. *et al.* (2023). A high-resolution satellite-based map of global methane emissions reveals missing wetland, fossil fuel, and monsoon sources. *Atmos. Chem. Phys.* 23, 3325-46

Zavala-Araiza, D., Omara, M., Gautam, R., Smith, M.L., Pandey, S., Aben, I. *et al.* (2021). A tale of two regions: methane emissions from oil and gas production in offshore/onshore Mexico. *Environmental Research Letters.* 16, 024019

Zhao, Y., Saunois, M., Bousquet, P., Lin, X., Berchet, A., Hegglin, M.I. *et al.* (2020). Influences of hydroxyl radicals (OH) on top-down estimates of the global and regional methane budgets. *Atmos. Chem. Phys.* 20, 9525-46

Zhou, H., Tao, F., Chen, Y., Yin, L., Li, Y., Wang, Y. et al, (2024). Paddy rice methane emissions, controlling factors, and mitigation potentials across Monsoon Asia. *Science of The Total Environment.* 935, 173441

Zimmerle, D., Bell, C.S., Emerson, E.W., Levin, E., Ilonze, C., Cheptonui, F. *et al.* (2025). *Advancing Development of Emissions Detection: DE-FE0031873 Final Report.* Fort Collins, CO: METEC, Colorado State

Chapter 5

Alberti, C. and Naran, B. (2023). *How to Start Scaling Methane Abatement Finance.* San Francisco, CA: Climate Policy Initiative. https://www.climatepolicyinitiative.org/wp-content/uploads/2023/11/How-to-Start-Scaling-Methane-Abatement-Finance.pdf

ADB. (2024). *Henan Tian Lun Safety Enhancement and Methane Leakage Reduction Project.* Mandaluyong City: Asian Development Bank. https://www.adb.org/projects/58130-001/main

Black, S., Liu, A., Perry, I. and Vernon-Lin, N. (2023). *IMF Fossil Fuel Subsidies Data: 2023 Update.* Washington, D.C.: International Monetary Fund. https://www.imf.org/en/Publications/WP/Issues/2023/08/22/IMF-Fossil-Fuel-Subsidies-Data-2023-Update-537281

CCAC and UNEP (2021). *Global Methane Assessment.* Paris: Climate and Clean Air Coalition; Nairobi: United Nations Environment Programme. https://www.ccacoalition.org/resources/global-methane-assessment-full-report

Damania, R., Balseca, E., de Fontaubert, C., Gill, J., Kim, K., Rentschler, J. et al, (2023). Detox Development: *Repurposing Environmentally Harmful Subsidies.* Washington, D.C.: World Bank. http://hdl.handle.net/10986/39423

de Aragao P., Naran B., Alberti C., Wignarajah D., Connolly J. and Zhang T. (2023). *Landscape of Methane Abatement Finance 2023.* San Francisco, CA: Climate Policy Initiative. https://www.climatepolicyinitiative.org/publication/landscape-of-methane-abatement-finance-2023/

Esmaeili, N., Janik, K., Lau, T., Menon, S., Roeyer, H. and Turnlund, M. (2025). *Funding trends 2024: Climate change mitigation philanthropy.* San Francisco: ClimateWorks Foundation. https://www.climateworks.org/report/funding-trends-2024/

Finance in Common. (2025). *Unlocking the Potential of Public Development Banks for Sustainable Development: A Finance in Common Contribution to FfD4.* https://financeincommon.org/unlocking-the-potential-of-public-development-banks-for-sustainable-development-a-finance-in-common

Global Methane Hub. (2023). *Enteric Fermentation Research & Development Accelerator, a US$200M Agricultural Methane Mitigation Funding Initiative.* https://www.globalmethanehub.org/2023/12/02/enteric-fermentation-research-development-accelerator-a-200m-agricultural-methane-mitigation-funding-initiative/

GCF. (2022). *Approved Project Preparation Facility Application PPF056.* Incheon: Green Climate Fund. https://www.greenclimate.fund/sites/default/files/document/ppf056-ifad-multi-country.pdf

GCF. (2025). FP269 DaIMA – *Dairy Interventions for Mitigation and Adaptation.* Incheon: Green Climate Fund. https://www.greenclimate.fund/project/fp269#documents

Harmsen, J.H.M., van Vuuren, D.P., Nayak, D.R., Hof, A.F., Höglund-Isaksson, L., Lucas, P.L. *et al.* (2019). Long-term marginal abatement cost curves of non-CO_2 greenhouse gases. *Environmental Science & Policy.* 99, 136-149. https://www.sciencedirect.com/science/article/abs/pii/S146290111830889X

Howell, A., Mathur, S. and Suki, L. (2024). *Financing Methane Abatement: An introduction to sustainable finance instruments.* New York, NY: Environmental Defense Fund. https://business.edf.org/wp-content/blogs.dir/90/files//Report-on-Sustainable-Finance-Instruments.pdf

IEA. (2024). *World Energy Investment 2024.* Paris: International Energy Agency. https://iea.blob.core.windows.net/assets/60fcd1dd-d112-469b-87de-20d39227df3d/WorldEnergyInvestment2024.pdf

IEA. (2025). Global Methane Tracker 2025. Paris: International Energy Agency. https://iea.blob.core.windows.net/assets/b83c32dd-fc1b-4917-96e9-8cd918801cbf/GlobalMethaneTracker2025.pdf

Methane Finance Working Group. (2025). *Guidance for Including Methane Abatement in Oil and Gas Debt Structuring.* New York, NY: Center on Global Energy Policy, Columbia University. https://methanefinance.org

Naran, B., Shankar, V., de Aragão Fernandes, P., Dixon, J., Burnett, J., Abraham, S. *et al.* (2025). *Global Landscape of Climate Finance 2025.* San Francisco: Climate Policy Initiative. https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2025/

UN environment programme

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

a UNEP convened initiative