China's Ongoing Efforts to Address Methane Emissions and Opportunities to Further Raise China's Methane Mitigation Ambition

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About the Institute for Governance & Sustainable Development

The Institute for Governance & Sustainable Development (IGSD) is a research institute with the mission to promote fast climate mitigation. This includes protecting existing carbon sinks, to slow near-term warming and self-propagating climate feedbacks, avoid or at least delay catastrophic climate and societal tipping points, and limit global temperatures to 1.5 °C—or at least keep this temperature guardrail in sight and limit overshoot.

IGSD's latest research shows that decarbonization alone is insufficient to slow near-term warming to keep us below 1.5 °C or even the more dangerous 2 °C guardrail and that the fastest and most effective strategy is to combine the marathon to zero out carbon dioxide (CO_2) emissions from decarbonizing the energy system *with* the sprint to rapidly cut non-CO_2 super climate pollutants and protect carbon sinks. The non-CO_2 super climate pollutants include four short-lived climate pollutants (SLCPs)—methane (CH_4), hydrofluorocarbons (HFCs), black carbon soot, and tropospheric ozone (O_3)—as well as the longer-lived climate pollutant, nitrous oxide (N_2O).

IGSD's theory of action is anchored in the urgency of responding rapidly and effectively to slow self-propagating feedbacks and avoid irreversible damage to the climate system with catastrophic consequences for all. Combining the fast mitigation sprint with the decarbonization marathon would reduce the rate of global warming by half from 2030 to 2050, slow the rate of warming a decade or two earlier than decarbonization alone, and make it possible for the world to keep the 1.5 °C guardrail in sight and reduce overshoot.

IGSD approaches to fast mitigation includes science, technology, law and policy, and climate finance. IGSD's latest research conducts an extensive overview of methane-related science and mitigation strategies in "A Primer on Cutting Methane: The Best Strategy for Slowing Warming in the Decade to 2030."

About the Asia-Pacific Centre for Environmental Law

The Asia-Pacific Centre for Environmental Law (APCEL) is a research centre at the Faculty of Law, National University of Singapore. APCEL is committed to promoting research-based capacity building and advancing innovative scholarship in a spirit of partnership. APCEL was established in 1996, in cooperation with the World Conservation Union-Commission on Environmental Law (IUCN-CEL) and UNEP, in response to the call in Agenda 21 to build capacity in environmental law and promote environmental consciousness.

Since its inception, APCEL has pioneered a wide-ranging programme of teaching, research and outreach to galvanise the use of legal mechanisms to address climate change, biodiversity loss, and plastics pollution. Recent projects include research on the Paris Rulebook, sustainability standards, and environmental courts and tribunals. APCEL also brings internationally renowned scholars together, alongside industry and other civil society stakeholders, to share the latest thinking on environmental law and policy at seminars and conferences.

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Executive Summary

Cutting methane emissions is the fastest way to slow warming in the near term and keep the goal of limiting global warming to 1.5 °C within reach,[1] thereby preventing the worst adverse impacts from affecting the most vulnerable populations.[2] The Global Methane Assessment from the Climate & Clean Air Coalition (CCAC) and the United Nations Environment Programme (UNEP) concludes that available mitigation measures could reduce human-caused methane emissions by 45% by 2030 and avoid nearly 0.3 °C warming by the 2040s.[3]

Methane plays an increasingly important role in China's responses to climate change. According to the official Chinese government inventory, China's methane emissions were 55.292 metric tons (Mt) in 2014.[4]

In the past few years, China adopted a number of measures aimed at reducing its methane emissions. For example, while methane is not explicitly included in China's Nationally Determined Contributions (NDCs) as a covered greenhouse gas (GHG) or with any quantitative reduction target, China's updated NDCs provide that China will take a number of policy and technical measures to effectively control methane emissions from coal mining, as well as from oil and gas extraction.[5]

Additionally, China released its Methane Emissions Control Action Plan on 7 November 2023.[6] The Action Plan prioritizes the improvement of China's methane-emissions measurement, monitoring, reporting, and verification (MMRV) system, as well as additional methane-emissions control actions in the energy, agriculture, and waste sectors. It also aims to strengthen the synergistic control of methane and other pollutants, such as volatile organic compounds. As an incentive mechanism, the Action Plan promotes the inclusion of methane mitigation and reutilization projects in the GHG voluntary emission trading system.[7]

China's commitment to methane mitigation is also reflected in its national planning documents. In particular, China's *Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035* provides that China will "strengthen the control of other GHGs such as methane, hydrofluorocarbons, and perfluorocarbons."[8] This prominent mention of methane provides China's national ministries and agencies with authority to include detailed requirements for methane in their 14th Five-Year implementation plans covering the period 2021-2025.

These and other domestic policy developments create a framework for China's additional methane-mitigation actions and efforts to prevent disasters attributable to global warming. Nevertheless, significant opportunities remain to maximize China's climate mitigation impact, as summarized below.

China could advance its climate ambitions through bilateral and multilateral engagement, building upon the commitments in the *U.S.-China Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis*, including incorporating targets to address economy-wide emissions of all GHGs in their 2035 NDCs. Furthermore, China could link its methane-mitigation actions to its goals of mitigating the climate and other environmental impacts of its overseas investments.

China could also strengthen national regulations and standards to control sectoral sources of methane emissions. This includes an immediate opportunity to promulgate more stringent national standards governing methane emissions in the coal-mining sector, in coordination with China's broader policies on controlling coal consumption and improving coal mine safety. Additionally, China could undertake research that supports methane-emissions regulatory requirements for other key sectors, such as oil and gas.

Finally, China can develop methane-reduction pilot projects at the subnational level. This could build upon China's plan to construct 100-zero waste cities during 2021-2025 and help set useful precedents for the deployment of sectoral methane-mitigation technologies and initiatives. Subnational pilots may eventually feed into nationally implemented programs or regulations.

1. Introduction

Cutting methane emissions is the biggest and fastest strategy for slowing warming and keeping global warming of 1.5 °C within reach.[9] Exceeding the 1.5 °C guardrail increases the risk that adverse and irreversible climate impacts will be triggered, exposing over 3 billion people to extreme weather events and other climate hazards.[10] For those in the tropics, limiting warming to 1.5 °C would prevent temperature and humidity levels from breaching survivable thresholds.[11]

The Global Methane Assessment from the Climate & Clean Air Coalition (CCAC) and the United Nations Environment Programme (UNEP) concludes that available mitigation measures could reduce human-caused methane emissions by 45% by 2030 and thereby avoid nearly 0.3 °C warming by the 2040s.[12] Slowing near-term warming is key to giving climate-vulnerable communities time to adapt and to reducing their adaptation burdens.[13] Additionally, because methane is a component of smog, cuts in methane emissions reduce harm to human health[14] and to crops.[15]

Methane plays an increasingly important role in China's responses to climate change. According to the official Chinese government inventory, China's methane emissions were 55.292 Mt in 2014.[16] The major emitting sources include energy (44.8%), agriculture (40.2%), and waste (11.9%).[17] An analysis by the Lawrence Berkeley National Laboratory (LBNL) shows that 17.52 Mt of methane emissions could be reduced annually in 2030 at an average abatement cost of US$550 per ton of methane.[18] See Box 1 for a discussion of global warming potential (GWP) and methane metrics.

Box 1: GWP and Methane Metrics

GWP is a metric that approximates the warming effect from emissions of a kilogram of methane with a kilogram of CO_2 averaged over a given timeframe (usually 20 or 100 years).[19] The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6) updated the GWP metrics for methane as follows: GWP_{20} is 81.2 and GWP_{100} is 27.9.[20] This means that methane is over 80 times more powerful than CO_2

in contributing to global warming over a 20-year time span and about 28 times more powerful over a 100-year time span.

However, the climate impacts from short-lived greenhouse gases like methane and long-lived greenhouse gases like CO_2 are fundamentally different, and any "single-basket" metric that seeks to combine them will misrepresent the climate response.[21] The appropriateness of the choice of metric depends on which aspect of climate change takes priority for particular applications or stakeholders and over a given time horizon.[22] When accounting for near-term climate impacts, using GWP_{100} alone underestimates the importance of methane emissions and can lead to skewed priorities and less effective policies.[23] Using GWP_{20} better captures near-term warming impact than GWP_{100}, in addition to being more aligned with keeping the 1.5 °C temperature goal within reach by limiting temporary overshoot.[24]

Independent of metric, tracking methane emissions in Mt of methane is the best way to track climate impacts and should be paired with the adoption of robust measurement, monitoring, reporting, and verification (MMRV) systems, which are necessary to evaluate the efficacy of methane mitigation policies and programs.[25] Accurate MMRV systems are especially important in reducing intended and unintended emissions from leaky oil and gas operations.[26]

The lion's share of methane mitigation potential in China resides in the coal mining sector. According to a 2019 United States Environmental Protection Agency (U.S. EPA) analysis, China has the potential to reduce 16.12 Mt of coal mine methane emissions by 2030, which represents 69% of the global methane mitigation potential in coal mining.[27] According to the same U.S. EPA analysis, in the waste sector, by 2030, China has the potential to reduce 1.08 Mt of landfill waste methane emissions.[28]

Methane, in the context of policy discussions in China, is covered under the broader category of "non-CO_2 greenhouse gases" (GHGs). This paper provides an overview of China's existing national targets and regulatory requirements that are relevant to methane. It is followed by a list of policy opportunities to strengthen China's efforts on methane emissions control in the near term and for achieving the country's longer-term 2060 carbon neutrality goal.

2. Overview of China's National Targets and Regulatory Requirements Relevant to Methane Mitigation

It is important to understand China's methane mitigation action and targets against the broader Chinse-government policy context of building a circular economy and promoting the green transition of the energy system, as well as key Chinese-government timelines relevant to realizing the basic goals for building a beautiful China by 2035[29] and achieving carbon neutrality before 2060. On 22 September 2020, at the United Nations General Assembly, China announced its target of achieving carbon neutrality before 2060.[30] This longer-term goal covers all GHGs, including methane.[31]

Thinking broadly, China's methane mitigation efforts are closely relevant to the country's overarching goal of building a circular economy. The development of circular economy encompasses activities to reduce consumption, increase recycling, and promote resource reutilization during the processes of production, transportation, and consumption.[32] As illustrated in the sections below, many of China's existing policy and technical measures to promote resource reutilization also contribute to methane mitigation in these sectors. Understanding the policy synergies between building a circular economy and reducing methane emissions provides helpful context when identifying priorities for and gaps in climate policy in China.

China's methane emissions reduction actions and policies are also linked to its overall energy-system transition, including the targets to increase the percentage of non-fossil fuels from 15.9% in 2020[33] to around 20% of total energy consumption by 2025,[34] to 25% by 2030,[35] and eventually to over 80% by 2060.[36] On 28 October 2021, China submitted its updated Nationally Determined Contributions (NDCs)[37] to the United Nations Framework Convention on Climate Change (UNFCCC). In the updated NDCs, China incorporated its goal of increasing the share of non-fossil fuels in primary energy consumption to around 25% by 2030 and noted that funds have already been expended on a major project titled "Development of Large Oil and Gas Fields and Coalbed Methane."[38]

While methane is not explicitly included in China's NDCs as a covered GHG or with any quantitative reduction target, China's updated NDCs provide that China will take a number of policy and technical measures to effectively control methane emissions from coal mining, as well as from oil and gas extraction.[39] In the *Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis*, issued on 14 November 2023, the U.S. and China commit to include actions/targets to address economy-wide emissions of all GHGs in their 2035 NDCs.[40] In this regard, the U.S. and China also mentioned previously that "[b]oth countries intend to communicate 2035 NDCs in 2025" in the *U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s* (10 November 2021).[41]

More specifically on methane, China's most recent, comprehensive methane policy document is the Methane Emissions Control Action Plan, released 7 on November 2023.[42] China's Ministry of Ecology and Environment (MEE) promulgated the Methane Action Plan together with ten other national ministries and agencies. Substantial interagency coordination is needed for the implementation of the Methane Action Plan at national and local government levels. Among other things, the Methane Action Plan highlights as key priorities the improvement of a MMRV system for methane emissions, as well as methane-emissions control actions in the energy, agriculture, and waste sectors. In addition, the Action Plan aims to strengthen the synergistic control of methane and other pollutants, such as volatile organic compounds. As an incentive mechanism, the Action Plan promotes the inclusion of methane mitigation and reutilization projects in the greenhouse gas voluntary emission trading system.[43]

Further, China's national targets and requirements on or related to methane emissions control are further provided in national laws, regulations and mandatory emissions standards, as well as planning documents, including China's Five-Year Plans. In particular, China's *Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035* provides that China will "strengthen the control of other GHGs such as methane, hydrofluorocarbons, and perfluorocarbons."[44] This prominent mention of methane provides China's national ministries and agencies with authority to include detailed requirements for methane in their 14th Five-Year implementation plans covering the period of 2021-2025.

The summary below provides additional details on China's key sectoral targets and policies relevant for the purpose of methane emissions reduction.

A. Coal Mine Sector

A number of China's regulatory requirements and financial incentives[45] in the coal mining sector that are aimed at improving worker safety and resource reutilization also contribute to methane mitigation. For example, the MEE issued the Emissions Standard for Coalbed Methane/Coal Mine Gas in 2008.[46] Notably, this standard includes a major exemption indicating that coal mines are not required to carry out the flaring and utilization measures if the drained gas has a methane content of <30%. Additionally, this standard only covers new and existing coal mines and is ambiguous as to its applicability to abandoned coal mines. Research has found that methane emissions from China increased by 1.1 ± 0.4 teragram (Tg) per year from 2010 to 2015 (largely attributable to coal mining), in spite of China's existing regulatory requirements for coalbed methane flaring and utilization.[47]

Box 2: Global Perspective - Methane Sources and Solutions from Coal Mining

Energy production activities from the oil and gas sector, and the coal sector account for about 35% of global anthropogenic methane emissions.[48] The coal mining sector, in particular, is responsible for 40 Mt CH_4 out of the 130 Mt CH_4 estimated for the sector in 2021.[49] Coal seams naturally contain methane, which can be released through ventilation during or after mining operations.[50] Thus, coal mine methane emissions may occur from active underground mines, abandoned coal mines that continue to leak methane, and some surface mines.

Oxidation of ventilation air methane and the recovery and use of methane through pre-mining degasification are among the main methods for reducing methane emissions from active underground coal mines.[51] For abandoned mines that continue to leak methane, the CCAC recommends flooding abandoned coal mines to eliminate these emissions.[52] Sometimes, abandoned mine methane can be recovered and used before flooding occurs[53] as an alternate fuel.[54]

In 2021, the MEE announced a plan to revise the emission standards for coalbed methane and coal mine gas.[55] With respect to abandoned coal mines, in 2020, China proposed policies to map out the methane mitigation and utilization potentials for such mines, and implement a number of methane mitigation and utilization pilot projects at such mines by 2025, and invited comments on these proposals.[56] The national ministries have yet to announce timelines for revision of the standard or finalization of the draft policies.

Furthermore, China provides that coal mine gas with a methane concentration of 8% or more shall be extracted and utilized.[57] The MEE, the National Development and Reform Commission (NDRC), and the National Energy Administration encourage exploring options to utilize coal mine gas with a methane concentration between 2 and 8%.[58] By 2025, the annual utilization of coal mine gas will reach 6 billion cubic meters.[59] This indicates a drop from the coal mine gas utilization goal by 2020.[60]

The 13th Five-Year Plan for the Development and Utilization of Coalbed Methane (Coal Mine Gas) (2016) provided that "by 2020, the coalbed methane (coal mine gas) extraction volume shall reach 24 billion cubic meters, within which the production of on-ground coalbed methane shall reach 10 billion cubic meters with a utilization rate of over 90%; the extraction of coal mine gas shall reach 14 billion cubic meters with a utilization rate of over 50%."[61] The Chinese government extends special funding to support coalbed methane extraction and utilization projects during the period 2023-2025.[62] At the provincial level, Shanxi Province announced that it had extracted 7.16 billion cubic meters of coalbed methane in the first eight months of 2023, a record high for the January-August period.[63]

Importantly, China's methane-emissions reduction success is closely linked to its ability to phase down coal consumption. For example, China has announced that it will strictly control coal consumption during 2021-2025 and gradually reduce coal consumption during 2026-2030.[64] Key regional targets include reducing the coal consumption in Beijing, Tianjin, Hebei, and surrounding areas[65] by about 10%, reducing the coal consumption in the Yangtze River Delta region[66] by about 5%, and achieving negative growth in coal consumption in the Fenwei Plain region[67] by 2025.[68]

According to the 14th Five-Year Comprehensive Work Plan on Energy Conservation and Emission Reduction, renewable energy will not be counted in the total energy consumption of localities during the 14th Five-Year period.[69] This provision further incentivizes the deployment of renewable energy to achieve carbon neutrality before 2060. However, the same Plan also indicates that use of fuel as feedstocks for chemical processes will not figure in national and provinces' energy consumption or intensity calculations.[70] This exemption may boost the use of coal in the coal-to-chemical industry.

B. Oil and Gas Sector

For the oil and gas sector, China will reach the plateau stage for oil/petroleum consumption during 2026-2030[71] and aim to peak land-transportation petroleum consumption by 2030.[72] By 2030, the collection rate of associated gas from oilfields will be on par with international advanced standards.[73] Particularly, the NDRC promotes some key methane mitigation technologies in the oil and gas industry planning and guidance documents, including technologies for leakage detection, gas recovery, and emissions reduction. For example, China's 13th Five-Year Development Plan for Natural Gas included the promotion of recovery technologies for oilfield-associated gas, strengthening of natural gas leakage detection, and reducing fugitive emissions of GHGs.[74] Additionally, The Guiding Catalogue for Industrial Restructuring that the NDRC updated in 2024 includes in the category of recommended technologies, the monitoring, recovery and utilization technologies and equipment for oil and gas leakage and ventilation, as well as extraction and utilization technologies for coalbed methane and coal mine gas.[75]

More recently, the 2024 Green and Low Carbon Transition Industries Guidance Catalogue lists, among other "green" initiatives, clean coal production, clean oil and natural gas production, oil and gas field methane capture and utilization, and coalbed methane extraction and utilization.[76] This Catalogue is used to guide national and local government agencies in developing and implementing support and incentive mechanisms for "green" industry actions. Financial institutions and investors can also use the Catalogue as basis for applying relevant environmental financing tools such as green bonds and green credit.

Box 3: Global Methane Sources and Solutions from the Oil and Gas Sector

Globally, the oil and gas sector is responsible for about 80 Mt CH_4 of global anthropogenic methane emissions estimated in 2020,[77] coming mostly from onshore extraction and downstream activities.[78] When leaks and fugitive emissions (gas that escapes at multiple points in the process)[79] are considered, methane emissions are about 70% higher than in reported data.[80]

Gas, in particular, presents a significant opportunity for methane mitigation as it is mostly comprised (70–90%) of methane. This means that when gas leaks occur, they contain mostly methane, thereby countering the argument that gas is a cleaner fuel than coal.[81]

Plugging leaks,[82] and reducing flaring and venting[83] of methane are key to lowering methane emissions and intensity in the oil and gas sector.[84] Plugging leaks involves increasing and improving implementation of leak detection and repair (LDAR) programs and replacing leaking devices and older equipment with modern low-emitting equipment.[85] Prohibiting venting of natural gas can also deliver significant emissions reductions.[86] Such actions should be paired with robust MMRV systems to ensure that methane mitigation reductions are actually occurring.[87]

Although China has not applied mandatory methane intensity requirements to oil and gas production and import, the following industry voluntary initiatives are noteworthy as springboards for methane action.

The China Oil and Gas Methane Alliance, an association of seven Chinese companies, has pledged to reduce their average methane emissions intensity in natural gas production to below 0.25% by 2025, and to cooperate and share technical experience on methane emissions control, including LDAR and gas-recovery systems.[88] On 15 October 2021, twelve municipal gas companies in China joined the *China Municipal Gas Company Methane Emission Control Initiative* to control methane emissions to help achieve China's carbon peaking and carbon neutrality goals.[89] The twelve companies are committed to strengthen gas leakage detection and repair, promote the deployment of methane emission MMRV technology, and identify industry best practices in methane emissions reduction.

Moreover, the promotion of green and clean transportation contributes to methane mitigation by reducing petroleum consumption. Key targets in the transportation sector include to increase new- and clean-energy-powered new transportation to about 40% of total new transportation per year in 2030[90] and green transportation deployment in cities with populations of one million or more to no less than 70% by 2030.[91]

It is also significant that the severe power shortages in 2021 and 2022[92] heightened China's concerns over energy security, which may complicate China's efforts to achieve its energy-sector climate goals. For example, China set the goal of cumulatively increasing, by 2025, natural gas production by about 3 billion cubic meters and the crude oil production by over 2 million tonnes.[93] China is also expected to increase its pipeline gas imports to 8.2% year on year and its total natural gas imports also to 8.2% in 2024.[94]

At the same time, China also called upon oil and gas companies to use more renewable energy during extraction and accelerate their renewable energy generation to help achieve China's carbon peaking and carbon neutrality goals.[95] China is expected to account for 56% of global renewable energy capacity additions in 2023–2028, ahead of the U.S. and the European Union.[96]

C. Waste Sector

China's Solid Waste Pollution Prevention and Control Law (2020) establishes the regulatory framework for the reduction, utilization, and harmless disposal of solid waste, including household and livestock wastes, urban waste, and sludge.[97] Wastewater disposal is also subject to controls under the Water Pollution Prevention and Control Law (2017) for discharges into water bodies.[98] Additionally, the Anti-Food Waste Law (2021) aims at, among other things, protecting the environment and promoting sustainable economic and social development.[99] While this Law does not focus on food waste disposal, it complements and could conceivably be a statutory link for future food waste regulatory actions that are relevant to methane emissions reduction.

Box 4: Global Methane Sources and Solutions from the Waste Sector

The waste sector accounts for about 20% of global anthropogenic emissions,[100] estimated at approximately 68 Mt CH_4 in 2017.[101] Waste sector methane comes from decomposition processes in landfills and wastewater treatment.

Worldwide, the waste sector can mitigate 29–36 Mt CH_4/yr,[102] largely from solid waste management.[103] Landfill operators can capture and convert to energy the methane emitted from existing landfills.[104] Collecting landfill gas can be costly,[105] although there are financial benefits in producing a biogas product fit for energy use.[106]

The diversion of organic waste from landfills can also significantly reduce methane emission,[107] particularly by reducing food waste, which can decrease methane emissions from the food system, including both the waste and agriculture sectors.[108] For organic waste already present in a landfill, biologically active covers or "biocovers," that are made of greenwaste/compost, can limit methane emissions by stimulating microbial methane oxidation.[109] Studies have shown that biocovers can improve methane oxidation[110] rates by over 60%, and in some cases nearly 80%.[111]

In addition to national statutes, China has also issued a number of national policy and planning documents to lay out key targets and implementation mechanisms for waste treatment and disposal. For example, China set targets including reaching, by 2025, 90% harmless disposal of urban sludge, and 25% sewage resource utilization in water-scarce cities at the prefectural level and above, in the 14th Five-Year Plan.[112] Additionally, the provisions in the 14th Five-Year Plan on improving environmental infrastructure for waste treatment and on strengthening environmental monitoring will contribute to methane emissions reduction.

To help reduce water and soil pollution, China also set targets to facilitate elimination of black and odorous water bodies in the Beijing, Tianjin, Hebei, and the Yangtze River Delta and Pearl River Delta[113] regions by 2024.[114] Other cities at the county level shall achieve the same goal by 2025. Furthermore, China set targets to increase the rate of domestic sewage treatment in rural areas to 40% by 2025,[115] and raise the rate of county sewage treatment to more than 95% by 2025.[116] Also, China is requiring that, by 2025, the utilization rate of recycled water shall reach over 35% in the Beijing, Tianjin, and Hebei regions, and strive to reach a utilization rate of 30% in water-scarce cities at the prefecture level and above in the middle and lower reaches of the Yellow River basin.[117] By 2030, China aims to increase the national average utilization rate of urban recycled water to 30%.[118]

Adding to the national policy and planning documents, China's ministries have issued various regulations, standards, and other norm-creating documents to implement key mechanisms such as China's household waste classification system.[119] The goals of this system are to increase the reutilization rate for urban household waste to around 60% by 2025 and to about 65% by 2030.[120] By the end of 2025, China plans to reach a domestic waste incineration treatment capacity in cities and townships of about 800,000 tonnes per day; about 65% of this incineration treatment capacity is for the treatment of domestic waste in cities.[121]

For the industrial sector, China is also promoting the recycling and reuse of industrial solid waste with the goal of increasing the comprehensive reutilization rate of bulk industrial solid waste to 57% by 2025.[122] For landfill methane, China is also considering a new rule to require reutilization of landfill gas if the methane emissions are at high intensity and last a long period of time.[123] For small amounts of methane emissions with low reutilization cost effectiveness, the proposed rule requires the landfill gas to be combusted to reduce the release of methane emissions into the atmosphere.[124]

Another significant policy development that can serve to control waste-related methane emissions is China's announcement to build 100 zero-waste cities by 2025.[125] The construction of zero-waste cities will include planned improvements in solid waste disposal in industrial sources, reduction of household waste landfills, management and reuse of livestock waste, and controls on the application of chemical fertilizers and pesticides.[126] In 2022, the MEE published the list of zero-waste cities.[127] Some of the cities and provinces on the list have promulgated their work plans on the construction of zero-waste cities.[128] Additionally, the 100 zero-waste cities are required to submit an annual report describing their actions, achievements, and challenges to the relevant provincial departments of ecology and environment by 2025.[129] The provincial departments of ecology and environment must provide the MEE with their annual summary reports on their respective zero-waste cities by 2025.[130]

D. Agriculture Sector

China plans key emissions reduction and carbon sequestration actions in the agriculture sector as part of its efforts to peak carbon emissions before 2030 and achieve carbon neutrality before 2060. These include, among other key actions, reducing methane emissions from rice farming and livestock manure management, promoting the replacement of fossil fuel with biogas, and improving methane emissions monitoring from agricultural sources.[131] Importantly, China is also looking into low-carbon compensation mechanisms to incentivize methane-mitigation action in the agricultural sector.[132]

Box 5: Global Methane Sources and Solutions from the Agriculture Sector

Agriculture accounts for around 40% of global anthropogenic emissions, coming mostly from livestock and rice cultivation.[133] The largest contribution within agriculture is from cattle, accounting for 77% of these emissions.[134] Livestock manure management practices also release methane.[135] In 2020, livestock and manure management resulted in 117 Mt CH_4 emissions.[136]

Flooded rice fields are also a major source of methane, particularly in rice-producing regions[137] like Asia where rice cultivation contributes around 20% of methane emissions.[138] Total global emissions in 2020 are estimated at approximately 30 Mt CH_4 from global rice cultivation.[139]

In terms of solutions, manure can be reused as biogas, feed, or fertilizer.[140] Protein content in animals may improve when manure is treated as feed.[141] Manure treated as fertilizer can significantly improve crop yield and increase soil fertility.[142] Similar to animal manure, crop straw can be substitute for chemical fertilizers, thereby reducing the demand for synthetic chemicals and the soil pollution associated with their use,[143] and decreasing the input costs to farmers.[144]

In 2021, China set a target for comprehensive reutilization of livestock and poultry manure to over 80% nationwide by 2025.[145] The Methane Action Plan raises the goal to over 85% by 2030.[146] The reutilization rate of livestock and poultry manure is 78% in 2023.[147] China also established a national policy strategy to reduce the application amounts, and increase the efficiency of chemical fertilizers and pesticides from 40% in 2020 to 43% by 2025.[148]

Additionally, the CCAC, through a collaborative project with the Chinese Academy of Agricultural Sciences, worked on research for developing effective methane mitigation strategies "such as carefully controlling the water, fertilizer, antibiotics, and type of feed, which can not only reduce emissions but can also increase agricultural production."[149]

E. Measurement, Monitoring, Reporting, and Verification of Methane Emissions

Access to data has been identified as one of key challenges for China to commit to quantitative methane mitigation targets and for the effective implementation of GHG mitigation policies.[150] China's Methane Action Plan also prioritizes the improvement of its methane emission MMRV system in the current 14th Five-Year period (2021-2025) and the upcoming 15th Five-Year period (2026-2030).[151] The Methane Action Plan provides guidance on strengthening inventory-based methane emission data collection, including promoting regular reporting of methane-emissions data from large emitting sources such as coal mines, oil and gas fields, farms, landfills and sewage treatment plants. It also lays out the plan for establishing a sky-earth methane monitoring system, including ground-based monitoring, unmanned aerial vehicles, and satellite remote sensing.

In this regard, China's efforts to strengthen its ecological and environmental monitoring system are relevant to the capacity building for a methane-emission MMRV system. Such initiatives include promoting remote sensing monitoring for proactive detection of and real-time response to methane emission anomalies in key industries.[152]

In order to support the development and implementation of national methane mitigation policies and targets, China has also launched a number of emissions monitoring pilots involving enterprises, municipalities, and regions.[153] Concerning enterprise pilot projects, in particular, pilot projects identified in the coal mining and oil and gas production sectors are focused on methane emissions monitoring. Pilot projects in the waste sector also highlight the monitoring of methane emissions. Such monitoring programs are crucial in ensuring that methane reductions occur.[154]

During its January 2023 press conference, the MEE underscored progress on methane monitoring pilot projects.[155] In particular, the MEE noted that the oil and gas sector pilots have established a methane leakage detection mechanism by implementing an integrated “satellite + unmanned aerial vehicle + cruise” monitoring system for tracking methane leakage in production processes. For the coal mining industry pilots, the MEE observed that methane emissions monitoring technologies have been developed in coordination with existing coal mine safety monitoring systems. The MEE also commented that it has established a preliminary understanding of the concentrations and the spatial and temporal distributions of global methane emissions through analysis of satellite remote sensing data.

According to the MEE, the second phase of emission monitoring pilots was launched in 2023. [156] Key focuses in this phase include expanding the pilots to other key industries such as: coal-fired power plants and iron and steel industries; improving the technical guidelines and standard specifications for emissions monitoring; and accelerating the development of key technologies in order to support the validation of inventory data against the monitoring data.

3. Opportunities for China to Strengthen Efforts on Methane Emissions Control

Methane mitigation actions are not only critical to China’s ability to help prevent domestic disasters attributable to global warming, they are also critical to the world’s ability to mitigate such events.[157] Against this backdrop, the following is a list of opportunities for China to raise its ambition and strengthen its methane-mitigation regulatory efforts in the near term.

- Advance China’s methane mitigation ambition through bilateral and multilateral engagement. This international engagement could build upon the commitments in the U.S.-China *Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis*, including to incorporate actions/targets to address economy-wide emissions of all

GHGs in their 2035 NDCs.[158] In this regard, the U.S. and China also mentioned that "[b]oth countries intend to communicate 2035 NDCs in 2025" in the *U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s*.[159] Additionally, bilateral engagement with China on methane mitigation could be informed and influenced by countries' efforts to reduce methane emissions under the Global Methane Pledge.[160]

- Link China's methane-mitigation actions to China's goals of mitigating the climate and other environmental impacts of its overseas investments. China's Methane Action Plan emphasizes that China will actively engage in international cooperation and exchanges on methane mitigation, including through China's Climate-Change South-South Cooperation efforts and the Belt and Road Initiative.[161] In this regard, methane mitigation could provide helpful perspectives for strengthening China's commitment to stop building new coal-fired power plants abroad.[162] Additionally, government-led initiatives and incentives could be pursued to implement the government guidelines recommending that Chinese enterprises comply with prevailing international standards or China's own standards if the host country: 1) lacks environmental standards applicable to the investment and project in question; or 2) has in place environmental standards for the investment or project in question that are lower than prevailing international standards or those applied to such investments and projects in China.[163]

- Strengthen national regulations and standards to control the sectoral sources of methane emissions. This includes an immediate opportunity to promulgate more stringent national standards on methane emissions in the coal mining sector, in coordination with China's broader policies on controlling coal consumption and improving coal mine safety. The MEE announced at the State Council press conference in late April 2021 its plan to revise China's emission standards for coalbed methane and coal mine gas.[164] It is also noteworthy that these national regulatory efforts can be complemented by market incentive mechanisms such as China's voluntary GHG emissions trading system.[165] Additionally, updating China's methane emissions inventory data and strengthening the MMRV system would be key for the development and implementation of China's regulatory measures and targets on methane mitigation.

- Develop methane reduction pilot projects at the subnational level. These projects could build upon China's plan to construct 100-zero waste cities during 2021-2025. They would help set useful precedents for the deployment of sectoral methane mitigation technologies and initiatives in China. Such pilots may eventually feed into a nationally implemented program or regulation. Methane mitigation efforts in U.S. states such as California can serve as inspiration and provide models. Indeed, in the California situation, California and the MEE renewed a Memorandum of Understanding on climate change and the environment in April 2022.[166] In 2023, California signed Memorandums of Understanding with China's Hainan Province,[167] Guangdong Province, Jiangsu Province, Beijing and Shanghai.[168] Institutions such as the California-China Climate Institute could facilitate training and exchanges on methane mitigation opportunities.

References

[1] United Nations Environment Programme & Climate & Clean Air Coalition (2021) Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions, 17 ("Mitigation of methane is very likely the strategy with the greatest potential to decrease warming over the next 20 years.").

[2] Intergovernmental Panel on Climate Change (2022) *Summary for Policymakers*, *in* Climate Change 2022: Impacts, Adaptation, and Vulnerability, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), SPM-11 ("Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*)."), SPM-13 ("Levels of risk for all Reasons for Concern (RFC) are assessed to become high to very high at lower global warming levels than in AR5 (*high confidence*). Between 1.2°C and 4.5°C global warming level very high risks emerge in all five RFCs compared to just two RFCs in AR5 (*high confidence*). Two of these transitions from high to very high risk are associated with near-term warming: risks to unique and threatened systems at a median value of 1.5°C [1.2 to 2.0] °C (*high confidence*) and risks associated with extreme weather events at a median value of 2°C [1.8 to 2.5] °C (*medium confidence*). Some key risks contributing to the RFCs are projected to lead to widespread, pervasive, and potentially irreversible impacts at global warming levels of 1.5–2°C if exposure and vulnerability are high and adaptation is low (*medium confidence*). … SPM.B.3 Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (*very high confidence*). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation (*high confidence*).").

[3] United Nations Environment Programme & Climate & Clean Air Coalition (2021) Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions, 8 ("Reducing human-caused methane emissions is one of the most cost-effective strategies to rapidly reduce the rate of warming and contribute significantly to global efforts to limit temperature rise to 1.5°C. Available targeted methane measures, together with additional measures that contribute to priority development goals, can simultaneously reduce human-caused methane emissions by as much as 45 per cent, or 180 million tonnes a year (Mt/yr) by 2030. This will avoid nearly 0.3°C of global warming by the 2040s and complement all long-term climate change mitigation efforts. It would also, each year, prevent 255 000 premature deaths, 775 000 asthma related hospital visits, 73 billion hours of lost labour from extreme heat, and 26 million tonnes of crop losses globally."). *See also* Sun, X., Wang, P., Ferris, T., Lin, H., Dreyfus, G., Gu, BH., Zaelke, D., Wang, Y., *Fast action on short-lived climate pollutants and nature-based solutions to help countries meet carbon neutrality goals*, Advances in Climate Change Res. (2022).

[4] The People's Republic of China Second Biennial Update Report on Climate Change, 17 (December 2018) ("China's CH_4 emissions in 2014 were 55.292 Mt, of which 24.757 Mt were from energy, accounting for 44.8%; 6 kt were from industrial processes; 22.245 Mt were from agriculture, accounting for 40.2%; 1.72 Mt were from LULUCF, accounting about 3.1%; 6.564 Mt were from waste, accounting for 11.9%."). Additionally, research estimated that China's total methane emissions were 65.0 (57.7–68.4) Tg a^{-1} by inverse analysis of 2019 TROPOMI satellite observations of atmospheric methane, much higher than the Chinese inventory reported to the UNFCCC (53.6 Tg a^{-1}). *See* Chen Z. *et al.* (2022) *Methane emissions from China: a high-resolution inversion of TROPOMI satellite observations*, Atmos. Chem. Phys. 22(16): 10809–10826, 10809 ("Our best estimate for total anthropogenic emissions in China is 65.0 (57.7–68.4) Tg a^{-1}, where parentheses indicate the uncertainty range determined by the inversion ensemble. Contributions from individual sectors include 16.6 (15.6–17.6) Tg a^{-1} for coal, 2.3 (1.8–2.5) for oil, 0.29 (0.23–0.32) for gas, 17.8 (15.1–21.0) for livestock, 9.3 (8.2–9.9) for waste, 11.9 (10.7–12.7) for rice paddies, and 6.7 (5.8–7.1) for other sources. Our estimate is 21% higher than the Chinese inventory reported to the UNFCCC (53.6 Tg a^{-1}), reflecting upward corrections to emissions from oil (+147 %), gas (+61 %), livestock (+37 %), waste (+41 %), and rice paddies (+34 %), but downward correction for coal (−15 %).").

[5] People's Republic of China (2021) *China's Achievements, New Goals and New Measures for Nationally Determined Contributions*, submission to the Secretariat of the UNFCCC. Note that China's 2016 Intended NDCs included a numeric target for coalbed methane production, but this target is absent from its updated 2021 submission.

[6] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[7] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.); *see also* Measures for the Administration of Greenhouse Gas Voluntary Emission Reduction Trading (Trial) [温室气体自愿减排交易管理办法（试行）] (promulgated by the Ministry of Ecology and Environment and the State Administration for Market Regulation, Oct. 19, 2023; effective Oct. 19, 2023) (hyperlink to original Chinese text).

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[10] Intergovernmental Panel on Climate Change (2022) *Summary for Policymakers*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), SPM-11 ("Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change (*high confidence*)."), SPM-13 ("Levels of risk for all Reasons for Concern (RFC) are assessed to become high to very high at lower global warming levels than in AR5 (*high confidence*). Between 1.2°C and 4.5°C global warming level very high risks emerge in all five RFCs compared to just two RFCs in AR5 (*high confidence*). Two of these transitions from high to very high risk are associated with near-term warming: risks to unique and threatened systems at a median value of 1.5°C [1.2 to 2.0] °C (*high confidence*) and risks associated with extreme weather events at a median value of 2°C [1.8 to 2.5] °C (*medium confidence*). Some key risks contributing to the RFCs are projected to lead to widespread, pervasive, and potentially irreversible impacts at global warming levels of 1.5–2°C if exposure and vulnerability are high and adaptation is low (*medium confidence*). … SPM.B.3 Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (*very high confidence*). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation (*high confidence*).").

[11] Zhang Y., Held I., & Fueglistaler S. (2021) *Projections of tropical heat stress constrained by atmospheric dynamics*, NAT. GEO. 14(3): 133–137, 133 ("For each 1 °C of tropical mean warming, global climate models project extreme TW (the annual maximum of daily mean or 3-hourly values) to increase roughly uniformly between 20° S and 20° N latitude by about 1 °C. This projection is consistent with theoretical expectation based on tropical atmospheric dynamics, and observations over the past 40 years, which gives confidence to the model projection. For a 1.5 °C warmer world, the probable (66% confidence interval) increase of regional extreme TW is projected to be 1.33–1.49 °C, whereas the uncertainty of projected extreme temperatures is 3.7 times as large. These results suggest that limiting global warming to 1.5 °C will prevent most of the tropics from reaching a TW of 35 °C, the limit of human adaptation."). *See also* Vecellio D. J., Kong Q., Kenney W. L., & Huber M. (2023) *Greatly enhanced risk to humans as a consequence of empirically determined lower moist heat stress tolerance*, PROC. NAT'L. ACAD. SCI. 120(42): 1–

9, 3 ("In climate change scenarios of 2 °C warming and below, conditions associated with threshold exceedance are limited to the Indus River Valley, east China, the Persian Gulf coastline, and sub-Saharan Africa. Increases in the number of hours over the threshold in these regions are mild in transitioning from 1.5 °C to 2 °C (Fig. 1 A and B)… . In this study's worst-case scenario of a 4 °C warmer world, around 2.7 billion persons will experience at least 1 wk of daytime (8 h) ambient conditions associated with uncompensable heat stress, 1.5 billion will experience a month under such conditions, and 363.7 million will be faced with an entire season (3 mo) of life-altering extreme heat (Fig. 1F).").

[12] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 8 ("Reducing human-caused methane emissions is one of the most cost-effective strategies to rapidly reduce the rate of warming and contribute significantly to global efforts to limit temperature rise to 1.5°C. Available targeted methane measures, together with additional measures that contribute to priority development goals, can simultaneously reduce human-caused methane emissions by as much as 45 per cent, or 180 million tonnes a year (Mt/yr) by 2030. This will avoid nearly 0.3°C of global warming by the 2040s and complement all long-term climate change mitigation efforts. It would also, each year, prevent 255 000 premature deaths, 775 000 asthma related hospital visits, 73 billion hours of lost labour from extreme heat, and 26 million tonnes of crop losses globally.").

[13] Zaelke D., Picolotti R., & Dreyfus G. (14 November 2021) *Glasgow climate summit: A glass half full*, THE HILL ("The new architecture also includes cutting not just carbon dioxide but also non-carbon dioxide climate emissions, with a specific focus on methane, a super climate pollutant responsible for 0.5 degrees Celsius of today's observed warming of 1.1 degrees Celsius. Cutting methane presents the single biggest and fastest mitigation action the world can take to keep warming from breaching the 1.5 degrees Celsius guardrail. This makes fast reductions of methane essential for adaptation as well."). *See also* Intergovernmental Panel on Climate Change (2022) *Summary for Policymakers*, *in* CLIMATE CHANGE 2022: IMPACTS, ADAPTATION, AND VULNERABILITY, *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Pörtner H.-O., Roberts D. C., Tignor M., Poloczanska E. S., Mintenbeck K., Alegría A., Craig M., Langsdorf S., Löschke S., Möller V., Okem A., & Rama B. (eds.), SPM-13 ("Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*)."); *and* Intergovernmental Panel on Climate Change (2018) GLOBAL WARMING OF 1.5 °C, *Special Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 22 ("Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off (*high confidence*).").

[14] International Energy Agency, United Nations Environment Programme, & Climate & Clean Air Coalition (2023) THE IMPERATIVE OF CUTTING METHANE FROM FOSSIL FUELS, 3 ("Immediate, targeted methane abatement in the fossil fuel sector can prevent nearly 1 million premature deaths due to ozone exposure, 90 million tonnes of crop losses due to ozone and climate changes, and about 85 billion hours of lost labour due to heat exposure by 2050, providing roughly U.S.D 260 billion in direct economic benefits.").

[15] Mbow C., *et al.* (2019) *Chapter 5: Food Security*, *in* CLIMATE CHANGE AND LAND, *Special Report of the Intergovernmental Panel on Climate Change on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*, Shukla P. R., *et al.* (eds.), 451 ("Methane increases surface ozone which augments warming-induced losses and some quantitative analyses now include climate, long-lived (CO_2) and multiple short-lived pollutants (CH_4, O_3) simultaneously (Shindell et al. 2017; Shindell 2016). Reduction of tropospheric ozone and black carbon can avoid premature deaths from outdoor air pollution and increases annual crop yields (Shindell et al. 2012). These actions plus methane reduction can influence climate on shorter time scales than those of carbon dioxide reduction measures. Implementing them substantially reduces the risks of crossing the 2°C threshold and contributes to achievement of the SDGs (Haines et al. 2017; Shindell et al. 2017)."); ("Ozone causes damage to plants through damages to cellular metabolism that influence leaf-level physiology to whole-canopy and root-system processes and feedbacks. … Using atmospheric chemistry and a global integrated assessment model, Chuwah et al. (2015) found that without a large decrease in air pollutant emissions, high ozone concentration could lead to an increase in crop damage of up to 20% in agricultural regions in 2050

compared to projections in which changes in ozone are not accounted for. Higher temperatures are associated with higher ozone concentrations; C3 crops are sensitive to ozone (e.g., soybeans, wheat, rice, oats, green beans, peppers, and some types of cottons) and C4 crops are moderately sensitive (Backlund et al. 2008)."). *See also* Climate & Clean Air Coalition, *Tropospheric ozone* (*last visited* 7 March 2024) ("79–121 million: Estimated global crop production losses owing to ozone total 79–121 million tonnes, worth USD 11–18 billion annually. … 1 million: Long-term exposure to ozone air pollution is linked to 1 million premature deaths per year due to respiratory diseases.").

[16] The People's Republic of China Second Biennial Update Report on Climate Change, 17 (December 2018) ("China's CH_4 emissions in 2014 were 55.292 Mt, of which 24.757 Mt were from energy, accounting for 44.8%; 6 kt were from industrial processes; 22.245 Mt were from agriculture, accounting for 40.2%; 1.72 Mt were from LULUCF, accounting about 3.1%; 6.564 Mt were from waste, accounting for 11.9%."). Additionally, published research estimated that China's total methane emissions were 65.0 (57.7–68.4) Tg a^{-1} by inverse analysis of 2019 TROPOMI satellite observations of atmospheric methane, much higher than the Chinese inventory reported to the UNFCCC (53.6 Tg a^{-1}). *See* Chen Z. *et al.* (2022) *Methane emissions from China: a high-resolution inversion of TROPOMI satellite observations*, ATMOS. CHEM. PHYS. 22(16): 10809–10826, 10809 ("Our best estimate for total anthropogenic emissions in China is 65.0 (57.7–68.4) Tg a^{-1}, where parentheses indicate the uncertainty range determined by the inversion ensemble. Contributions from individual sectors include 16.6 (15.6–17.6) Tg a^{-1} for coal, 2.3 (1.8–2.5) for oil, 0.29 (0.23–0.32) for gas, 17.8 (15.1–21.0) for livestock, 9.3 (8.2–9.9) for waste, 11.9 (10.7–12.7) for rice paddies, and 6.7 (5.8–7.1) for other sources. Our estimate is 21% higher than the Chinese inventory reported to the UNFCCC (53.6 Tg a^{-1}), reflecting upward corrections to emissions from oil (+147 %), gas (+61 %), livestock (+37 %), waste (+41 %), and rice paddies (+34 %), but downward correction for coal (−15 %).").

[17] The People's Republic of China Second Biennial Update Report on Climate Change, 17 (December 2018) ("China's CH_4 emissions in 2014 were 55.292 Mt, of which 24.757 Mt were from energy, accounting for 44.8%; 6 kt were from industrial processes; 22.245 Mt were from agriculture, accounting for 40.2%; 1.72 Mt were from LULUCF, accounting about 3.1%; 6.564 Mt were from waste, accounting for 11.9%.").

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[19] Forster P., Storelvmo T., Armour K., Collins W., Dufresne J.-L., Frame D., Lunt D. J., Mauritsen T., Palmer M. D., Watanabe M., Wild M., & Zhang H. (2021) *Chapter 7: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 1017 ("Global warming potentials (GWP) and global temperature-change potentials (GTP) give the relative effect of pulse emissions, that is, how much more energy is trapped (GWP) or how much warmer (GTP) the climate would be when unit emissions of different compounds are compared (Section 7.6.1.2). Consequently, these metrics provide information on how much energy accumulation (GWP) or how much global warming (GTP) could be avoided (over a given time period, or at a given future point in time) by avoiding the emission of a unit of a short-lived greenhouse gas compared to avoiding a unit of CO_2.").

[20] Forster P., Storelvmo T., Armour K., Collins W., Dufresne J.-L., Frame D., Lunt D. J., Mauritsen T., Palmer M. D., Watanabe M., Wild M., & Zhang H. (2021) *Chapter 7: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), Table 7.SM.7.

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lived and short-lived gases is fundamentally misconceived and should be abandoned in favor of sets of metrics that aggregate gases in similar lifetime classes.").

[22] Forster P., Storelvmo T., Armour K., Collins W., Dufresne J.-L., Frame D., Lunt D. J., Mauritsen T., Palmer M. D., Watanabe M., Wild M., & Zhang H. (2021) *Chapter 7: The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity*, *in* CLIMATE CHANGE 2021: THE PHYSICAL SCIENCE BASIS, *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Masson-Delmotte V., *et al.* (eds.), 1017 ("Emissions metrics can facilitate the comparison of effects of emissions in support of policy goals. They do not define policy goals or targets but can support the evaluation and implementation of choices within multi-component policies (e.g., they can help prioritize which emissions to abate). The choice of metric will depend on which aspects of climate change are most important to a particular application or stakeholder and over which time horizons. Different international and national climate policy goals may lead to different conclusions about what is the most suitable emissions metric (Myhre et al., 2013b).").

[23] Cohen-Shields N., Sun T., Hamburg S. P., & Ocko I. B. (2023) *Distortion of sectoral roles in climate change threatens climate goals*, FRONT. CLIM. 5: 1–6, 4 ("Given how GWP100-based CO_2e calculations distort the roles of economic sectors in contributing to future warming, relying solely on GWP100 can lead to suboptimal policies and priorities by misleading climate actors from the top levels of government (e.g., U.S. NDC)[2] to grassroots organizations. This is because the importance of methane emissions in several sectors is systematically underestimated by GWP100. … there are examples of acknowledgment of the metric issue by stakeholders (such as work by the Irish Climate Change Advisory Council to establish multi-gas GHG budgets, as well as the State of New York publishing their emissions inventory using GWP20). Given that prioritizing sectoral mitigation efforts is often necessary under cost and political constraints, the current sectoral share distortion imposed by GWP100/CO_2e risks mis-prioritizing sectors for emissions reductions, undervaluing the benefits of methane-sector mitigation—especially in the near-term—and potentially overlooking important abatement measures. This can have implications for the temperature outcomes of climate policies. For example, if CO_2-dominated sectors are regularly prioritized for mitigation, the realized temperature benefits in the near-term will be lower than anticipated because the remaining warming impact from methane-dominated sectors will be underestimated. The bottom line is that GWP100 should never be singularly relied upon for emissions assessments.").

[24] Abernethy S. & Jackson R. B. (2022) *Global temperature goals should determine the time horizons for greenhouse gas emission metrics*, ENVIRON. RES. LETT. 17(2): 1–10, 7 ("Although NDCs and long-term national pledges are currently insufficient to keep warming below 2 °C, let alone 1.5 °C [50–52], the time horizons used for emission metrics should nevertheless be consistent with that central goal of the Paris Agreement. We therefore support the use of the 20 year time horizon over the 100 year version, when binary choices between these two must be made, due to the better alignment of the former with the temperature goals of the Paris Agreement. The 50 year time horizon, not yet in widespread use but now included in IPCC AR6, is in fact the only time horizon that the IPCC presents that falls within the range of time horizons that align with the Paris Agreement temperature goals (24–58 years). However, to best align emission metrics with the Paris Agreement 1.5 ° C goal, we recommend the use of the 24 year time horizon, using 2045 as the end point time, with its associated $GWP_{1.5°C} = 75$ and $GTP_{1.5\,°C} = 41$."). *See also* Reisinger A. & Geden O. (2023) *Temporary overshoot: Origins, prospects, and a long path ahead*, ONE EARTH 6(12): 1631–37, 1631 ("A subsequent decline in global warming relies on sustained net-negative CO_2 emissions from human activities, with total removals outweighing residual emissions of all long-lived greenhouse gases. Reductions of short-lived climate forcers, in particular methane (CH_4), would reduce peak warming further and, if reductions continue afterward, could contribute to the subsequent decline in temperature.").

[25] Dreyfus G. & Ferris T. (2023) *Annex 1: Metrics and Measurement of Methane Emissions*, *in* INNOVATIVE TECHNOLOGIES FOR GREENHOUSE GAS EMISSIONS AND CARBON SEQUESTRATION MONITORING, China Council for International Cooperation on Environment and Development, 23 ("Without robust monitoring, reporting, and verification (MRV) of methane emissions, we will not be able to know the efficacy of methane mitigation policies and programs or whether we are meeting methane mitigation targets.").

[26] Dreyfus G. & Ferris T. (2023) *Annex 1: Metrics and Measurement of Methane Emissions*, *in* INNOVATIVE TECHNOLOGIES FOR GREENHOUSE GAS EMISSIONS AND CARBON SEQUESTRATION MONITORING, China Council for International Cooperation on Environment and Development, 23 ("Reducing intended and unintended emissions to

achieve lower-emission goals with a transition to gas, and as we work toward a transition away from gas, requires measurement and MRV along the full well-to-gate scope (producers, processors, and transporters of gas) both for domestic producers and for importers seeking to impose methane emission intensity requirements. Such quantification-based intensity requirements complement established approaches for controlling methane leaks through prescriptive regulations. Measuring methane accurately is key to enabling these types of policies.").

[27] United States Environmental Protection Agency Office of Atmospheric Programs (October 2019) GLOBAL NON-CO_2 GREENHOUSE GAS EMISSION PROJECTIONS & MITIGATION 2015-2050, 15 ("Taken together, the top 5 countries in terms of emissions represent 86% of all potential global abatement from coal mining in 2030. China is responsible for 69% of global abatement potential in coal mining (403 $MtCO_2e$).")

[28] United State Environmental Protection Agency Office of Atmospheric Programs (October 2019) GLOBAL NON-CO_2 GREENHOUSE GAS EMISSION PROJECTIONS & MITIGATION 2015-2050, 71 ("China and the United States are the top 2 emitters and collectively can mitigate 5% of total landfill emissions in 2030—27 $MtCO_2e$ in China and 8 $MtCO_2e$ in the United States. The United States already has a high rate of adoption of abatement measures, leading to a lower future mitigation potential.")

[29] Opinions on Comprehensively Promoting the Construction of a Beautiful China [关于全面推进美丽中国建设的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Dec. 27, 2023; effective Dec. 27, 2023) (hyperlink to original Chinese text).

[30] China Ministry of Foreign Affairs (22 September 2020) *Statement by H.E. Xi Jinping, President of the People's Republic of China, At the General Debate of the 75th Session of The United Nations General Assembly* ("China will scale up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060."). *See also* China Ministry of Foreign Affairs (1 November 2021) *Written Statement by H.E. Xi Jinping, President of the People's Republic of China, Unite for Action, To Protect the Planet, Our Shared Home, At the World Leaders Summit*, 5 ("Recently, China released two directives: Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy, and the Action Plan for Carbon Dioxide Peaking Before 2030. Specific implementation plans for key areas such as energy, industry, construction and transport, and for key sectors such as coal, electricity, iron and steel, and cement will be rolled out, coupled with supporting measures in terms of science and technology, carbon sink[s], fiscal and taxation [measures], and financial incentives. Taken together, these measures will forma. '1+N' policy framework for delivering carbon peak and carbon neutrality, with clearly defined timetable, roadmap and blueprint."); *and* Institute for Governance & Sustainable Development (25 October 2021) *Briefing: China Details Plans for Achieving Carbon-Peaking and Carbon-Neutrality Goals* ("On October 22 and 24, 2021, China issued two policy documents detailing its plans for achieving its carbon-peaking and carbon-neutrality goals: (1) the Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy, and (2) the Action Plan for Achieving Carbon Peaking Before 2030.").

[31] National Center for Climate Change Strategy and International Cooperation (27 July 2021) *Xie Zhenhua Details on the Development of 1+N Policy System as A Timeline and Roadmap to Achieve the Carbon Peaking and Carbon Neutrality Goals* [解振华详解制定 1+N 政策体系作为实现双碳目标的时间表、路线图] (hyperlink to original Chinese text).

[32] Law on Promotion of Circular Economy［循环经济促进法］(promulgated by the Standing Committee of the National People's Congress, Aug. 29, 2008; amended Oct. 26, 2018) (hyperlink to original Chinese text).

[33] China National Development and Reform Commission (25 December 2021) *Assessment of the 13th Five-Year Plan, No. 28: Completion of Major Indicators* ["十三五"规划《纲要》总结评估之 28/ 主要指标完成情况] (hyperlink to original Chinese text).

[34] Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 [国民经济和社会发展第十四个五年规划和 2035 年远景目标纲要] (China) (2021) (hyperlink to original Chinese text).

[35] H.E. Xi Jinping, President of the People's Republic of China (12 December 2020) *Remarks by Chinese President Xi Jinping at Climate Ambition Summit*.

[36] China's Mid-Century Long-Term Low Greenhouse Gas Emission Development Strategy, submission to the Secretariat of UNFCCC 8-9 (28 October 2021); *see also* Institute for Governance & Sustainable Development (28 October 2021) *Ahead of COP 26, China Submits Update to NDC and Mid-Century Development Strategy* (explaining China's updated NDCs and Mid-Century Strategy).

[37] People's Republic of China (2021) *China's Achievements, New Goals and New Measures for Nationally Determined Contributions*, submission to the Secretariat of UNFCCC; *see also* Institute for Governance & Sustainable Development (28 October 2021) *Ahead of COP 26, China Submits Update to NDC and Mid-Century Development Strategy* (listing actions to address non-CO_2 GHGs incorporated into China's updated NDCs.).

[38] People's Republic of China (2021) *China's Achievements, New Goals and New Measures for Nationally Determined Contributions*, 2, 40, submission to the Secretariat of UNFCCC.

[39] Note that China's 2016 Intended NDCs included a numeric target for coalbed methane production, but this target is absent from its updated 2021 submission.

[40] United States Department of State (14 November 2023) Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis.

[41] United States Department of State (10 November 2021) U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s.

[42] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[43] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.); s*ee also* Measures for the Administration of Greenhouse Gas Voluntary Emission Reduction Trading (Trial) [温室气体自愿减排交易管理办法（试行）] (promulgated by the Ministry of Ecology and Environment and the State Administration for Market Regulation, Oct. 19, 2023; effective Oct. 19, 2023) (hyperlink to original Chinese text).

[44] Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 [国民经济和社会发展第十四个五年规划和 2035 年远景目标纲要] (China) (2021) (hyperlink to original Chinese text).

[45] Opinions on Further Accelerating Coalbed Methane (Coal Mine Gas) Extraction and Utilization [关于进一步加快煤层气（煤矿瓦斯）抽采利用的意见] (promulgated by the General Office of the State Council, Sept. 14, 2013; effective Sept. 14, 2013) (hyperlink to original Chinese text).

[46] Emission Standard of Coalbed Methane / Coal Mine Gas (Trial) [煤层气（煤矿瓦斯）排放标准（暂行）] (promulgated by the Ministry of Environmental Protection (now "Ministry of Ecology and Environment") and the General Administration of Quality Supervision, Inspection and Quarantine (the responsibilities of which are now merged into the State Administration for Market Regulation), Apr. 2, 2008; effective Jul. 1, 2008) (hyperlink to original Chinese text).

[47] Miller S. M., *et al.* (2019) *China's coal mine methane regulations have not curbed growing emissions*, NAT. COMMUN. 10:303 ("We find that emissions from China rose by 1.1 ± 0.4 Tg CH_4 yr^{-1} from 2010 to 2015, culminating in total anthropogenic and natural emissions of 61.5 ± 2.7 Tg CH_4 in 2015. The observed trend is consistent with pre-2010 trends and is largely attributable to coal mining. These results indicate that China's CMM [coal mine methane] regulations have had no discernible impact on the continued increase in Chinese methane emissions.").

[48] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 28 ("Fossil fuels: release during oil and gas extraction, pumping and transport of fossil fuels accounts for roughly 23 per cent of all anthropogenic emissions, with emissions from coal mining contributing 12 per cent.").

[49] Höglund-Isaksson L., Gómez-Sanabria A., Klimont Z., Rafaj P., & Schöpp W. (2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe – results from the GAINS model*, ENVIRON. RES. COMM. 2(2): 1–21, 7–8 (Table 2 and Supplementary material tab "World"). *See also* International Energy Agency (2022) GLOBAL METHANE TRACKER 2022, 4 ("We estimate that the global energy sector was responsible for around 135 million tonnes of methane emitted into the atmosphere in 2021. Following the Covid-induced decline in 2020, this represents a year-on-year increase in energy-related methane emissions of almost 5%, largely due to higher fossil fuel demand and production as economies recovered from the shock of the pandemic... Of the 135 million tonnes of energy-related emissions, an estimated 42 Mt are from coal operations, 41 Mt from oil, 39 Mt are from extracting, processing and transporting natural gas, 9 Mt from the incomplete combustion of bioenergy (largely when wood and other solid biomass is used as a traditional cooking fuel), and 4 Mt leaks from end-use equipment.").

[50] Ozgen Karacan C., Ruiz F.A., Cote M., & Phillipe S. (2011) *Coal mine methane: A review of capture and utilization practices with benefits to mining safety and to greenhouse gas reduction*, INT'L J. OF COAL GEOLOGY 86(2–3): 122 ("Coal mine methane (CMM) is a general term for all methane released mainly during and after mining operations. Although, methane captured prior to mining can also be considered associated to mining and thus can be considered as coal mine methane, it can also be termed as coalbed methane (CBM). CMM shows great variability in flow rate and composition. At a typical gassy coal mine, ventilation air may contain 0.1–1% methane, whereas gas drained from the seam before mining can contain 60% to more than 95% methane depending on the presence of other gasses in the coal seam. Gas drained from fractured formations above mined seams (gobs), on the other hand, may contain 30–95% methane depending on the locations of the boreholes and other operation and completion parameters (Karacan, 2009a).").

[51] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 107 ("Coal mining: pre-mining degasification; air methane oxidation with improved ventilation."). *See also* DeFabrizio S., Glazener W., Hart C., Henderson K., Kar J., Katz J., Pratt M. P., Rogers M., Tryggestad C., & Ulanov A. (2021) CURBING METHANE EMISSIONS: HOW FIVE INDUSTRIES CAN COUNTER A MAJOR CLIMATE THREAT, McKinsey Sustainability, 22 ("Levers such as full ventilation and degasification of underground mines are standard coal mine methane (CMM) abatement technology but would likely see adoption rates of only 0.5 to 1.0 percent by 2030 and 2 to 4 percent by 2050. Other levers—such as ventilation air methane (VAM) capture and utilization, capture of abandoned mine gas, degasification of surface mines, and predrainage of surface mine—are less technically challenging but are expensive. They could see 2 to 16 percent adoption rates in 2030, growing to 20 to 30 percent adoption rates by 2050."); *and* United States Environmental

Protection Agency (2019) GLOBAL NON-CO_2 GREENHOUSE GAS EMISSION PROJECTIONS & MITIGATION 2015-2050, EPA-430-R-19-010, 14 ("In 2030, VAM oxidation is the leading emission abatement measure, but using degasification for power generation presents the largest abatement potential at prices below $0/t$CO_2$e. The two technologies combined contribute 90% of potential abatement in 2030.").

[52] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, Table 4.1 ("Coal mining: flooding abandoned mines.").

[53] United Nations Economic Commission for Europe (2019) BEST PRACTICE GUIDANCE FOR EFFECTIVE METHANE RECOVERY AND USE FROM ABANDONED COAL MINES, ECE Energy Series No. 64, 3 ("Technologies and management practices allow methane from abandoned mines to be extracted, providing significant environmental, economic, social and public safety benefits. The methods for extracting gas from abandoned mines differ from those employed to capture and recover gas from working mines. Once a mine is sealed from the atmosphere, gas from all underground sources becomes potentially available for extraction at a single production location. Methane concentrations recovered from a well-sealed former gassy mine typically range from 15% to 90%, and with no oxygen. The other major gaseous components may be nitrogen, including de-oxygenated air, and carbon dioxide. Low concentrations of carbon monoxide and trace hydrocarbons such as ethane are sometimes present.").

[54] United Nations Economic Commission for Europe (2019) BEST PRACTICE GUIDANCE FOR EFFECTIVE METHANE RECOVERY AND USE FROM ABANDONED COAL MINES, ECE Energy Series No. 64, iii ("Closed mines can provide a small but significant opportunity to exploit a clean energy resource, known as Abandoned Mine Methane (AMM), that can be extracted and used. AMM capture and use offers many benefits, such as improved safety, air quality and health, energy supply and environmental performance. Technology exists that can recover methane from abandoned coal mines.").

[55] Institute for Governance & Sustainable Development (28 April 2021) *China Announces Further Steps Toward Reduction of Non-CO_2 Super Climate Pollutant Emissions*.

[56] China National Development and Reform Commission (20 May 2020) Guidance on Promoting the Comprehensive Management and Utilization of Abandoned Coal Mine Methane (Draft for Comments) [关于推进关闭煤矿瓦斯综合治理与利用的指导意见（征求意见稿）] (hyperlink to original Chinese text).

[57] Circular on Further Strengthening the Management of Environmental Impact Assessment of Coal Resources Development [关于进一步加强煤炭资源开发环境影响评价管理的通知] (promulgated by the Ministry of Ecology and Environment, the National Development and Reform Commission and the National Energy Administration, Oct. 30, 2020; effective Oct. 30, 2020) (hyperlink to original Chinese text).

[58] Circular on Further Strengthening the Management of Environmental Impact Assessment of Coal Resources Development [关于进一步加强煤炭资源开发环境影响评价管理的通知] (promulgated by the Ministry of Ecology and Environment, the National Development and Reform Commission and the National Energy Administration, Oct. 30, 2020; effective Oct. 30, 2020) (hyperlink to original Chinese text).

[59] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[60] 13th Five-Year Plan for the Development and Utilization of Coalbed Methane (Coal Mine Gas) [煤层气（煤矿瓦斯）开发利用"十三五"规划] (promulgated by the National Energy Administration, Nov. 24, 2016; effective Nov. 24, 2016) (hyperlink to original Chinese text).

[61] 13th Five-Year Plan for the Development and Utilization of Coalbed Methane (Coal Mine Gas) [煤层气（煤矿瓦斯）开发利用“十三五”规划] (promulgated by the National Energy Administration, Nov. 24, 2016; effective Nov. 24, 2016) (hyperlink to original Chinese text).

[62] Administrative Measures on Specialized Investment within the Central Government Budget for Coal Mine Safety Retrofit [煤矿安全改造中央预算内投资专项管理办法] (amended by the National Development and Reform Commission, the National Energy Administration, the Ministry of Emergency Management and the National Mine Safety Administration, Jan. 17, 2023; effective Jan. 17, 2023) (hyperlink to original Chinese text).

[63] Xinhua News Agency, (3 October 2023) *Shanxi extracts record amount of coalbed methane* (“China’s coal-rich province of Shanxi extracted 7.16 billion cubic meters of coalbed methane in the first eight months of 2023, a record high for the January-August period, according to the provincial statistics bureau. Shanxi’s coalbed methane output accounted for about 81.8 percent of the country’s total in the first eight months this year.”).

[64] Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy [关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Sept. 22, 2021; effective Sept. 22, 2021) (hyperlink to original Chinese text).

[65] Asia-Pacific Economic Cooperation Policy Support Unit (2017) *Partnerships for the Sustainable Development of Cities in the APEC Region*, 160 (“The Beijing–Tianjin–Hebei Region, known as the Jing-Jin-Ji Region (JJJR), is one of the most important political, economic and cultural areas in China. ... The Jing-Jin-Ji Region covers the municipalities of Beijing and Tianjin and Hebei province (including 11 prefecture cities in Hebei). Beijing and Tianjin are integrated geographically with Hebei province. In 2012, the total population of the Jing-Jin-Ji Region was 107.7 million.”).

[66] Wei Z., Li J., Wang Z., Zhou A., & Li M. (2022) *County carbon emissions in the Yangtze River Delta region: Spatial layout, dynamic evolution and spatial spillover effects*, FRONTIERS IN ENVIRON. SCI. 10: 977198, 3 (“[T]he Yangtze River Delta region, … is located in the lower reaches of the Yangtze River in eastern China, bordering the Yellow Sea and the East China Sea, and is one of the most economically developed, densely populated, and innovative regions in China.”).

[67] Lin C., Huang R., Zhong H., Duan J., Wang Z., Huang W., & Wei X. (2023) *Elucidating ozone and $PM_{2.5}$ pollution in the Fenwei Plain reveals the co-benefits of controlling precursor gas emissions in winter haze*, ATMOSPHERIC CHEMISTRY & PHYSICS 23:3595–3607, 3596 (“The Fenwei Plain (about 760 km in length and 40–100 km in width) is the largest plain in the middle reaches of the Yellow River. It is home to over 50 million people in central China, surrounded by the Chinese Loess Plateau to the northwest and Qinling Mountains to the south.”).

[68] Opinions on Strengthening the Battle for Pollution Prevention and Control [关于深入打好污染防治攻坚战的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Nov. 2, 2021; effective Nov. 2, 2021) (hyperlink to original Chinese text).

[69] 14th Five-Year Comprehensive Work Plan on Energy Conservation and Emission Reduction [“十四五”节能减排综合工作方案] (promulgated by the State Council. Dec. 28, 2021; effective Dec. 28, 2021) (hyperlink to original Chinese text).

[70] 14th Five-Year Comprehensive Work Plan on Energy Conservation and Emission Reduction [“十四五”节能减排综合工作方案] (promulgated by the State Council. Dec. 28, 2021; effective Dec. 28, 2021) (hyperlink to original Chinese text).

[71] Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy [关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见] (promulgated

by the Central Committee of the Chinese Communist Party and the State Council, Sept. 22, 2021; effective Sept. 22, 2021) (hyperlink to original Chinese text).

[72] China's Mid-Century, Long-Term Low Greenhouse Gas Emission Development Strategy, submission to the Secretariat of UNFCCC (28 October 2021). *See also* Action Plan for Achieving Carbon Peaking Before 2030 [2030 年前碳达峰行动方案] (promulgated by the State Council, Oct. 24, 2021; effective Oct. 24, 2021) (hyperlink to original Chinese text).

[73] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[74] 13th Five-Year Development Plan for Natural Gas [天然气发展"十三五"规划] (promulgated by the National Development and Reform Commission, Dec. 24, 2016; effective Dec. 24, 2016) (hyperlink to original Chinese text).

[75] Guiding Catalogue for Industrial Restructuring (2024 Edition) [产业结构调整指导目录（2024 年本）] (promulgated by the National Development and Reform Commission, Dec. 27, 2023; effective Feb. 1, 2024) (hyperlink to original Chinese text).

[76] Green and Low Carbon Transition Industries Guidance Catalogue (2024 Edition) [绿色低碳转型产业指导目录（2024 年版）] (promulgated by the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Natural Resources, the Ministry of Ecology and Environment, the Ministry of Housing and Urban-Rural Development, the Ministry of Transportation, the People's Bank of China, the National Financial Regulatory Administration, the Securities Regulatory Commission, and the National Energy Administration, Feb. 2, 2024; effective Feb. 2, 2024) (hyperlink to original Chinese text).

[77] Höglund-Isaksson L., Gómez-Sanabria A., Klimont Z., Rafaj P., & Schöpp W. (2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe – results from the GAINS model*, ENVIRON. RES. COMM. 2(2): 1–21, 7–8 (Table 2 and Supplementary material tab "World"). *See also* International Energy Agency (2022) GLOBAL METHANE TRACKER 2022, 4 ("We estimate that the global energy sector was responsible for around 135 million tonnes of methane emitted into the atmosphere in 2021. Following the Covid-induced decline in 2020, this represents a year-on-year increase in energy-related methane emissions of almost 5%, largely due to higher fossil fuel demand and production as economies recovered from the shock of the pandemic... Of the 135 million tonnes of energy-related emissions, an estimated 42 Mt are from coal operations, 41 Mt from oil, 39 Mt are from extracting, processing and transporting natural gas, 9 Mt from the incomplete combustion of bioenergy (largely when wood and other solid biomass is used as a traditional cooking fuel), and 4 Mt leaks from end-use equipment.").

[78] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 30 (Figure 2.3, "Within the fossil fuel sector, extraction, processing and distribution of the three main fuels have comparable impacts, with emissions from oil and gas each contributing 34 per cent followed by coal with 32 per cent of sectoral emissions in 2020 (Höglund-Isaksson 2020). Emissions from the coal subsector are entirely from mining-related activities, including both active and abandoned facilities. Within oil and gas, methane emissions associated with onshore conventional extraction along with downstream gas usage are the largest sources (Figure 2.3). Venting, the deliberate release of unwanted gas, is the primary cause of emissions during onshore conventional extraction, whereas fugitive emissions, the inadvertent release or escape of gas from fossil fuel systems, dominate downstream gas emissions. Within the fossil fuel sector, at the national level, emissions from the oil subsector in Russia and the coal subsector in China appear to be far larger than any other national level subsectors (Scarpelli *et al*. 2020). While these types of data based on national inventories

are useful, it is important to note that many local measurements show large differences and often substantially higher emissions than conventional reporting, in many cases due to the presence of a small number of super-emitters, and imply these estimates may be too low (Zhang *et al*. 2020; Duren *et al*. 2019; Varon *et al*., 2019; Zavala-Araiza *et al*. 2018). These emissions give a sense of mitigation opportunities by region and sector, which is explored in Chapter 4.").

[79] Hope M. (2014) *Explained: Fugitive methane emissions from natural gas production*, CARBON BRIEF ("Natural gas is mainly methane, some of which escapes during the drilling, extraction, and transportation process. Such outbreaks are known as fugitive emissions."). *See also* Picard D. (2000) *Fugitive emissions from oil and natural gas activities*, Background Paper in IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories ("In general, fugitive emissions from oil and gas activities may be attributed to the following primary types of sources: • fugitive equipment leaks; • process venting; • evaporation losses; • disposal of waste gas streams (e.g., by venting or flaring), and • accidents and equipment failures.").

[80] International Energy Agency (2022) GLOBAL METHANE TRACKER 2022, 6 ("Globally, our analysis finds that methane emissions from the energy sector are about 70% greater than the sum of estimates submitted by national governments.").

[81] Dreyfus G. & Ferris T. (2023) *Annex 1: Metrics and Measurement of Methane Emissions*, *in* INNOVATIVE TECHNOLOGIES FOR GREENHOUSE GAS EMISSIONS AND CARBON SEQUESTRATION MONITORING, China Council for International Cooperation on Environment and Development, 23. *See also* Gordon D., Reuland F., Jacob D. J., Worden J. R., Shindell D., & Dyson M. (2023) *Evaluating net life-cycle greenhouse gas emissions intensities from gas and coal at varying methane leakage rates*, ENVIRON. RES. LETT. 18(8): 084008; *and* calculator developed by RMI to compare the net GHG emissions parity between gas and coal using varying inputs.

[82] Clean Air Task Force, *Oil and Gas Mitigation Program* (*last visited* 7 March 2024) ("Fortunately, most leaks are straightforward to repair (and fixing leaks is paid for by the value of the gas that is saved by repairing them). Further, finding leaks has become efficient with modern technology. The standard approach today is to use special cameras that can detect infrared light (think of night-vision goggles) which are tuned to make methane, which is invisible to our eyes, visible. They allow inspectors to directly image leaking gas in real time, with the ability to inspect entire components (not just connections and other areas most likely to leak) and pinpoint the precise source, making repair more straightforward. And, technology promises to make this process even more efficient (and cheaper) over the coming years. These technologies can be utilized to reduce harmful leak emissions, by using regular inspections as the lynchpin of rigorous "leak detection and repair" (LDAR) programs. These programs require operators to regularly survey all of their facilities for leaks and improper emissions, and repair all the leaks they identify in a reasonable time. For example, California requires operators to survey all sites four times a year. Colorado has a different approach, requiring operators of the largest sites to survey them monthly, but requiring less frequent inspections for site with smaller potential emissions.").

[83] Clean Air Task Force, *Oil and Gas Mitigation Program* (*last visited* 7 March 2024) (Listing pneumatic equipment venting, compressor seal venting, tank venting, well completion venting, oil well venting and flaring, and dehydrator venting as sources of the "biggest mitigation opportunities.").

[84] International Energy Agency (2021) METHANE TRACKER 2021 ("Many pieces of equipment in the oil and natural gas value chains emit natural gas in their regular course of operation, including valves, and gas-driven pneumatic controllers and pumps. Retrofitting these devices or replacing them with lower-emitting versions can reduce emissions."). *See also* Dreyfus G. & Ferris T. (2023) *Metrics and Measurement of Methane Emissions*, *in* INNOVATIVE TECHNOLOGIES FOR GREENHOUSE GAS EMISSIONS AND CARBON SEQUESTRATION MONITORING, China Council for International Cooperation on Environment and Development, 29 ("Leak detection and repair (LDAR) is an essential component of monitoring and reducing methane emissions"); *and* United Nations Economic Commission for Europe (2019) BEST PRACTICE GUIDANCE FOR EFFECTIVE METHANE MANAGEMENT IN THE OIL AND GAS SECTOR, xiii ("Major gaps exist in information about emissions originating from the oil and gas sector. Reported estimates often diverge by 10% or more, and revisions of national inventory reports from some of the largest emitters highlight the lack of reliable data. Methane emissions cannot be quantified through continuous measurement alone. Emissions originate from a vast

number of sources and monitoring each source would be prohibitively expensive. Emission detection and measurement must complement calculation-based approaches that quantify emissions by multiplying activity data by relevant emission factors. Estimates will be more reliable if they reflect field and country specific circumstances, so empirical studies of emissions and emission intensities are a key to improved quantification. Detection and measurement consist of top-down methods that measure concentrations of methane in the atmosphere and bottom-up methods involving on-site quantification of emissions from individual sources. The technology for both top-down and bottom-up approaches is improving and the choice of approach depends on the objective. Best practices for top-down or bottom-up detection and measurement and for calculation-based methods depend on the objectives and the manner of reporting.").

[85] International Energy Agency (2021) METHANE TRACKER 2021 (Listing replacement of existing devices, installing new emissions control devices, leak detection and repair (LDAR), and alternative and innovative technologies as the four "main mitigation measures."). *See also* Clean Air Task Force, *Oil and Gas Mitigation Program* (*last visited* 7 March 2024 ("Fortunately, most leaks are straightforward to repair (and fixing leaks is paid for by the value of the gas that is saved by repairing them). Further, finding leaks has become efficient with modern technology. The standard approach today is to use special cameras that can detect infrared light (think of night-vision goggles) which are tuned to make methane, which is invisible to our eyes, visible. They allow inspectors to directly image leaking gas in real time, with the ability to inspect entire components (not just connections and other areas most likely to leak) and pinpoint the precise source, making repair more straightforward. And, technology promises to make this process even more efficient (and cheaper) over the coming years. These technologies can be utilized to reduce harmful leak emissions, by using regular inspections as the lynchpin of rigorous "leak detection and repair" (LDAR) programs. These programs require operators to regularly survey all of their facilities for leaks and improper emissions, and repair all the leaks they identify in a reasonable time. For example, California requires operators to survey all sites four times a year. Colorado has a different approach, requiring operators of the largest sites to survey them monthly, but requiring less frequent inspections for site with smaller potential emissions.").

[86] Clean Air Task Force, *Oil and Gas Mitigation Program* (*last visited* 7 March 2024) ("Venting is even more harmful than flaring, since methane warms the climate so powerfully, and VOC and toxic pollutants are released unabated. Venting of this gas should be prohibited in all cases as an absolutely unnecessary source of harmful air pollution. There are numerous low-cost (and usually profitable) ways to utilize natural gas from oil wells. Flaring should be a last resort: only in the most extreme cases should oil producers be allowed to flare gas, and it should be strictly a temporary measure. Rules prohibiting venting of natural gas can easily reduce emissions by 95%.").

[87] Dreyfus G. & Ferris T. (2023) *Annex 1: Metrics and Measurement of Methane Emissions*, *in* INNOVATIVE TECHNOLOGIES FOR GREENHOUSE GAS EMISSIONS AND CARBON SEQUESTRATION MONITORING, China Council for International Cooperation on Environment and Development, 23 ("Without robust monitoring, reporting, and verification (MRV) of methane emissions, we will not be able to know the efficacy of methane mitigation policies and programs or whether we are meeting methane mitigation targets."; "Conventional wisdom has held that gas is 'cleaner' than coal because generating electricity from gas produces about half the CO_2 for a given electricity output than coal.[3] However, this comparison ignores the methane emissions associated with producing natural gas and coal. Many studies have analyzed the crossover point at which venting and fugitive emissions from gas outweigh the climate benefits of a transition from coal to gas, generally finding that leakage rates above 2.4%–3.4% eliminate the climate benefit.[4] and as low as 0.2% when masking from sulfate co-emission for coal is included.[5]). *See also* Gordon D., Reuland F., Jacob D. J., Worden J. R., Shindell D., & Dyson M. (2023) *Evaluating net life-cycle greenhouse gas emissions intensities from gas and coal at varying methane leakage rates*, ENVIRON. RES. LETT. 18(8): 084008; *and* calculator developed by RMI to compare the net GHG emissions parity between gas and coal using varying inputs.

[88] China National Petroleum Corporation (19 May 2021) *China Oil and Gas Methane Alliance was inaugurated* ("It has seven members: CNPC, SINOPEC, CNOOC, PipeChina, Beijing Gas, CR Gas and ENN Energy, with CNPC serving as its first president. At the conference, the founding members jointly announced their pledge to control methane emissions across the entire industry chain and take practical measures to push for the clean and low-carbon transformation of energy. The China Oil and Gas Methane Alliance is committed to building a high-quality and open platform for technical experience sharing and cooperation, improving methane emissions control, and actively engaging in global climate governance. It will join the global efforts to ensure systematic, regular, standardized and international methane monitoring and measurement, promote and adopt leak detection and repair (LDAR) and other

effective emissions control measures throughout the industry chain, from oil and gas production, storage and transportation to sales, increase the recovery and utilization of vented gas during exploration and development, actively develop new energy sources, and reduce dependence on fossil fuels during oil and gas production…. Through the China Oil and Gas Methane Alliance, member companies will incorporate methane emissions control into their carbon emissions reduction plan, comprehensively improve methane emissions control, strive to reduce the average methane intensity in natural gas production to below 0.25% by 2025.”).

[89] Environmental Defense Fund (15 October 2021) *Advocating Methane Emission Control, Beijing Gas Group Partners with City Gas Companies to Promote Green and Low-Carbon Energy Development* [倡导甲烷控排，北京燃气集团携手城燃企业，推动能源绿色低碳发展] (hyperlink to original Chinese text).

[90] Action Plan for Achieving Carbon Peaking Before 2030 [2030 年前碳达峰行动方案] (promulgated by the State Council, Oct. 24, 2021; effective Oct. 24, 2021) (hyperlink to original Chinese text).

[91] Action Plan for Achieving Carbon Peaking Before 2030 [2030 年前碳达峰行动方案] (promulgated by the State Council, Oct. 24, 2021; effective Oct. 24, 2021) (hyperlink to original Chinese text).

[92] South China Morning Post (27 August 2022) *China's Power Crisis: Why Is It Happening and What Does It Mean for the Economy?*

[93] Action Plan for Accelerating the Integrated Development of Oil and Gas Exploration with New Energy (2023-2025) [加快油气勘探开发与新能源融合发展行动方案（2023-2025 年）] (promulgated by the National Energy Administration, Feb. 27, 2023; effective Feb. 27, 2023) (hyperlink to original Chinese text).

[94] Liang C. (29 February 2024) *China 2024 LNG imports expected to rise 8.1% on year to 77 mil mt: CNPC ETRI*, S&P GLOBAL (“China's pipeline gas imports are expected to rise 8.2% year on year to 72.6 Bcm in 2024, and its total natural gas imports (including both piped gas and LNG) are also expected to see a year-on-year increase of 8.2% to 179.1 Bcm in 2024, ETRI said.”).

[95] Action Plan for Accelerating the Integrated Development of Oil and Gas Exploration with New Energy (2023-2025) [加快油气勘探开发与新能源融合发展行动方案（2023-2025 年）] (promulgated by the National Energy Administration, Feb. 27, 2023; effective Feb. 27, 2023) (hyperlink to original Chinese text).

[96] Russell C. (January 11, 2024) *China dominates renewable energy and coal power forecasts*, REUTERS (“The International Energy Agency said in its Renewables 2023 report, released on Thursday, that China will account for 56% of renewable energy capacity additions in the 2023-28 period. China is expected to increase renewable capacity by 2,060 gigawatts (GW) in the forecast period, while the rest of the world will add 1,574 GW, the IEA data showed. The European Union and the United States are the next biggest builders of renewable energy, at 429 GW and 337 GW respectively.”). *See also* International Energy Agency (2023) *Renewables 2023: Analysis and forecast to 2028*, 16 (“China's renewable electricity capacity growth t triples in the next five years compared with the previous five, with the country accounting for an unprecedented 56% of global expansion. Over 2023-2028, China will deploy almost four times more renewable capacity than the European Union and five times more than the United States, which will remain the second- and third-largest growth markets. The Chinese government's Net Zero by 2060 target, supported by incentives under the 14th Five-Year Plan (2021-2025) and the ample availability of locally manufactured equipment and low-cost financing, stimulate the country's renewable power expansion over the forecast period.”).

[97] Guti Feiwu Wuran Huanjing Fangzhi Fa (固体废物污染环境防治法) [Solid Waste Pollution Prevention and Control Law] (China) (amended by the Standing Committee of the National People's Congress, Apr. 29, 2020; effective Sept. 1, 2020) (hyperlink to original Chinese text).

[98] Shui Wuran Fangzhi Fa (水污染防治法) [Water Pollution Prevention and Control Law] (China) (amended by the Standing Committee of the National People's Congress, Jun. 27, 2017; effective Jun. 27, 2017) (hyperlink to original Chinese text).

[99] Fan Shipin Langfei Fa (反食品浪费法) [Anti-Food Waste Law] (China) (promulgated by the Standing Committee of the National People's Congress, Apr. 29, 2021; effective Apr. 29, 2021) (hyperlink to original Chinese text).

[100] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 28 ("Waste: landfills and waste management represents the next largest component making up about 20 per cent of global anthropogenic emissions.").

[101] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, Table 2.1 (showing estimated natural and anthropogenic source and sinks of methane in 2017, with landfill and waste accounting for 68 [64-71] Mt CH_4). *See also* Höglund-Isaksson L., Gómez-Sanabria A., Klimont Z., Rafaj P., & Schöpp W. (2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe – results from the GAINS model*, ENVIRON. RES. COMM. 2(2): 1–21.

[102] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 87 ("Analysis of the technical potential to mitigate methane from four separate studies shows that for 2030, reductions of 29–57 Mt/yr could be made in the oil and gas subsector, 12–25 Mt/yr from coal mining, 29–36 Mt/yr in the waste sector and 6–9 Mt/yr from rice cultivation. Values for the livestock subsector are less consistent, ranging from 4–42 Mt/yr.").

[103] United States Climate Alliance (2018) FROM SLCP CHALLENGE TO ACTION: A ROADMAP FOR REDUCING SHORT-LIVED CLIMATE POLLUTANTS TO MEET THE GOALS OF THE PARIS AGREEMENT, 102 ("Within the waste sector, all cost abatement potential is concentrated within the solid waste subsector which has three to six times the potential found in the wastewater (sewage) subsector (Figure 4.9). Totals in the three available analyses are very similar for the full waste sector, so that the full range is captured by 32 ± 4 Mt/yr. Hence this sector has about half the potential of the fossil sector for all cost measures and a much narrower uncertainty range. Evaluating this mitigation potential as a share of projected 2030 waste sector emissions is complicated by a large divergence between them, which were ~70 Mt/yr in the Harmsen and US EPA analyses, whereas there was a much larger value of 114 Mt/yr in the IIASA analysis. Hence although all the studies find similar abatement potential, the share of 2030 emissions from waste estimated to be abatable ranges from just 25 per cent in the IIASA analysis to ~40-50 per cent in the US EPA and Harmsen analyses. For low-cost measures in the waste sector, the analyses are again fairly consistent with all falling within the range 16 ±5 Mt/yr.").

[104] United States Environmental Protection Agency (2019) GLOBAL NON-CO_2 GREENHOUSE GAS EMISSION PROJECTIONS & MITIGATION 2015-2050, EPA-430-R-19-010, 70 ("Collection of LFG is feasible at most engineered landfills. It prevents high concentrations of gas in the landfill, which addresses public health and facility safety concerns. After collecting LFG, the least capital-intensive way to reduce emissions is flaring, which burns off the gas. However, flaring does not deliver any economic benefits for landfill operators. Energy production represents a potential revenue stream for landfills. It includes electricity generation, anaerobic digestion, and direct use. A variety of engine types and waste-to-energy processes can achieve electricity generation. Anaerobic digestion provides CH_4 for on-site electricity or for selling to the market. Direct use implies that a landfill transports captured methane to a facility, which uses it for electricity generation, as process heat, or as an input into other processes.").

[105] United States Environmental Protection Agency, *Basic information about landfill gas* (*last visited* 7 March 2024).

[106] United States Environmental Protection Agency (2019) GLOBAL NON-CO_2 GREENHOUSE GAS EMISSION PROJECTIONS & MITIGATION 2015-2050, EPA-430-R-19-010, 70 ("Energy production represents a potential revenue stream for landfills. It includes electricity generation, anaerobic digestion, and direct use. A variety of engine types and waste-to-energy processes can achieve electricity generation. Anaerobic digestion provides CH_4 for on-site

electricity or for selling to the market. Direct use implies that a landfill transports captured methane to a facility, which uses it for electricity generation, as process heat, or as an input into other processes.”).

[107] DeFabrizio S., Glazener W., Hart C., Henderson K., Kar J., Katz J., Pratt M. P., Rogers M., Tryggestad C., & Ulanov A. (2021) CURBING METHANE EMISSIONS: HOW FIVE INDUSTRIES CAN COUNTER A MAJOR CLIMATE THREAT, McKinsey Sustainability, 45–46 (“Methane emissions from solid waste could be abated by about 40 percent by 2030 and 90 percent by 2050 (Exhibit 18). Almost all of the reduction would be through diversion of organic material to secondary purposes, such as composting or biogas extraction. Organic waste could be sorted and processed through anaerobic digestion facilities to generate feedstock, fertilizer, soil enhancer, and renewable natural gas—or incinerated for energy.”). *See also* United States Environmental Protection Agency (2019) GLOBAL NON-CO_2 GREENHOUSE GAS EMISSION PROJECTIONS & MITIGATION 2015-2050, EPA-430-R-19-010, 70 (“Furthermore, enhanced waste diversion practices redirect biodegradable components of the waste stream from the landfill for reuse through recycling or conversion to a value-added product (e.g., energy or compost). Diverting organic waste components lowers the amount of CH4 generated at the landfill. Other benefits from the measures under this category include the sale of recyclables, electricity, and cost savings in avoided tipping fees.”); *and* United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 87 (“Solid waste management: (residential) source separation with recycling/reuse; no landfill of organic waste; treatment with energy recovery or collection and flaring of landfill gas; (industrial) recycling or treatment with energy recovery; no landfill of organic waste.”).

[108] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 114 (“While more than 10 per cent of the global population lives in hunger (FAO 2017) roughly a third of all food produced for human consumption turns into lost or wasted at some point along the food supply chain (Porter *et al*. 2018; Gustavsson *et al*. 2011). Many studies highlight the mitigation benefits of reducing this large volume and indicate that the potential reductions of emissions can be substantial but also diverse (FAO 2019; Springmann *et al*. 2018; Wollenberg *et al*. 2015; Bajželi *et al*. 2014). Most of these provide both base case emissions and emissions reductions estimates only in terms of carbon dioxide equivalent rather than separating the various greenhouse gases. For example, an FAO report (2019) suggests that the global carbon footprint of food loss and waste, excluding emissions from land-use change, is 3.3 gigatonnes[12] of carbon dioxide equivalent (Gt CO_2e). Similarly, an earlier report from the FAO estimated total emissions related to food loss and waste of 2.7 Gt CO_2e (FAO, 2014). Based on the source data reported in Chapter 2, methane emissions from ruminants and rice cultivation are ~145 Mt/yr. Hence if it is assumed here that loss and waste in these two categories is similar to the total across all food types, methane emissions associated with food loss and waste would be nearly 50 Mt/yr.”). *See also* DeFabrizio S., Glazener W., Hart C., Henderson K., Kar J., Katz J., Pratt M. P., Rogers M., Tryggestad C., & Ulanov A. (2021) CURBING METHANE EMISSIONS: HOW FIVE INDUSTRIES CAN COUNTER A MAJOR CLIMATE THREAT, McKinsey Sustainability, 46 (“As the world accelerates its efforts to align with the 1.5°C pathway, a key lever would be to reduce the volume of organic municipal solid waste. This would mean reducing food and paper waste by changing individual behaviors (for example, broad adoption of composting) and improving efficiency in supply chains (for example, ensuring food does not rot in transit and reducing overstocking at supermarkets). Local volumes of organic waste are linked to population size, but there are actions society can take to control organic-waste volumes. Recycling of organic materials, such as paper, cardboard, and leather, as well as reduction of food waste are two effective approaches.”).

[109] United Nations Climate Technology Centre & Network, *Biocovers of landfills* (*last visited* 7 March 2024) (“Landfill top covers, which optimise environmental conditions for methanotrophic bacteria and enhance biotic methane consumption, are often called ‘biocovers’ and function as vast bio-filters. Biocovers are typically spread over an entire landfill area. They are often waste materials, such as diverse composts, mechanically-biologically treated waste, dewatered sewage sludge or yard waste. Methane oxidation in compost materials shows high oxidation capacity. Manipulation of landfill covers to maximise their oxidation capacity provides a promising complementary strategy for controlling methane emissions.”). *See also* Yazdani R. & Imhoff P. (2010) BIOCOVERS AT LANDFILLS FOR METHANE EMISSIONS REDUCTION DEMONSTRATION, CalRecycle, 70 (“Results from laboratory and field tests indicated both fresh and aged green material could oxidize CH_4 at high rates, up to 100-200 g CH_4/m^2/day in field tests. These rates are on the high end of oxidation rates reported for composts in the literature. Thus, at least for the duration of the field tests pH, P, and NO_2-N conditions did not significantly affect biocover performance. However, the biocovers were installed in relatively thick layers (~ 90 cm), and after seven months of operation with a high

loading of [landfill gas] LFG (500-700 g CH_4/m^2/day) thick anaerobic zones developed. The formation of these zones was undoubtedly linked to the high LFG loading and the cooler winter temperatures. In this state both materials generated significant CH_4 (> 100 g CH_4/m^2/day, aged green material) and were ineffective in oxidizing CH_4. However, for the aged green material the performance was improved considerably when the loading rate was decreased to 200-250 g CH_4/m^2/day. In this case the green material oxidized 50-70 g CH_4/m^2/day. When both biocovers were operated at this smaller loading rate for several months, the aged green material performed reasonably well with measured CH_4 removal rates matching independent model predictions. The same was not true for the fresh green material, though, where it appeared that CH_4 continued to be generated and the biocover performance was always significantly less efficient at removing CH_4 than model predictions.").

[110] Chavan D. & Kumar S. (2018) *Reduction of methane emission from landfill using biocover as a biomitigation system: A review*, INDIAN J. EXP. BIOL. 56(7): 451–459, 456 (Table 3, "Lee et al.[54] found that rate of CH_4 oxidation of sandy biocover improved by 60 % with the addition of 100 mg-N NH_4 per kg of soil. Vegetation on biocover might affect the growth and activities of methanatophic bacteria in different ways. Bohn andJager[55] observed that the rate of CH_4 oxidation could be increased by 50% through vegetation growth on landfill biocover. A vegetation root assists the process of transporting O_2 from the atmosphere into deeper soil layers.").

[111] Franqueto R., Cabral A., Capanema M. A., & Schirmer W. N. (2019) *Fugitive Methane Emissions From Two Experimental Biocovers Constructed With Tropical Residual Soils: Field Study Using a Large Flux Chamber*, DETRITUS 7: 119–127, 126 ("The methane oxidation capacity was quite high for both subareas (control and enriched). Oxidation efficiencies (at a depth of 0.10 m) averaged 42% for the control subarea and 80% for the enriched area. CH_4 and CO_2 surface fluxes averaged 20 $g.m^{-2}.d^{-1}$ and 316 $g.m^{-2}.d^{-1}$ in the organic-matter-enriched subarea during the monitoring period, while those measured in the control subarea averaged 34 $g.m^{-2}.d^{-1}$ and 251 $g.m^{-2}.d^{-1}$, respectively. It is noteworthy that the surface fluxes were obtained using a custom-made 4.5-m^2 flux chamber, which allows for better representativeness of surface fluxes, because it allows inclusion of cracks and other imperfections that may affect measurements. The lower CH_4 fluxes and higher oxidation efficiency in the enriched subarea can be associated with the greater organic matter content in the enriched subarea, which created more favourable conditions for the development of ubiquitous methanotrophic colonies (Humer and Lechner, 2001). Temperature conditions, which ranged from 20 to 42°C at the surface and within the first 10 cm of the cover, favoured methane oxidation.").

[112] Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 [国民经济和社会发展第十四个五年规划和 2035 年远景目标纲要] (China) (2021) (hyperlink to original Chinese text). The Methane Action Plan reiterated the goal of reaching 90% of harmless disposal of urban sludge by 2025. Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration,, Nov. 7, 2023; effective Nov. 7, 2023) (link to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[113] Tong Z. (2019) *Rural revitalization and scientific management in the Pearl River Delta— scientific decision based on scientific rationality and public understanding*, GLOBAL TRANSITIONS 1:241–250, 241 ("The Pearl River Delta is located in the Pearl River basin of Guangdong Province, China, and belongs to the subtropical zone, referred to as the 'Pearl River Delta'.")

[114] Opinions on Strengthening the Battle for Pollution Prevention and Control [关于深入打好污染防治攻坚战的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Nov. 2, 2021; effective Nov. 2, 2021) (hyperlink to original Chinese text).

[115] Opinions on Strengthening the Battle for Pollution Prevention and Control [关于深入打好污染防治攻坚战的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Nov. 2, 2021; effective Nov. 2, 2021) (hyperlink to original Chinese text).

[116] 14th Five-Year Urban Sewage Treatment and Resource Utilization Development Plan [“十四五”城镇污水处理及资源化利用发展规划] (promulgated by the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development, Jun. 6, 2021; effective Jun. 6, 2021) (hyperlink to original Chinese text).

[117] 14th Five-Year Urban Sewage Treatment and Resource Utilization Development Plan [“十四五”城镇污水处理及资源化利用发展规划] (promulgated by the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development, Jun. 6, 2021; effective Jun. 6, 2021) (hyperlink to original Chinese text). *See* Zhu Y., Lin Z., Wang J., Zaho Y., & He F. (2016) *Impacts of Climate Changes on Water Resources in Yellow River Basin, China*, PROCEDIA ENG'G 154:687–695, 688 (“The Yellow River (YRB) is located in northern China. It is the second longest river in China and the sixth longest river in the world at the estimated 5464 km. Its total basin area is 0.75 million km^2.”).

[118] Implementation Plan for Carbon Peaking in Urban and Rural Development [城乡建设领域碳达峰实施方案], 5, (promulgated by the Ministry of Housing and Urban-Rural Development and the National Development and Reform Commission, Jun. 30, 2022; effective Jun. 30, 2022) (hyperlink to original Chinese text).

[119] *See e.g.*, Circular on Fully Implementing Household Waste Classification in Cities at and above the Prefecture Level [关于在全国地级及以上城市全面开展生活垃圾分类工作的通知] (promulgated by the Ministry of Housing and Urban-Rural Development, the National Development and Reform Commission, the Ministry of Ecology and Environment, the Ministry of Education, the Ministry of Commerce, the Office of the Central Steering Committee for the Construction of Spiritual Civilization, the Central Committee of the Communist Youth League of China, the All-China Women's Federation, and the State Administration of Institutional Affairs, Apr. 26, 2019; effective Apr. 26, 2019) (hyperlink to original Chinese text).

[120] Action Plan for Achieving Carbon Peaking Before 2030 [2030 年前碳达峰行动方案] (promulgated by the State Council, Oct. 24, 2021; effective Oct. 24, 2021) (hyperlink to original Chinese text). The Methane Action Plan reiterated the goal of increasing the reutilization rate for urban household waste to around 60% by 2025. Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (link to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[121] 14th Five-Year Urban Domestic Waste Classification and Treatment Facility Development Plan [“十四五”城镇生活垃圾分类和处理设施发展规划] (promulgated by the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development, May 6, 2021; effective May 6, 2021) (hyperlink to original Chinese text).

[122] 14th Five-Year Plan on Industry Green Development [“十四五”工业绿色发展规划] (promulgated by the Ministry of Industry and Information Technology, Nov. 15, 2021; effective Nov. 15, 2021) (hyperlink to original Chinese text).

[123] General Office of the Ministry of Housing and Urban-Rural Development (29 January 2023) Construction Standards for Stockpile Landfill Facilities Treatment Projects (Draft for Comments) [存量填埋设施治理工程项目建设标准（征求意见稿）] (hyperlink to original Chinese text).

[124] General Office of the Ministry of Housing and Urban-Rural Development (29 January 2023) Construction Standards for Stockpile Landfill Facilities Treatment Projects (Draft for Comments) [存量填埋设施治理工程项目建设标准（征求意见稿）] (hyperlink to original Chinese text).

[125] 14th Five-Year Work Plan on the Construction of Zero-Waste Cities ["十四五" 时期"无废城市" 建设工作方案] (promulgated by the Ministry of Ecology and Environment, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Affairs, the Ministry of Commerce, the Ministry of Culture and Tourism, the National Health Commission, the People's Bank of China, the State Administration of Taxation, the State Administration for Market Regulation, the National Bureau of Statistics, the National Government Offices Administration, the China Banking and Insurance Regulatory Commission, the State Post Bureau, and the All-China Federation of Supply and Marketing Cooperatives, Dec. 15, 2021; effective Dec. 15, 2021) (hyperlink to original Chinese text).

[126] 14th Five-Year Work Plan on the Construction of Zero-Waste Cities ["十四五" 时期"无废城市" 建设工作方案] (promulgated by the Ministry of Ecology and Environment, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Affairs, the Ministry of Commerce, the Ministry of Culture and Tourism, the National Health Commission, the People's Bank of China, the State Administration of Taxation, the State Administration for Market Regulation, the National Bureau of Statistics, the National Government Offices Administration, the China Banking and Insurance Regulatory Commission, the State Post Bureau, and the All-China Federation of Supply and Marketing Cooperatives, Dec. 15, 2021; effective Dec. 15, 2021) (hyperlink to original Chinese text).

[127] Circular on the Release of the List of "Zero-Waste Cities" During the 14th Five-Year Period [关于发布"十四五"时期"无废城市"建设名单的通知] (promulgated by the General Office of the Ministry of Ecology and Environment, Apr. 24, 2022; effective Apr. 24, 2022) (hyperlink to original Chinese text).

[128] *See e.g.*, Workplan for the Construction of Zero-Waste Cities throughout Jiangsu Province [江苏省全域"无废城市"建设工作方案] (promulgated by the General Office of Jiangsu Provincial Government, Jan. 9, 2022; effective Jan. 9, 2022) (hyperlink to original Chinese text).

[129] 14th Five-Year Work Plan on the Construction of Zero-Waste Cities ["十四五" 时期"无废城市" 建设工作方案] (promulgated by the Ministry of Ecology and Environment, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Affairs, the Ministry of Commerce, the Ministry of Culture and Tourism, the National Health Commission, the People's Bank of China, the State Administration of Taxation, the State Administration for Market Regulation, the National Bureau of Statistics, the National Government Offices Administration, the China Banking and Insurance Regulatory Commission, the State Post Bureau, and the All-China Federation of Supply and Marketing Cooperatives, Dec. 15, 2021; effective Dec. 15, 2021) (hyperlink to original Chinese text).

[130] 14th Five-Year Work Plan on the Construction of Zero-Waste Cities ["十四五" 时期"无废城市" 建设工作方案] (promulgated by the Ministry of Ecology and Environment, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Affairs, the Ministry of Commerce, the Ministry of Culture and Tourism, the National Health Commission, the People's Bank of China, the State Administration of Taxation, the State Administration for Market Regulation, the National Bureau of Statistics, the National Government Offices Administration, the China Banking and Insurance Regulatory Commission, the State Post Bureau, and the All-China Federation of Supply and Marketing Cooperatives, Dec. 15, 2021; effective Dec. 15, 2021) (hyperlink to original Chinese text).

[131] Implementation Plan for Emission Reduction and Carbon Sequestration in Agriculture Sector and Rural Area [农业农村减排固碳实施方案] (promulgated by the Ministry of Agriculture and Rural Affairs and the National Development and Reform Commission, Jun. 30, 2022; effective Jun. 30, 2022) (hyperlink to original Chinese text).

[132] Guiding Opinions for Promoting the Construction of Ecological Farms [推进生态农场建设的指导意见] (promulgated by the General Office of the Ministry of Agriculture and Rural Affairs, Feb. 9, 2022; effective Feb. 9, 2022) (hyperlink to original Chinese text).

[133] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 28 ("Agriculture: emissions from enteric fermentation and manure management represent roughly 32 per cent of global anthropogenic emissions. Rice cultivation adds another 8 per cent to anthropogenic emissions. Agricultural waste burning contributes about 1 per cent or less.").

[134] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 29 (*see* Figure 2.2 *showing* annual livestock methane emissions with cattle accounting for majority of enteric methane emissions). *See also* Food and Agriculture Organization of the United Nations (2016) *Reducing Enteric Methane for Improving Food Security and Livelihoods*, 3 ("Globally, ruminant livestock produce about 2.7 Gt CO_2 eq. of enteric methane annually, or about 5.5% of total global greenhouse gas emissions from human activities. Cattle account for 77% of these emissions (2.1 Gt), buffalo for 14% (0.37 Gt) and small ruminants (sheep and goats) for the remainder (0.26 Gt).").

[135] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 29 ("The two largest sources are livestock and fossil fuels. Within the livestock subsector, enteric fermentation and manure management are the two processes generating emissions, with the former dominant and cattle the dominant animal (Figure 2.2). Within the manure category, pigs play the largest role though cattle are again important.").

[136] Höglund-Isaksson L., Gómez-Sanabria A., Klimont Z., Rafaj P., & Schöpp W. (2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe – results from the GAINS model*, ENVIRON. RES. COMM. 2(2): 1–21, 7–8 (Table 2) and Supplementary material tab "World."

[137] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 29 ("While rice cultivation feeds up to a third of the world's population, rice fields are a significant source of methane (Mbow *et al*. 2019; Dlugokencky and Houweling 2015). Methane is produced through anaerobic decomposition of organic material in flooded rice fields which are responsible for approximately 8–11 per cent of global anthropogenic methane emissions (Saunois *et al*. 2020; Mbow *et al*. 2019).").

[138] United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, Figure 2.6 (Showing that rice cultivation accounted for an estimated 26.6 million tons of methane emissions in 2017, out of a total of 129 million tons of methane emissions in Asia and a total of 10.4 million tons ins Southeast Asia, Korea, and Japan.).

[139] Höglund-Isaksson L., Gómez-Sanabria A., Klimont Z., Rafaj P., & Schöpp W. (2020) *Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe – results from the GAINS model*, ENVIRON. RES. COMM. 2(2): 1–21, 7–8 (Table 2) and Supplementary material tab "World."

[140] Qi J., Yang H., Wang X., Zhu H., Wang Z., Zhao C., Li B., & Li Z. (2023) *State-of-the-art on animal manure pollution control and resource utilization*, J. OF ENVIRON. CHEM. ENG'G 5(11): 110462 ("However, AM has excellent ecological services that have economic value and can help reduce environmental pollution and the demand for limited resources in agricultural production. AM is rich in organic matter and essential nutrients such as N, P, and K for plant growth, making it suitable for reuse and conversion into biogas or preparation as feed or fertilizer.").

[141] Qi J., Yang H., Wang X., Zhu H., Wang Z., Zhao C., Li B., & Li Z. (2023) *State-of-the-art on animal manure pollution control and resource utilization*, J. OF ENVIRON. CHEM. ENG'G 5(11): 110462 ("The nutrient contents of different types of AM are shown in Table 2 [3], [17]. There are differences in the substance content of these AM,

which may be related to differences in the dietary structure of AF. As shown in Table 2, AM is rich in nutrients and mineral elements. Its protein content can reach 13.0–28.7%. If treated as feed, it can improve the protein content in animals and has high economic value.").

[142] Qi J., Yang H., Wang X., Zhu H., Wang Z., Zhao C., Li B., & Li Z. (2023) *State-of-the-art on animal manure pollution control and resource utilization*, J. OF ENVIRON. CHEM. ENG'G 5(11): 110462 ("AM is also rich in organic matter and N, P, and K content. If applied to crops, it can significantly improve crop yield and increase soil fertilization efficiency. A study found that applying AM to soil can improve the effectiveness of soil nutrients for plant growth [18].").

[143] Chen L., Zhang J., Xia X., Yang Z., Wang B., & Long C. (2023) *The potential capability of substituting chemical fertilizers with crop straw and human-livestock-poultry manure in areas with different topographic characteristics*, HELIYON 9:e18845, 1–2 ("CSHLPM is rich in nutrients, such as N, P_2O_5 and K_2O, which are necessary for the growth of various types of crops. In actual agricultural production, CSHLPM is often used as an organic fertilizer to improve crop yield [4]. … The use of CSHLPM can improve the soil structure and microecological environment, greatly improving soil fertility [5]. Thus, the use of CSHLPM as a fertilizer plays an active role in both energy resource development and food security strategies [6]. The reutilization of CSHLPM as a farmland fertilizer can reduce the environmental damage and treatment costs caused by CSHLPM itself. Moreover, it can reduce the demand for inorganic fertilizers of N, P_2O_5 and K_2O in the agricultural system and alleviate agricultural nonpoint pollution.").

[144] Qi J., Yang H., Wang X., Zhu H., Wang Z., Zhao C., Li B., & Li Z. (2023) *State-of-the-art on animal manure pollution control and resource utilization*, J. OF ENVIRON. CHEM. ENG'G 5(11): 110462 ("Compared to traditional chemical fertilizers, organic fertilizers derived from AM are more comprehensive, more effective, and easier for crops to absorb [20]. Using AM to replace chemical fertilizers can reduce soil pollution and costs for farmers. As such, AM has potential value for resource treatment.").

[145] Opinions on Strengthening the Battle for Pollution Prevention and Control [关于深入打好污染防治攻坚战的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Nov. 2, 2021; effective Nov. 2, 2021) (hyperlink to original Chinese text).

[146] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[147] China Ministry of Agriculture and Rural Affairs (28 July 2023) *Response to Recommendation No. 6904 from the First Session of the Fourteenth National People's Congress* [对十四届全国人大一次会议第 6904 号建议的答复] (hyperlink to original Chinese text).

[148] Opinions on Strengthening the Battle for Pollution Prevention and Control [关于深入打好污染防治攻坚战的意见] (promulgated by the Central Committee of the Chinese Communist Party and the State Council, Nov. 2, 2021; effective Nov. 2, 2021) (hyperlink to original Chinese text).

[149] Climate & Clean Air Coalition (1 November 2021) *Methane Mitigation Through Manure Management is Key to Successfully Transforming China's Agricultural Sector* ("Research developed in partnership with the CCAC on the most effective methane mitigation strategies was presented to the group drafting the work plan and the majority of the suggestions were included. These strategies include improved manure management systems such as carefully controlling the water, fertilizer, antibiotics, and type of feed, which can not only reduce emissions but can also increase agricultural production. A key contribution of the CCAC was developing baseline emissions scenarios and projections

of emissions reductions based on different policy implementations, which helped to determine the most effective methane mitigation strategies.”).

150 Speech by Xie Zhenhua at the COP 27 event: It’s Time to Sprint: Targeting Methane Emissions, held on 8 November 2022.

151 Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD’s annotated, English reference translation of the China Methane Action Plan is available here.).

152 Mid- and Long-term Development Plan for Eco-Satellites (2021-2035) [生态环境卫星中长期发展规划（2021-2035 年）] (promulgated by the Ministry of Ecology and Environment, Oct. 2022; effective Oct. 2022) (hyperlink to original Chinese text).

153 Carbon Monitoring and Assessment Pilot Work Plan [碳监测评估试点工作方案](promulgated by the General Office of the Ministry of Ecology and Environment, Sept. 12, 2021; effective Sept. 12, 2021) (hyperlink to original Chinese text).

154 Dreyfus G. & Ferris T. (2023) *Annex 1: Metrics and Measurement of Methane Emissions*, *in* INNOVATIVE TECHNOLOGIES FOR GREENHOUSE GAS EMISSIONS AND CARBON SEQUESTRATION MONITORING, China Council for International Cooperation on Environment and Development, 23 (“Without robust monitoring, reporting, and verification (MRV) of methane emissions, we will not be able to know the efficacy of methane mitigation policies and programs or whether we are meeting methane mitigation targets.”; “Conventional wisdom has held that gas is ‘cleaner’ than coal because generating electricity from gas produces about half the CO_2 for a given electricity output than coal.[3] However, this comparison ignores the methane emissions associated with producing natural gas and coal. Many studies have analyzed the crossover point at which venting and fugitive emissions from gas outweigh the climate benefits of a transition from coal to gas, generally finding that leakage rates above 2.4%–3.4% eliminate the climate benefit.[4] and as low as 0.2% when masking from sulfate co-emission for coal is included.[5]).

155 Institute for Governance & Sustainable Development (17 January 2023) *China Announces Progress in Methane Monitoring and Evaluation In Preparation for the Release of Its National Action Plan on Methane*.

156 China Ministry of Ecology and Environment (29 May 2023) *The MEE Held Its Monthly Press Conference in May* [生态环境部召开 5 月例行新闻发布会] (hyperlink to original Chinese text).

157 United Nations Environment Programme & Climate & Clean Air Coalition (2021) GLOBAL METHANE ASSESSMENT: BENEFITS AND COSTS OF MITIGATING METHANE EMISSIONS, 17 (“Mitigation of methane is very likely the strategy with the greatest potential to decrease warming over the next 20 years.”).

158 United States Department of State (14 November 2023) Sunnylands Statement on Enhancing Cooperation to Address the Climate Crisis.

159 United States Department of State (10 November 2021) U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s.

160 Countries currently supporting the Global Methane Pledge include many developed and developing countries that have collaborated with China in the past to help secure the Earth’s future against climate devastation. Countries supporting the Pledge aim to reduce global methane emissions at least 30 percent from 2020 levels by 2030, and

develop and share information on best available inventory methodologies to quantify methane emissions, with a particular focus on high-emission sources. The Global Methane Pledge was formally launched at the UN Climate Change Conference (COP 26) in November in Glasgow, United Kingdom. *See* United States Department of State (2 November 2021) *United States, European Union, and Partners Formally Launch Global Methane Pledge to Keep 1.5C Within Reach*. The list of countries currently supporting the Global Methane Pledge can be found at: https://www.globalmethanepledge.org/.

[161] Methane Emissions Control Action Plan [甲烷排放控制行动方案] (promulgated by the Ministry of Ecology and Environment, the Ministry of Foreign Affairs, the National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Natural Resources, the Ministry of Housing and Urban-Rural Development, the Ministry of Agriculture and Rural Development, the Ministry of Emergency Management and the National Energy Administration, Nov. 7, 2023; effective Nov. 7, 2023) (hyperlink to original Chinese text) (IGSD's annotated, English reference translation of the China Methane Action Plan is available here.).

[162] China State Council (21 September 2021) *Full Text of Xi's Statement at the General Debate of the 76th Session of the United Nations General Assembly* ("China will step up support for other developing countries in developing green and low-carbon energy, and will not build new coal-fired power projects abroad.").

[163] China Ministry of Ecology and Environment and Ministry of Commerce (5 January 2022) Guidelines on Ecological and Environmental Protection of Foreign Investment and Construction Projects [对外投资合作建设项目生态环境保护指南] (hyperlink to original Chinese text); *see also* Opinions on Promoting the Green Development of the "Belt and Road Initiative" [关于推进共建"一带一路"绿色发展的意见] (promulgated by the National Development and Reform Commission, the Ministry of Foreign Affairs, the Ministry of Ecology and Environment, and the Ministry of Commerce, Mar. 16, 2022; effective Mar. 16, 2022) (hyperlink to original Chinese text).

[164] Institute for Governance & Sustainable Development (28 April 2021) *China Announces Further Steps Toward Reduction of Non-CO_2 Super Climate Pollutant Emissions* ("At the State Council press conference on 27 April 2021, the China Ministry of Ecology and Environment announced the following action items… Revise emission standards for coal-bed methane and coal-mine gas.").

[165] Measures for the Administration of Greenhouse Gas Voluntary Emission Reduction Trading (Trial) [温室气体自愿减排交易管理办法（试行）] (promulgated by the Ministry of Ecology and Environment and the State Administration for Market Regulation, Oct. 19, 2023; effective Oct. 19, 2023) (hyperlink to original Chinese text).

[166] Memorandum of Understanding Between the Ministry of Ecology and Environment of the People's Republic of China and the State of California of the United States of America (April 2022).

[167] Office of Governor Gavin Newsom (3 August 2023) California and Chinese Province of Hainan Partner to Fight Climate Change.

[168] Office of Governor Gavin Newsom (30 October 2023) What Governor Newsom's Trip to China Accomplished.