PATHWAYS TO REDUCE CHINA'S AGRICULTURAL METHANE EMISSIONS

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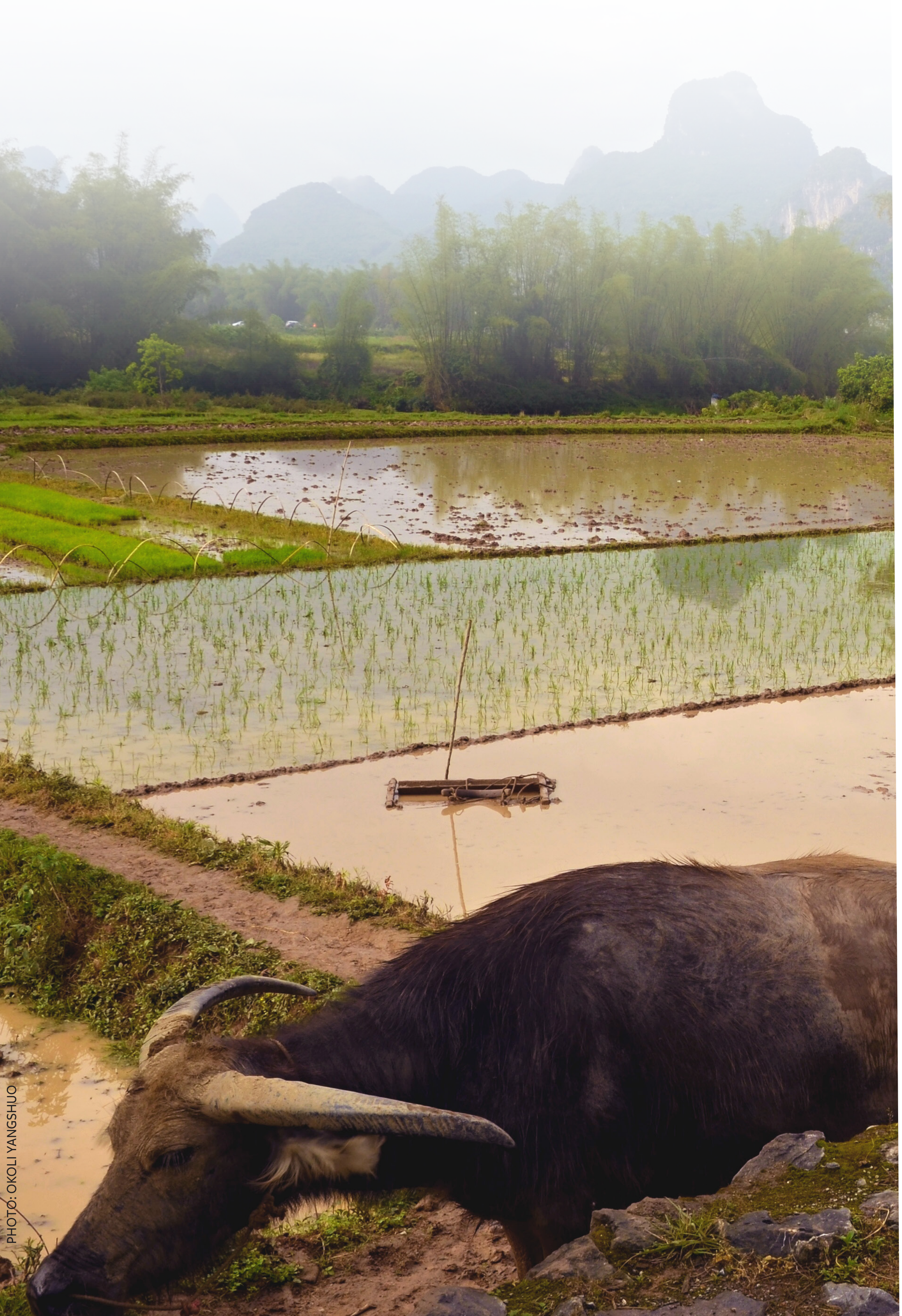

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About the California-China Climate Institute

The California-China Climate Institute was launched in September 2019 and is a University of California-wide initiative housed jointly at UC Berkeley's School of Law (through its Center for Law, Energy, and the Environment) and the Rausser College of Natural Resources. It is chaired by Jerry Brown, former Governor of the State of California, and vice-chaired by the former Chair of the California Air Resources Board Mary Nichols. The Institute also works closely with other University of California campuses, departments, and leaders. Through joint research, training, and dialogue in and between California and China, this Institute aims to inform policymakers, foster cooperation and partnership, and drive climate solutions at all levels.

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Summary for Policymakers

Key Messages
• China, one of the world's largest methane emitters, must reduce its emissions from rice cultivation and manure management to achieve its national carbon neutrality target. Key challenges relate to data gaps, regulatory frameworks, and the small-scale nature of most farms. • Reducing methane emission intensity is an effective strategy for reducing rice and manure methane in China. Innovation in low-cost technologies and policy support are needed to improve the profitability of methane mitigation projects. • Adjustment to the structure of livestock production and consumption is an important driver of manure methane mitigation. Improving anaerobic digesters, dietary changes, and avoiding food waste are potential solutions. • Mitigation measures should be tailored to regional characteristics. Manure methane mitigation should be prioritized in Sichuan, Hunan, Yunnan, Henan, Guangxi, and western provinces, while rice methane mitigation should be prioritized in Hunan, Jiangxi, Hubei, Anhui, and Jiangsu. • Establishing a robust monitoring, reporting, and verification (MRV) system is crucial for methane mitigation in China. Various levels of government should support legal, institutional, and technical efforts in MRV development. China must also address gaps in emission data collection and conduct more local studies involving farmers and enterprises to refine its MRV systems.

Methane is a prominent greenhouse gas (GHG) with a high global warming potential compared to carbon dioxide. China is one of the highest methane-emitting countries in the world, and reducing these emissions will be essential to achieving its carbon neutrality goal by 2060. Rice cultivation and manure management are two important sources of the country's methane emissions, together accounting for over half (53.6%) of China's agricultural sector methane emissions and one-fifth of its human-caused methane emissions.

China acknowledges the importance of reducing its methane emissions and has begun taking action. Over the past decade, it has released policies mentioning agricultural methane mitigation and intends to include methane in its 2060 carbon neutrality target. In November 2023, China took a decisive step toward methane mitigation with the release of its first comprehensive, specialized policy document on methane emissions control. This document set targets for manure utilization rates and identified specific rice and manure methane mitigation measures.

China has made some progress in mitigating its agricultural methane emissions. Pilot projects for rice methane mitigation have appeared across the country, while the capacity of biogas power plants using manure keeps increasing. Nevertheless, several challenges remain. Major gaps exist in methane emission data and setting quantitative targets due to a lack of robust monitoring, reporting, and verification (MRV) systems for agricultural methane. Further, regulatory and management frameworks for rice and manure methane also need improvement. The small-scale nature of most Chinese farms further complicates the widespread adoption of methane mitigation practices.

China can seize significant opportunities for mitigating methane emissions from agriculture. Political momentum supports reducing agricultural methane, and synergies exist between agricultural methane mitigation, the circular economy, and energy security, all of which are near-term priorities for China. The country's voluntary carbon market also offers an incentive for developing rice and manure methane mitigation projects.

To support China's ability to leverage these opportunities, implement its action plan, and ultimately reduce methane emissions, this report presents an integrated analytical framework (Figure SP-1). The purpose of this framework is threefold: (1) to facilitate understanding of the factors driving methane emissions; (2) to reflect regional agricultural contexts and the need for localized policy approaches; and (3) to recognize the need for a robust MRV system to measure the impact of policy. It should be noted that this report will focus only on methane from rice and manure.

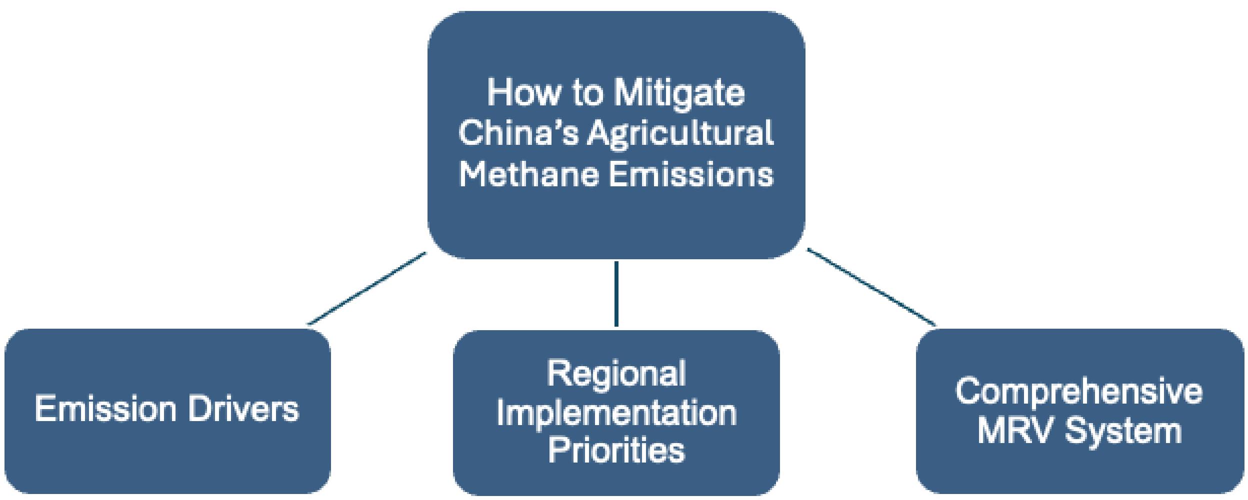

Figure SP-1. Analytical Framework of the Report

Drivers of Agricultural Methane Emissions

China's agricultural methane mitigation efforts should target two key emissions drivers: (1) methane emission intensity; and (2) structural changes in livestock production and consumption.

Methane Emission Intensity

Studies show that reducing methane emission intensity (i.e., the amount of methane emissions per agricultural output value) is an effective strategy for reducing rice and manure methane in China. This requires technological innovation, enabling policies, and improved agricultural practices.

To mitigate rice methane, China should prioritize:

- Reducing technology costs
- Promoting the application of practices such as water management and biochar application
- Improving the collection and transportation system for rice straw
- Integrating technologies for crop yield improvement and soil productivity enhancement in the methane-mitigating technology portfolio.

To address manure methane, China should prioritize:

- Promoting large-scale, integrated manure management measures (e.g., large anaerobic digesters, manure drying, and solid-liquid separation)
- Improving the collection and transportation system for manure.

Supportive policies are also important, particularly those aiming to improve the profitability of emission intensity reduction projects. Potential policy solutions include increasing government financing, implementing climate-smart agricultural commodity programs, and incorporating methane mitigation projects into China's voluntary carbon market through the China Certified Emission Reduction (CCER) program. Collectively, these instruments can help China address its methane reduction challenge by establishing a regulatory and management framework, minimizing gaps in emission data, directing investment to rice and manure methane projects, and promoting mitigation practices, especially at small farms.

Structural Changes of Livestock Production and Consumption

China's rapid economic development has brought growing demand for food, especially beef. Beef production is growing, and cattle farms' profitability is increasing, surpassing that of pig and poultry farms. Studies show that the share of beef production in the livestock industry is an important driver of methane increases, as cattle generally produce more manure methane than goats, sheep, or pigs. Potential solutions (that do not compromise food security) include:

- **Targeted investment and innovation** in anaerobic digesters and manure methane capture. This is particularly important for intensive cattle feeding systems, which help satisfy growing demand for beef but generate more emissions.
- **Encouraging dietary changes** for the public. This will both reduce the overall methane footprint of beef production and improve public health.
- **Reducing food waste**, especially for beef and dairy products, to slow the production of food and its associated manure methane emissions.

Regional Variation in Implementation

China is a large country, with different regions having diverse characteristics of rice cultivation and manure management. Implementing measures tailored to regional circumstances is important for effective methane mitigation.

Sichuan, Hunan, Yunnan, Henan, and Guangxi have the largest manure methane emissions, and China should therefore prioritize these provinces for manure methane mitigation investments. Further, it will also be necessary to improve western provinces' mitigation capacity for methane emissions from manure. This is because China's livestock industry is expected to migrate to these provinces, which have less agricultural infrastructure and human and financial resources compared to other, more economically developed provinces.

Hunan, Jiangxi, Hubei, Anhui, and Jiangsu have the highest amount of rice methane emissions; consequently, China should prioritize these provinces for rice methane mitigation investments. For Hunan, Jiangxi, Hubei, and Anhui, interest in rice farming is waning as people seek higher-paying opportunities in more economically developed provinces nearby (e.g., Guangdong and Jiangsu), making it difficult to promote mitigation technologies in these provinces. It is therefore crucial to explore strategies that not only reduce emissions but also keep rice yield steady or even increase it, thus making cultivation more profitable. Two potential solutions are compensation or subsidies for climate-smart rice farming and the promotion of water-saving and drought-resistant rice breeds in these provinces.

Establishing a Comprehensive MRV System

Robust MRV systems can identify emission trends, pinpoint sources, and guide mitigation actions, making them crucial to successful methane mitigation efforts. However, progress in establishing MRV systems for agriculture has been slow in China compared to other industries, and consequently its MRV systems for agricultural methane are in a nascent stage.

Going forward, China faces both challenges and opportunities for MRV system development:

1. **Insufficient legal and institutional support exists** for MRV development. The agricultural methane MRV system is a complex structure consisting of laws, regulations, and technical standards whereby the system's operation can be institutionalized. China has not yet established such a structure, leading to challenges in complying with national carbon neutrality targets and developing MRV among localities and businesses due to institutional uncertainty. To address this barrier, China's national departments should lead the development of MRV technical guidelines, which will form the foundation for making subsequent laws and regulations. Designating a government agency to oversee MRV systems for agricultural methane and fostering interagency collaboration will also help.

2. **Emission data collection gaps must be closed**. The absence of legal and technical standards results in inadequate data to support the monitoring of agricultural methane. China should explore advanced measures (e.g., remote sensing) to enhance methane monitoring and calculate and refine methane emission factors in different scenarios based on monitoring data. In addition, releasing the methodology and data used to estimate agricultural methane emissions in the national greenhouse gas inventory could encourage more research on methodology and help refine the existing methodology and support development of MRV systems. Introducing third-party verification is another important measure to ensuring the data quality and credibility of MRV systems.

3. **More micro-level studies are needed**. Research on agricultural methane emissions monitoring has primarily focused on macro-level analyses at the national and provincial levels, with limited attention given to micro-level studies involving farms and enterprises. However, considering farmers' production decisions and their direct impact on methane emissions is crucial for acquiring accurate data and evaluating trends. Additionally, more studies of farmers' and enterprises' willingness to install MRV systems will provide useful feedback on the overall direction of MRV technology innovation and the refinement of MRV technical guidelines.

Abbreviations and Acronyms

CCER	China Certified Emission Reduction
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
tCO_2e	Tonnes of Carbon Dioxide Equivalent
GHG	Greenhouse Gas
MEE	Ministry of Ecology and Environment
MRV	Monitoring, Reporting, and Verification
NDC	Nationally Determined Contribution
USDA	United States Department of Agriculture

Context and Objectives of this Report

In support of the California-China Climate Institute's goal of spurring climate action through joint research, training, and dialogue in California and China, this report, *Pathways to Reduce China's Agricultural Methane Emissions*, provides an analysis of how China should implement agricultural methane mitigation policies. The report should be considered in the context of China's announcement that it will gradually reduce its agricultural methane emissions from 2021 to 2030. Further, the report may be useful to China in developing its agricultural methane utilization and mitigation policies and targets, as well as incentives for agricultural methane projects through, for example, its greenhouse gas emissions trading system.

Introduction

As a major carbon-emitting economy and the world's largest developing country, China faces the daunting dual challenge of peaking its carbon emissions by 2030 and achieving carbon neutrality by 2060. Because studies show China cannot achieve carbon neutrality by reducing its carbon dioxide (CO2) emissions alone, mitigating non-CO2 greenhouse gas (GHG) emissions is essential. China's annual non-CO2 GHG emissions are estimated to peak at around 2.5 billion tonnes of CO2 equivalent (tCO2e) by 2030, after which it must rapidly reduce its annual emissions to 1.3 billion tCO2e by 2050, representing a reduction of 48% below the 2020 level.[1]

Methane, a prominent non-CO2 GHG, has a high global warming potential relative to CO2 and is the second-most abundant anthropogenic GHG after CO2 globally.[2] China's methane emissions, including from Land Use, Land-Use Change, and Forestry (LULUCF),[3] totaled 64.11 million tonnes in 2018, representing a roughly 16% increase from the 2014 level and accounting for roughly 10% of national GHG emissions by weight.[4] Agriculture is a major source of China's methane emissions, accounting for nearly 24 million tonnes annually and about 37% of total methane emissions.[5] As it works toward carbon neutrality, China has prioritized addressing methane emissions from agriculture in its recent methane reduction policies.[6]

Within the agricultural sector, rice cultivation and manure management are two important sources of methane (Figure 1). Rice methane is a product of soil chemistry. When rice paddies are flooded,[7] the water cuts off oxygen from the soil, triggering anaerobic fermentation of organic matter in the soil and generating methane.[8] Reducing rice emissions involves modifications to rice plant characteristics as well as crop management. Methane emissions from manure, on the other hand, usually occur when farm animals are kept in confinement and their manure is pooled in environments lacking oxygen, as is commonly done at large livestock farms, leading to conditions where methane-generating bacteria thrive.[9] Livestock enteric fermentation[10] is another important source of China's agricultural methane emissions and a rather complicated issue, given technological uncertainties and animal welfare and environmental justice concerns. This report will focus only on methane from rice and manure.

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[1] (He et al., 2022)
[2] (Zhu et al., 2023)
[3] 1.3 billion tonnes of carbon dioxide equivalent (CO_2e), based on 100-year global warming potential (GWP).
[4] (Ministry of Ecology and Environment, 2023a)
[5] (Ministry of Ecology and Environment, 2023a)
[6] (Ministry of Agriculture and Rural Affairs, 2022a; Ministry of Ecology and Environment, 2023d)
[7] Farmers flood rice paddies to ensure sufficient water and control weeds (Kaspary et al., 2020).
[8] (Adhya et al., 2014)
[9] (Searchinger et al., 2021)
[10] Enteric fermentation is a natural component of the digestive process in ruminant animals such as cattle, sheep, goats, and buffalo. Microorganisms in the digestive tract, or the rumen, break down and ferment food, leading to the production of methane as a by-product (United Nations Environment Programme & Climate and Clean Air Coalition, 2021).

In China, rice cultivation is the third-largest source of anthropogenic methane emissions. In 2018, the sector emitted about 9.3 million tonnes[11] of methane into the atmosphere, ranking after coalbed methane from mining (25.1 million tonnes) and livestock enteric fermentation (10.8 million tonnes).[12] Rice methane also accounted for roughly 39% of total agricultural methane emissions in 2018, 24.7% of total agricultural GHG emissions, and 14.6% of all human-caused methane emissions nationwide. By comparison, manure management accounted for 14.5% of total agricultural methane emissions, 9.2% of total agricultural GHG emissions, and 5.4% of nationwide human-caused methane emissions.[13]

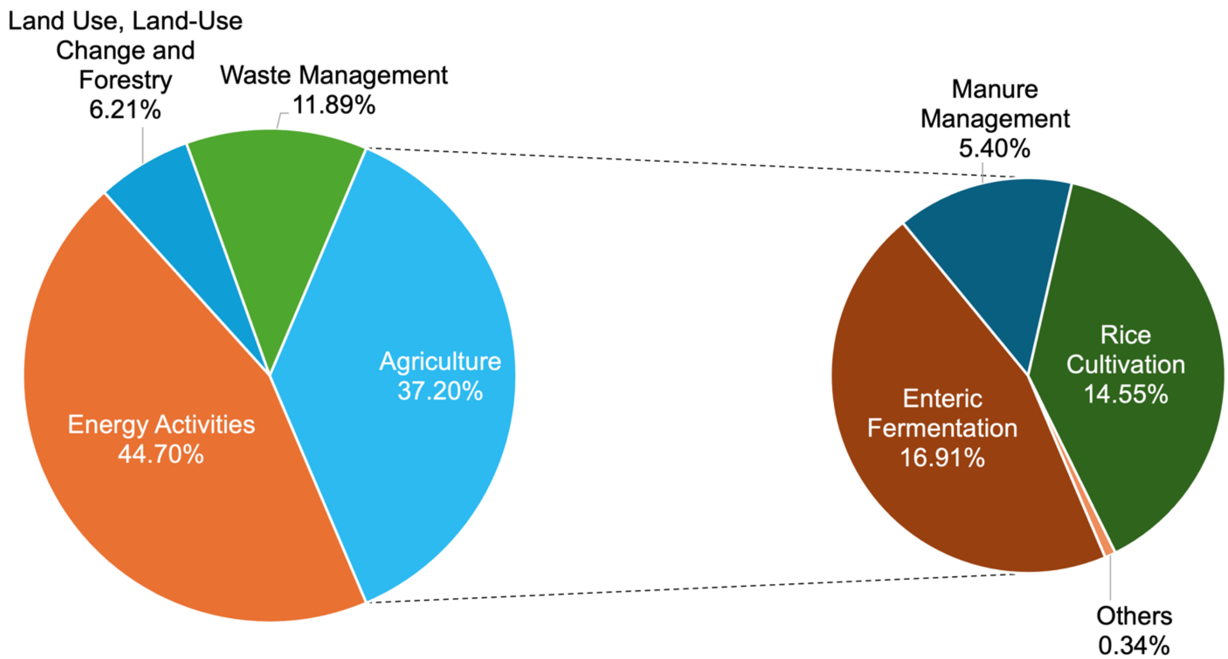

Figure 1. Sources of Methane Emissions in China, 2018 (Numbers Indicate Percentages of National Totals)[14]

China has slowly taken action to mitigate agricultural methane emissions (Figure 2). Since 2011, the country's climate change policies have mentioned methane emissions, and methane has been incorporated into the 12th, 13th, and 14th Five-Year National Development Plans, which set China's overall development strategy.[15] In October 2019, China's National Development and Reform Commission released the 2019 version of the Guiding Category for Industrial Structure Adjustment, listing biogas production based on livestock manure and rice straw under the "Encouraging"

[11] Equal to about 261 million tonnes of carbon dioxide equivalent (CO_2e), based on U.S. EPA's Greenhouse Gas Equivalencies Calculator (U.S. EPA, 2023).
[12] (Ministry of Ecology and Environment, 2023a)
[13] (Ministry of Ecology and Environment, 2023a)
[14] (Ministry of Ecology and Environment, 2023a, p. 9)
[15] (China's State Council, 2011, 2016; The National People's Congress of the People's Republic of China, 2021)

category, meaning China's government would prioritize investment in such projects.[16] In April 2021, China released the 2021 version of the Category of Projects Supported by Green Bonds, which provides financial incentives for agricultural methane mitigation projects.[17] But despite China's long recognition of the need to mitigate agricultural methane emissions, there have been few implementation actions on legislation and governmental financing.

It was not until mid-2021 that China began taking concrete steps toward agricultural methane mitigation. In July 2021, former China Special Envoy for Climate Change Xie Zhenhua announced that China's 2060 carbon neutrality target would include methane emissions.[18] In October 2021, China submitted its updated Nationally Determined Contribution (NDCs), which included actions on methane emissions.[19] In November 2021, China and the U.S. released the *Joint Glasgow Declaration on Enhancing Climate Action in the 2020s*, stressing cooperation on methane, especially on "incentives and programs to reduce methane from the agricultural sector."[20] After Glasgow, China's government released *Guidelines for Promoting the Construction of Ecological Farms* in January 2022.[21] This document addresses compensation policies for low-carbon projects that reduce methane from rice paddies, animal digestive systems, and livestock and poultry manure.[22] Finally, in June 2022, two of China's national departments jointly released the *Implementation Plan for Emission Reduction and Carbon Sequestration in Agriculture and Rural Areas* to mitigate GHG emissions in rural areas, which listed the reduction of methane emissions from rice paddies among top ten major actions.[23]

Figure 2. Development Timeline of China's Policies Related to Agricultural Methane Mitigation

[16] (National Development and Reform Commission, 2019)
[17] (People's Bank of China et al., 2021)
[18] (Xie, 2021)
[19] (Lin et al., 2023)
[20] (United States Department of State, 2021)
[21] According to China's government, ecological farms are "agriculture production and operation entities, targeting maximum sustainable output while being compatible with local resources and environment, being environmentally friendly, and ensuring food safety" (Ministry of Agriculture and Rural Affairs, 2022b).
[22] (Ministry of Agriculture and Rural Affairs, 2022b)
[23] (Ministry of Agriculture and Rural Affairs, 2022a)

China's provincial governments are also taking action to mitigate agricultural methane. Many provinces have incorporated methane emission control requirements into major local planning documents. Provinces and municipalities such as Shanghai, Jiangsu, Zhejiang, Henan, and Hubei have proposed agricultural methane control in their 14th Five-Year Plans for ecological and environmental protection. In addition, Beijing, Shanghai, and other provinces have prioritized establishing systems for monitoring, accounting, reporting, and verifying methane emissions in key sectors such as agriculture. These provinces are also pursuing demonstration projects and other initiatives to drive innovation in agricultural methane emission control technologies.[24]

In November 2023, China took its most important step to date on agricultural methane mitigation by releasing its first comprehensive and specialized policy document on methane emissions control, setting targets for manure utilization rates[25] and identifying specific measures for rice and manure methane mitigation.[26] This plan will serve as the top-level design of China's agricultural methane control in the 14th (2021 - 2025) and 15th (2026 - 2030) Five-Year Plan periods. This national methane action plan will serve as the top-level design of China's agricultural methane control for the 14th (2021–2025) and 15th (2026–2030) Five-Year Plan periods. Importantly, the plan will also guide improvements in methane monitoring, reporting, and verification (MRV) systems while fostering technology innovation and promoting international collaboration. The plan's agricultural content is summarized in the table below.

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[24] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)

[25] The target specifies that, by 2025, the utilization rate of livestock and poultry waste will exceed 80%, and by 2030, 85% (Ministry of Ecology and Environment, 2023d).

[26] (Ministry of Ecology and Environment, 2023d)

Table 1. Agricultural Elements in China's Methane Control Action Plan[27]

Item	Action
General Targets	2021–2025 ● Gradually establish frameworks for methane mitigation policies, technologies, and standards ● Strengthen methane inventory calculation and emission monitoring 2026–2030: ● Establish comprehensive policy, technology, and standard frameworks ● Significantly improve methane inventory calculation and emission monitoring
Methane Monitoring, Verification, and Reporting System	● Conduct methane monitoring pilot projects ● Gradually establish methane monitoring systems consisting of ground-based, airborne, and satellite-based technologies ● Establish methane monitoring, verification, and reporting systems ● Promote regular methane emission reporting in farms
Methane Mitigation in the Agricultural Sector	● Utilize animal manure to produce fertilizer and natural gas ● By 2025, the utilization rate of livestock and poultry manure will reach more than 80%, and by 2030, more than 85% ● Mitigate methane emissions from rice cultivation through water and fertilizer management, rice type selection, and aerobic rice cultivation
Technology Innovation and Policy Enforcement	● Conduct technical innovation and pilot projects
Regulation Framework	● Formulate technical standards for agricultural methane mitigation ● Increase investment and subsidies for methane mitigation projects; incorporate methane mitigation projects in a voluntary carbon market
International Collaboration	● Participate in international methane mitigation dialogue and collaboration ● Collaborate on methane mitigation technologies and standards

While China has begun to demonstrate its determination to mitigate agricultural methane emissions, these efforts are not enough as China is still facing foundational problems such as a lack of standardized, mature monitoring systems for methane.[28] For China's action plan to be implemented successfully, it is important to (1) identify the driving forces of agricultural methane

[27] (Zhu et al., 2023)
[28] (Ministry of Ecology and Environment, 2023d)

emissions in China, along with appropriate actions; (2) identify methane mitigation measures suitable for different regions in China; and (3) identify measures to establish a robust MRV system. This report analyzes China's challenges and opportunities with agricultural methane from a policy perspective and addresses these three areas. Specifically, the report contains three sections: (1) a summary of the current state of rice and manure methane mitigation in China, (2) an analysis of how China could further mitigate methane from rice cultivation and manure management, and (3) discussion and conclusions, with specific policy recommendations.

Rice and Manure Methane Mitigation in China

China has made progress on rice and manure methane mitigation. For example, pilot projects to mitigate rice cultivation methane have adopted techniques such as furrow flooding, remote sensing, biochar, and dry cultivation, and new drought-resistant rice species have been planted across the country.[29] Some of these projects turn a profit through selling carbon credits.[30] Meanwhile, biogas projects have used livestock and poultry manure as raw materials. From 2016 to 2022, the installed capacity of biogas power projects has continued to increase (Figure 3), reaching 1.22 gigawatts in 2022, with annual electricity generation of 4 billion kilowatt-hours.[31] Of this amount, 3.3 billion kilowatt-hours of electricity were sent to the grid.[32]

Figure 3. Trends in China's Installed Biogas Power Generation Capacity, 2016-2022[33]

[29] (Jiang et al., 2021; Xia, 2023)
[30] (Ren & Li, 2024)
[31] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)
[32] (Biomass Energy Industry Promotion Association, 2023)
[33] (Biomass Energy Industry Promotion Association, 2023)

China's agricultural methane mitigation efforts still face several important challenges, including the following:[34]

- ***Major gaps in methane emission data and quantitative targets***. Existing agricultural methane emission policies and programs are difficult to implement, as they lack emissions data and quantitative targets. Most methane mitigation targets adopted to date are qualitative, and no systematic tracking and evaluation process exists. The few quantitative agricultural targets in China's first methane reduction action plan simply echo prior targets for manure utilization, rather than actual methane reduction.[35] Further, there is no robust agricultural methane monitoring, reporting, and policy evaluation system in place in China, causing a shortage of methane data.
- ***Regulatory and management frameworks need improvement***. China listed rice and manure methane mitigation as important tasks in its 2022 plan, but the plan lacks regulatory incentives for reducing agricultural methane emissions.[36] China's low-carbon compensation policy is a good start, but the overall policy framework remains in its infancy and needs further development. Further, China's policymakers have not set any methane control standards for the agricultural sector. There is also a lack of capacity-building activities and cross-department collaboration at all levels of China's government which would help raise awareness of agricultural methane problems, establish agricultural methane reduction plans, and support agricultural methane mitigation efforts. Put simply, China must clearly incorporate agricultural methane reduction in its carbon neutrality plans, especially at the subnational level.
- ***The limited extent of technology application***. Most farms in China are small and managed by individual farmers.[37] This makes it difficult to apply methane-mitigating technology at a large scale.[38] In addition, persuading individual farmers to adopt methane-mitigating production practices through education and communication is difficult and time-consuming; individual farmers may not correctly perceive the risks and benefits of methane-mitigating technologies and, as a rule, tend to avoid making changes due to risks such as lower crop yields.[39] Consequently, while many methane-mitigating technologies exist, their application is very limited.

Despite the above challenges, there are also many opportunities to mitigate rice and manure methane.

Despite these challenges, there are also many opportunities to mitigate rice and manure methane – first and foremost, because political momentum exists within China for achieving agricultural

[34] (Zhu et al., 2023)
[35] (Ministry of Ecology and Environment, 2023d)
[36] (S. Yu et al., 2023)
[37] (Qiao, 2019)
[38] (Wang et al., 2023)
[39] (Zhao et al., 2022)

methane reductions, as demonstrated by its national methane action plan,[40] China has also set targets for manure utilization for 2025 and 2030,[41] listed rice and manure methane mitigation as important missions in many policy documents,[42] and committed to promoting international dialogue on methane, such as the Glasgow Declaration and Sunnylands Statement between China and the U.S.[43] Moreover, China is actively seeking international collaboration on various climate topics, including agricultural methane mitigation, and there are many planned cooperative projects at both the national[44] and subnational[45] levels. Given China's top-down governance structure, its commitment to methane mitigation at the national level will create a conducive environment for mitigating agricultural methane emissions. The next decade will be a kind of "grace period" for developing rice and manure methane mitigation strategies, as more institutional and financial support from the government is expected to become available.

There are also synergies between agricultural methane mitigation and the circular economy, as well as energy security, for several reasons. Rice methane mitigation measures, for example, can save water, reduce fertilizer usage and energy input, and improve rice production. At the same time, manure management practices can capture methane for heat and electricity generation and also yield fertilizer for crops. As both circular economy and energy security are emphasized in China's 14th Five-Year Plan,[46] the above projects offer a compelling opportunity to address both issues simultaneously and for that reason could appeal to governmental and private investors.

Finally, China's voluntary carbon market provides an excellent incentive for developing rice and manure methane mitigation projects. The Chinese Ministry of Ecology and Environment (MEE) restarted a voluntary carbon market, the China Certified Emissions Reduction (CCER) program, in late 2023. This market, where companies and individuals can sell carbon credits for voluntary GHG emission reductions, could soon become a new funding source for agricultural methane mitigation projects. Manure methane projects are likely to be attractive options for selling carbon credits under the CCER, as they had been part of the earlier voluntary climate market. Thus, measurement and verification of manure biogas capture is relatively mature.[47] However, the CCER does not yet have clear criteria for measuring and monitoring methane reductions for manure and rice methane projects, and new methane calculation methodologies are needed for both manure and rice methane projects.

[40] (Ministry of Ecology and Environment, 2023d)
[41] (Ministry of Ecology and Environment, 2023d)
[42] (Ministry of Agriculture and Rural Affairs, 2022a; Ministry of Ecology and Environment, 2023d)
[43] (United States Department of State, 2023)
[44] (United States Department of State, 2023)
[45] (California Office of Governor, 2022)
[46] (The National People's Congress of the People's Republic of China, 2021)
[47] (C. Luo & Chen, 2023)

Mitigation Pathways for Rice and Manure Methane

To effectively mitigate agricultural methane emissions, it is important to identify major contributors to China's agricultural emissions and develop appropriate mitigation strategies. In our review of the literature, we found two key drivers of methane emissions in China: (1) methane emission intensity and (2) structural changes in livestock production and consumption.[48] Additionally, tailoring methane mitigation measures to specific regional circumstances is important for effective mitigation, as China's different regions have varying characteristics in terms of their rice cultivation and manure management. Finally, establishing robust MRV systems is crucial because such systems are instrumental in identifying emission trends, pinpointing sources, and guiding mitigation actions.

This section analyzes these aspects of rice and manure methane mitigation and identifies implementation gaps and opportunities.

Driver #1: Methane Emission Intensity

Recent studies emphasize that reducing methane emission intensity (i.e., the amount of methane emissions per agricultural output value) is key to mitigating China's agricultural methane emissions.[49] From 2010 to 2020, reductions in methane emission intensity are estimated to account for 59% of all methane mitigation in livestock production and over one-third of methane mitigation in rice cultivation in China.[50] Reducing methane emission intensity and improving the efficiency of manure management and rice cultivation are therefore effective strategies for reducing China's methane emissions. Achieving such reductions requires both innovative technologies and supportive policies.

Technological Innovation and Improved Agricultural Practices

Technology and agricultural practice innovation play a crucial role in agricultural methane mitigation, as they improve production efficiency, enable methane capture and re-utilization, reduce the amount of methane emission per unit of output, and reduce China's reliance on imported equipment.

Innovation in rice methane mitigation is particularly critical, both because rice has been the major contributor to an increase in agricultural methane emissions over the past decade,[51] and because high implementation costs have limited the application of methane mitigation technologies and practices for rice.[52] Therefore, reducing costs and promoting adoption of available mitigation technologies and practices (summarized in Table 2 below) should be a priority. In addition,

[48] (Duan et al., 2023; Xu et al., 2024)
[49] (Duan et al., 2023)
[50] (Duan et al., 2023)
[51] (Xu et al., 2024)
[52] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023, p. 20)

improving the collection and transportation system for rice straw is necessary for establishing an integrated and efficient straw recycling system.[53] Beyond methane mitigation, key aspects of improving rice cultivation in China include increasing food production and enhancing soil productivity through carbon sequestration. It is therefore necessary to combine all three types of technologies – methane mitigation, food production, and soil productivity – in optimizing an overall technology portfolio to achieve methane mitigation without sacrificing food security or soil productivity.[54]

Table 2. Selected Rice Methane Mitigation Practices

Technology and Practices	**Overview**	**Future Innovation Areas**
Water Management	Methane production occurs in oxygen-free conditions, such as those found in flooded paddy soils. Consequently, methane emissions can be significantly reduced by periodically introducing oxygen through water management practices. When implemented correctly, these practices can also improve crop yield. However, allowing fields to remain dry for too long can have the opposite effect. Coordination between fertilizer application and water management is essential to preventing increases of nitrous oxide, another potent greenhouse gas. Examples of water management measures include single midseason water drawdown (drain rice paddies for five to ten days); alternate wet-dry method (alternate flooding and drainage for paddies where precise water management is possible); and dry seeding (direct seeding of rice into dry fields).[55]	● Research to develop management patterns suitable for local conditions ● Ways to achieve net GHG mitigation considering both methane and nitrous oxide ● Lowering infrastructure costs
Plastic Film Mulching	When placed over rice paddies, thin plastic films can enrich soil oxygen levels, enhance water productivity, and decrease methane emissions. In cooler climates, this method has led to crop yield increases ranging from 5-20% and water savings of up to 84% per hectare. However, this approach can	● Less labor-intensive deployment measures ● Lowering costs ● Plastic film recycling

[53] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023, p. 20)
[54] (Qin et al., 2023)
[55] (Adhya et al., 2014)

	be labor-intensive, leading some farmers to hesitate despite potential savings from reduced pesticide and fertilizer use.[56]	
Biochar Application	Biochar, a negative emission technology in agriculture, is created by converting biomass into charcoal in a low-oxygen environment. When applied to rice fields, this regenerative agriculture practice offers benefits such as soil carbon sequestration, yield gains, and potential reductions in methane and nitrous oxide emissions. Challenges of biochar application in rice paddies include high costs and lack of biomass supply. However, using crop residues as feedstock for biochar could offset expenses. Biochar shows promise in reducing methane emissions in rice fields by 6-13%, along with yield increases of about 9%.[57] While it does not impact nitrous oxide emissions, it likely contributes to soil carbon gains, showcasing its potential as a sustainable mitigation strategy.	• Lowering costs • Using crop residues as feedstock • Local research to customize and standardize deployment patterns • Quantifying measure effectiveness
Rice Straw Returning Timing Adjustment	Experimental evidence highlights the substantial impact that the timing of rice straw return can have on rice field methane emissions. Returning rice straw through plowing during the off-season (rather than during the rice-growing season) can cut methane emissions by about half. The reason for this is likely that earlier returns can reduce biomass availability for methane-producing bacteria. Scaling this practice globally could reduce methane emissions by an estimated 6.65 million tonnes annually, with reductions of roughly 6-40% in major rice-producing countries.[58]	• Local research to quantify effectiveness • Integration with other technologies such as nitrogen fertilizer management[59]

As for methane from manure management, the collection and transportation system for manure should be improved to increase collection efficiency and lower the transportation cost of manure

[56] (Adhya et al., 2014)
[57] (Liao et al., 2021)
[58] (Searchinger et al., 2021)
[59] (Qin et al., 2023)

from households to large treatment facilities.[60] In addition, even though small-scale manure-to-biogas projects once were common in Chinese households, fewer homes are relying on biogas for energy.[61] Given the high up-front cost and technical complexity of household manure-to-biogas facilities, as well as their relatively low methane utilization rates,[62] China should prioritize large-scale, integrated manure management measures to improve methane utilization efficiency. Examples include large-scale anaerobic digesters, manure drying, and solid-liquid separation.

Anaerobic Digesters

Anaerobic digesters were used in China's rural households to generate energy but had limited capacity for manure management or electricity generation from methane. By comparison, large-scale anaerobic digesters can produce more methane, which provides a revenue stream as operators can sell electricity to the power grid and sell carbon credits to the carbon market.[63] A livestock manure management project in Shandong, China provides an example.

Shandong Minhe Large-scale Livestock Manure Management Project[64]
Built in 2008, this project involved building eight anaerobic digesters with a cumulative volume of 3,300 cubic meters. The digesters recover nearly 11 million cubic meters of biogas per year and generate roughly 22 million kilowatt-hours of electricity, all of which is delivered to the grid. The waste heat from the power generation units is used to warm the anaerobic system, eliminating the need for external heating sources. The fermented slurry is utilized as organic fertilizer in nearby apple orchards, grape vineyards, and vegetable fields. This project, which is incorporated into the Clean Development Mechanism (CDM) framework, reduces GHG emissions by 60,000 to 80,000 metric tons of CO_2 equivalent per year and yields annual revenues of 7-8 million RMB from the selling of carbon credits.

Two areas where innovation can improve anaerobic digesters are (1) addressing methane leakage, and (2) avoiding negative environmental impacts. Digesters maximize the conversion of biomass in manure into methane and therefore can generate more methane than standard manure storage systems. Although digesters intend to capture methane and use it as an energy source, their climate benefits can be nullified if methane leakage occurs.[65] Additionally, the potential for air and water pollution from anaerobic digesters should be addressed to honor environmental justice principles.

Manure Drying

The process of manure drying includes utilizing various techniques (e.g., open solar drying and closed solar drying) to decrease moisture content and achieve a solid content of at least 13%. This method is typically employed at poultry farms to facilitate manure storage and transportation.

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[60] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023, p. 20)
[61] (Sun & Zhao, 2023)
[62] (C. Luo & Chen, 2023; J. Luo et al., 2022)
[63] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)
[64] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)
[65] (Searchinger et al., 2021)

Drying reduces the amount of manure entering anaerobic manure lagoons, thereby reducing methane emissions from lagoons.[66] This measure is popular in California, as 45 open solar manure drying projects now operate under its Alternative Manure Management Program.[67] Because nitrous oxide emissions may increase during the drying process, a lifecycle analysis must be conducted to ensure net GHG mitigation.[68]

Solid-Liquid Separation

At larger livestock farming operations, combining liquids and solids in manure storage restricts oxygen and promotes methane production. Solid-liquid separation prior to entry into a wet/anaerobic environment aims to decrease solids stored in liquid, thereby lowering methane production potential. This process can reduce methane emissions up to 93%.

Various separation methods exist for facilities of different sizes. Basic systems rely on gravity, grates, or ponds to separate solids, while mechanical systems employ presses or centrifuges for greater precision and efficiency. The introduction of flocculants (chemicals that aid in solid binding) can separate up to 75% of solid material and capture almost all phosphorus content.[69]

Once separated, solid manure can enhance nearby soil nutrients and water retention, while the nitrogen-rich liquid can serve as fertilizer and generating revenues.[70] Annually, the cost of manure separation ranges from $5 per cow in basic systems to $75 per cow in advanced setups.[71] A solid-liquid separation system in the U.S., described below, offers an example.

Solid-liquid Separation at Goshen Ridge Farms[72]
The United States Department of Agriculture (USDA) conducted a study at Goshen Ridge Farms in Duplin County, North Carolina to determine the effectiveness of a solid-liquid separation module in mitigating methane emissions from swine farming. In this study, the research team installed a solid-liquid separation system in one swine production unit and, in another unit, used a conventional lagoon-based manure treatment system as the control. By comparing methane emissions from these units, the study showed that the separation unit emitted nearly two-thirds less methane than the conventional system.

Creating an Enabling Policy Environment

Supportive policies are needed, especially for improving the profitability of projects to reduce methane emission intensity. Policy solutions include increasing government financing,

[66] (Ghaly & MacDonald, 2012)
[67] (California Department of Food and Agriculture, 2024)
[68] (H. A. Aguirre-Villegas et al., 2019)
[69] (Searchinger et al., 2019)
[70] (H. Aguirre-Villegas et al., 2017)
[71] (Searchinger et al., 2019)
[72] (Sohoulande et al., 2024)

implementing climate-smart agricultural commodity programs, and incorporating methane mitigation projects into China's voluntary carbon market via CCER. All apply to both rice and manure methane mitigation. A brief introduction to these approaches is provided below.

Policy Approach 1: Increasing government financing

Government financing is a common approach to encouraging methane mitigation actions. Governments of countries in the Global Methane Pledge, for example, continue to increase the amount of available funding for mitigation projects.[73] Meanwhile, the State of California is leveraging its own investment to fund mitigation projects and stay on track to reduce dairy methane emissions 40% by 2030.[74]

In China, three problems hinder the development of rice and manure methane mitigation projects: high initial investment,[75] low prospects for short-term profitability,[76] and uncertainty around technology effectiveness.[77] Further, China has not yet established a compensation or subsidy mechanism for rice or manure methane mitigation.[78] As a result, these projects are not attractive to private investors and only a few pilot projects exist, most of which rely on government subsidies to be financially sustainable.[79] Governmental financing via grants, subsidies, or direct compensation could significantly alleviate the cost and risk burden on farmers to adopt new technologies while also attracting private sector investment. It will also enhance methane MRV systems, thus addressing a big challenge - lack of data - for rice and manure methane mitigation.

Since 2010, China has emphasized agricultural subsidies for resource-efficient and environmentally friendly practices. Various subsidies have been implemented, including those for returning straw to fields, utilizing manure, and maintaining product quality and safety standards. While these initiatives have achieved results, their overall effectiveness could be improved.[80] As China explores low-carbon compensation and subsidy policies targeting rice and manure methane, it should consider the following:

- *Government financing should be long-term and stable*. China's previous rice and manure subsidy programs were only for short periods and pilot projects.[81] While this approach may have made an impact during the project period, it did not lead to systematic changes in farming practices.[82]
- *Enhancing adoption among small farmers is the key.* Because most of China's farms are small, adoption of methane-mitigating practices by small farmers is critical. However, small

[73] (U.S. Department of State, 2023)
[74] (Kebreab et al., 2022)
[75] (International Institute of Green Finance (IIGF) Central University of Finance and Economics, 2023)
[76] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)
[77] (M. Hu et al., 2022)
[78] (Wang et al., 2023)
[79] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)
[80] (Cai et al., 2023)
[81] (Chen F. et al., 2023)
[82] (Cai et al., 2023)

farmers typically resist such practices due to a lack of awareness about methane and the low profitability of small-scale projects.[83] One solution is to include education programs in financing schemes to raise awareness about methane emissions and green technologies. Another is to offer subsidies to larger entities first to demonstrate methane mitigation projects can be profitable, thereby attracting small farmers.[84]

- *Integrated information for farmers on government financing*. Since many governmental agencies have subsidy and compensation programs for China's farmers, it is burdensome for farmers to collect information and decide which to apply for. A one-stop-shop for information could be very useful. The California Department of Food and Agriculture website, which includes all environmental farming grants, offers a good example.[85]
- *Governmental agencies should coordinate the purpose, scope, and compensation measures of their grants for manure and rice methane mitigation*. Currently, government grants have varying purposes. Some focus on increasing food production or poverty alleviation, while others focus on reducing agriculture GHGs such as methane.[86] Consequently, the implementation of one program could possibly offset the benefits of another. Governmental agencies should coordinate to ensure their money is spent effectively and achieve synergies while minimizing burdens on farmers. This would also facilitate the establishment of a cross-departmental methane management framework.
- *Grants should include technical assistance*. Such assistance is instrumental in reducing the technological and financial knowledge barriers that could inhibit technology adoption. The Farm Bill[87] in the U.S. offers as an example, as it not only authorizes grants to farmers but also provides technical assistance.

Policy Approach 2: Climate-smart agricultural commodity programs

Climate-smart commodities are produced using practices that reduce GHG emissions or sequester carbon. Climate-smart commodity programs, which involve grants for pilot projects that produce agricultural products using climate-smart practices, quantify GHG mitigation, and develop market and promote commodities, could accelerate adoption of methane mitigation techniques and promote profitable business models.[88] In doing so, these programs would address two key challenges – a lack of data and lack of incentives – facing rice and manure methane mitigation projects. Climate-smart commodities can play an important role in achieving China's carbon neutrality target,[89] as well as developing the "new quality productive forces" in agriculture (i.e.,

[83] (W. Yu et al., 2017)
[84] (Cai et al., 2023)
[85] See https://www.cdfa.ca.gov/oefi/ for more information.
[86] (Xu et al., 2024)
[87] The Farm Bill is a package of legislation passed roughly once every five years that has a tremendous impact on agriculture. It encompasses various agricultural and food programs, offering policymakers a chance to systematically address agricultural and food-related matters on a regular basis (Monke & Johnson, 2024). The Natural Resources Conservation Service offers incentives and technical support via Farm Bill programs like the Environmental Quality Incentives Program and the Conservation Stewardship Program to aid in agricultural methane mitigation, especially mitigating manure methane emissions (The White House, 2021).
[88] (U.S. Department of Agriculture, 2022)
[89] (Chen F. et al., 2023)

implementing new technologies and business models under the rubric of GHG mitigation and environmental protection; reallocating land, labor, capital, and energy to improve production efficiency; and thus transforming traditional agricultural production).[90]

China released "Opinions on Establishing and Improving the Value Realization Mechanism of Ecological Products" in 2021, which aimed to improve the policy framework for compensating ecological protection and establish a system for estimating the ecological value of eco-friendly products (e.g., climate-smart agricultural commodities) by 2025.[91] However, a large gap remains for developing China's climate-smart agricultural commodity programs. The country still lacks policy frameworks, laws, and accountability systems for the valuation and marketing of green agricultural commodities, resulting in low participation rates among private companies and the public as well as an insufficient supply of climate-smart agricultural commodities (e.g., low-emissions rice, biogas from advanced manure management, etc.).[92] To resolve this, China should establish a climate-smart agricultural commodity framework, guided by the government and operated through market mechanisms, to encourage adoption of mitigation technologies.

Going forward, China should consider several important questions to ensure climate-smart commodity programs deliver actual climate benefits:

- *How to designate commodities as climate-smart?* Standards and guidelines are needed to determine climate-smart agricultural practices. Methane monitoring and measurement will facilitate their development. Meanwhile, funding applicants should make public detailed information about project methodology and amount of methane mitigation, thereby improving transparency and avoiding greenwashing.
- *What price premium would consumers pay?* This is a difficult but important question to answer, as it could affect the long-term financial sustainability of climate-smart agriculture projects.
- *How to encourage purchases of climate-smart commodities?* China's government has a key role to play here and should guide the market. One potential solution is to require certain purchase amounts by state-owned enterprises and governmental staff. A book-and-claim system is another option.
- *How to benefit underserved farmers?* Underserved farmers, such as small- and early-stage farmers, usually have limited access to funding or technical assistance, and adopting climate-smart practices is therefore difficult. Specific funding amounts and profit shares from price premiums should be set aside for these groups to reduce emissions from China's many small farms[93] and to ensure environmental justice.
- *How to get farmers to stick with climate-smart practices?* It can take up to a decade for farmers to benefit from climate-smart practices.[94] Beyond startup costs, China must

[90] (Li, 2024)
[91] (Xinhuanet, 2021)
[92] (Chen F. et al., 2023, p. 60)
[93] (C. Luo & Chen, 2023)
[94] (Popkin, 2023)

establish a market for methane-mitigating rice and biogas or fertilizer from manure to sustain the financial feasibility of climate-smart agricultural projects.

Policy Approach 3: Voluntary carbon market

The voluntary carbon market can provide a valuable mechanism for incentivizing and supporting methane reduction efforts in rice cultivation and manure management. This market offers economic benefits to farmers and landowners and can therefore promote methane-mitigating practices among farmers (especially small farmers, which has been challenging).[95] China has already realized benefits from the voluntary carbon market and intends to incorporate methane reduction and utilization projects into the carbon market framework.[96] It should be noted that voluntary carbon markets, while beneficial, do not substitute for regulatory action.

China originally incorporated agricultural GHG reduction projects into its voluntary carbon market starting in 2012, when the CCER began.[97] By 2021, 143 agricultural GHG reduction projects had been registered in the CCER framework, with two main categories being household biogas production and forestry carbon sequestration.[98] In contrast, no rice methane mitigation projects were registered.

However, since China restarted its voluntary carbon market, in 2023,[99] the CCER framework has excluded agricultural GHG mitigation projects.[100] Reintegrating them into the CCER framework is therefore essential for harnessing market mechanisms to mitigate rice and manure methane. It is still unclear whether pre-2023 GHG reduction verification methodologies will be replaced, or how the MEE might select new ones. Given these uncertainties, improvements to current rice and manure methane methodologies could increase the likelihood of their inclusion in the CCER framework. According to MEE, the four most recent methodologies (for forestry carbon sink projects, grid-connected photothermal power projects, grid connected offshore wind power projects, and mangrove creation projects) share three important similarities:[101]

- ***Non-controversial GHG mitigation mechanisms***
- ***High-quality data***
- ***Straightforward GHG mitigation monitoring***

Efforts to support the inclusion of rice and manure methane mitigation projects into the CCER framework should therefore focus on these three aspects. For the first, laboratory and field research can help avoid controversy by providing data-backed evidence for methane mitigation technologies

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95 (Everhart, 2023)
96 (Ministry of Ecology and Environment, 2023d, p. 12)
97 (Bai, 2024)
98 (C. Luo & Chen, 2023)
99 (Ministry of Ecology and Environment, 2023b)
100 So far, China's Ministry of Ecology and Environment has released only four methodologies for GHG mitigation verification for four types of projects: forestation, mangrove cultivation, solar thermal power, and grid-connected offshore wind power projects. There is currently no methodology for agricultural GHG mitigation projects (Ministry of Ecology and Environment, 2023c).
101 (Ministry of Ecology and Environment, 2023c)

and strategies. Importantly, GHG mitigation should not occur at the expense of food production capacity, as this may violate MEE's principle of "achieving both social and ecological benefits" it employs in evaluating methodologies.[102] For the last two bullets, establishing an MRV system for rice and manure methane is critical for generating high-quality data, calculating baseline emissions, estimating project effectiveness, and verifying additionality.[103]

Beyond those high-level measures, China should pursue different approaches to establishing markets for rice and manure methane reduction. Developing a market for manure methane reduction would be relatively easy, as China already promotes renewable energy including biogas power generation. As a result, the capacity of biogas utilization projects has been steadily increasing[104] and is projected to increase further, which in turn has created demand for more biogas projects and stimulated more financial support for project development. Further, China's experience with earlier biogas projects registered in the CCER framework[105] can help create new methodologies.

For now, efforts to establish a carbon market for manure management should focus on refining existing methodologies; developing large-scale, integrated manure management projects; and encouraging such projects to apply for voluntary carbon offset credits. An excellent example is a poultry manure methane mitigation project in China's Fujian Province, which uses a high-temperature aerobic digestion system to decompose manure and avoid methane and has acquired carbon credit certification from Verra.[106] One important caveat is that once a market for manure methane reduction is established, the financial incentive it creates could lead to the installation of more manure treatment facilities (e.g., digesters), which in turn could negatively impact air, water, and public health.[107] China's government should conduct robust environmental impact assessments to avoid offsetting the benefits of methane mitigation.

China's voluntary carbon market for rice methane mitigation, on the other hand, is in its initial stage. In the previous CCER framework, only one methodology covered rice cultivation methane.[108] Therefore, efforts to establish a carbon market for rice cultivation should explore methane mitigation technologies (especially for small farmers), quantify their mitigation potential, and design methodologies for GHG reduction estimation. Projects that reduce methane by adjusting water management could be a good starting point, as this is a relatively mature technology; further,

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[102] (Ministry of Ecology and Environment, 2023c)

[103] According to MEE, "additionality" means that even though the voluntary GHG emission reduction project is not the best choice in terms of internal rate of return, financial indicators, etc., and there are problems in financing, key technologies, etc., compared to alternatives that can provide equivalent products or services, the implementation of such a project can help overcome these obstacles and have additional GHG mitigation effects compared to a baseline scenario determined by the relevant project methodology (Ministry of Ecology and Environment, 2023b).

[104] (Policy Research Center for Environment and Economy, Ministry of Ecology and Environment, 2023)

[105] (C. Luo & Chen, 2023)

[106] (H. Zhang, 2023)

[107] (Elkind et al., 2022)

[108] (National Development and Reform Commission, 2013a)

there are international examples of methodologies, such as the Compliance Offset Protocol for rice cultivation projects in California.[109]

One project, in China's Jiangsu Province, used biochar to reduce rice methane and successfully sold carbon offset credits.[110] It is summarized below.

Application of Biochar to Rice Reduce Methane Emissions in Jiangsu, China[111]
Since 2022, China's MEE has conducted a project in Nanjing, Jiangsu Province to determine the efficiency of biochar in mitigating methane emissions from rice paddies. By deploying 60 tonnes of biochar into about 33 hectares of rice paddies, the project team found that biochar increased the amount of organic matter in the soil by 6.1% and reduced methane emissions by more than 130 tonnes of CO2 equivalent in a year (November 30, 2022 to November 30, 2023). In March 2024, the carbon credits earned from methane mitigation were sold to a company, with a total transaction value of about 9,800 RMB. Overall, the project marks an important step forward for incorporating biochar projects that mitigate rice methane into China's carbon market.

Driver #2: Livestock Production and Consumption Trends

China's rapid economic development in recent decades has been accompanied by growing food demand, especially for beef. Data shows that beef production in China has increased dramatically in recent years[112] and that beef consumption has also increased.[113] Between 2012 and 2021, China's cattle population grew from about 91 million to 98 million (Figure 4).[114] Moreover, profit margins for cattle farming have swelled in recent years, significantly surpassing those of pig and poultry farming. For dairy cows, profit margins surged from about 25% in 2015 to 42% in 2021, marking 69% growth in six years. In contrast, pig farming profit margins dipped from about 15% to 8.6% over the same period.[115] These market shifts motivated some farmers to switch from pigs and poultry to beef.

[109] (California Air Resources Board, 2015)
[110] (Ren & Li, 2024)
[111] (Ren & Li, 2024)
[112] (Food and Agriculture Organization of the United Nations, 2023)
[113] (Duan et al., 2023; Gale & Dong, 2023)
[114] (National Bureau of Statistics, 2024)
[115] (Duan et al., 2023)

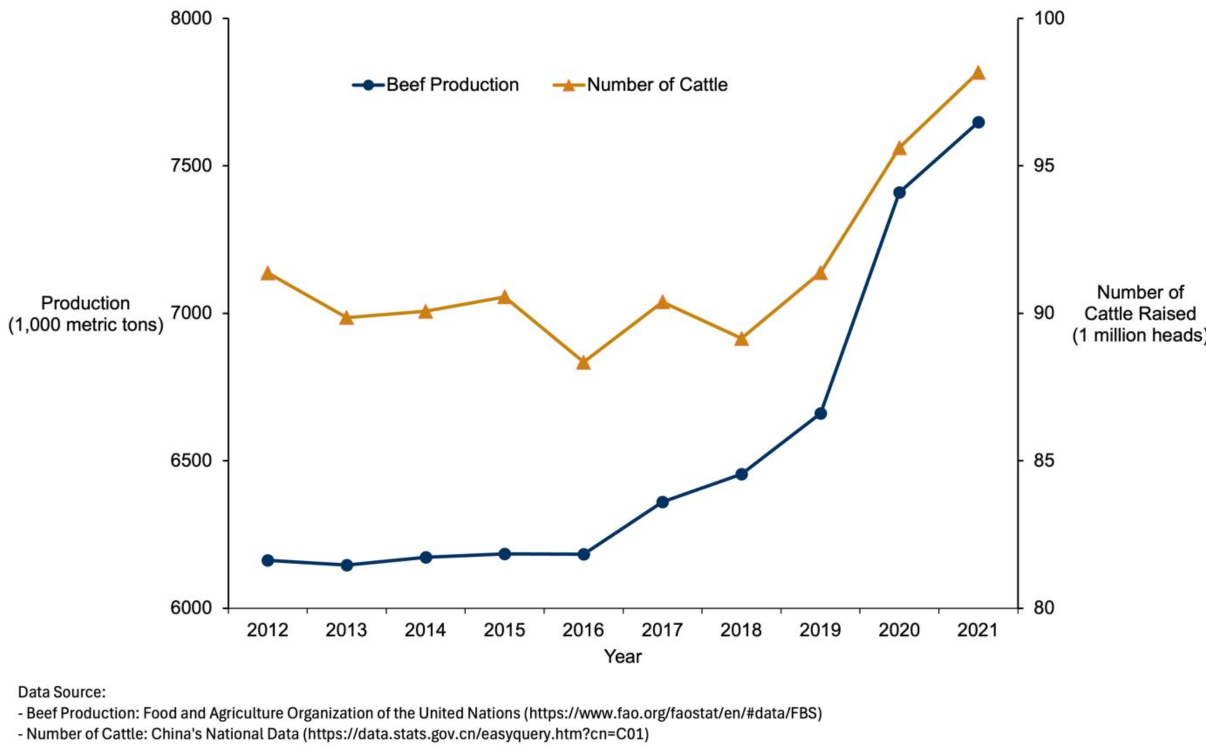
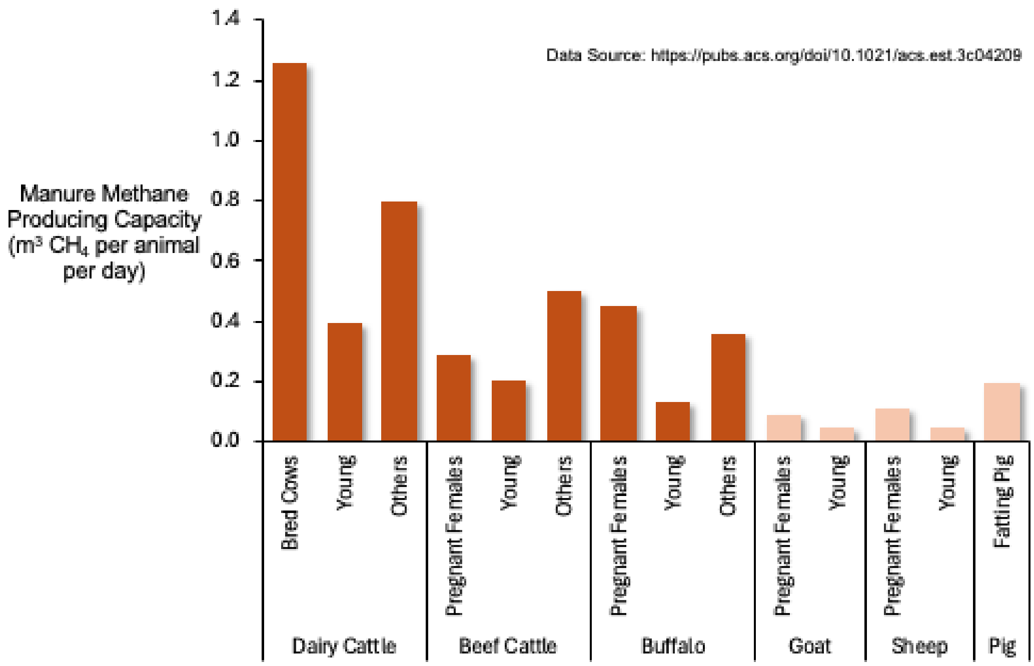


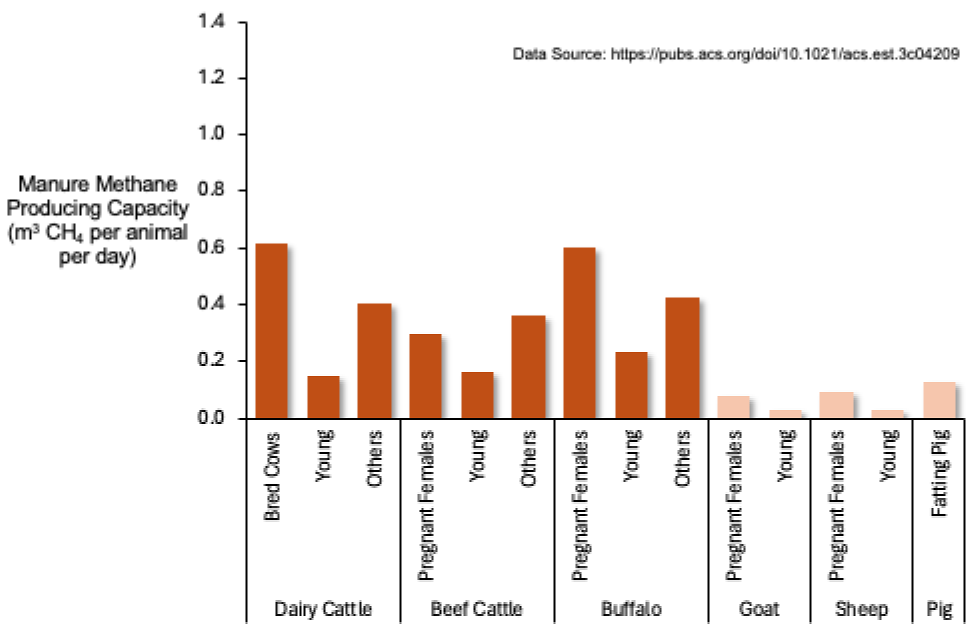
Figure 4. Trends in China's Beef Production and Number of Cattle, 2012-2021[116]

Studies show that growth in beef production is a key driver of increased livestock manure methane emissions.[117] Because cattle tend to generate more manure and manure methane than goats, sheep, or pigs (Figure 5), it follows that the growth of cattle farming in China has increased its methane emissions from manure management. Notably, for dairy cattle, intensive feeding[118] tends to generate much more manure methane than non-intensive[119] feeding.

[116] (Food and Agriculture Organization of the United Nations, 2023; National Bureau of Statistics, 2024)
[117] (Duan et al., 2023; Xu et al., 2024)
[118] Intensive livestock feeding refers to a system where animals are kept in confined spaces such as feedlots, pens, or barns and fed specially formulated diets to promote rapid growth and maximize production. In this system, animals have limited access to grazing areas and rely heavily on concentrated feed sources (Mpofu, 2020).
[119] Non-intensive livestock feeding, also known as extensive livestock production, involves allowing animals more freedom to graze on pasture or forage crops in open spaces. Animals have a more varied diet that includes natural vegetation along with supplemental feeds as needed. This system emphasizes natural behaviors and can align with sustainable farming practices by reducing environmental impacts associated with concentrated animal feeding operations (World Wildlife Fund, n.d.).



(a)



(b)

Figure 5. Maximum Daily Production Capacity of Manure Methane by China's Livestock in Different Feeding Situations (m^3 of methane [CH_4] per animal per day): (a) Intensive Feeding; (b) Non-intensive Feeding[120]

Three potential solutions can address increases in manure methane emissions due to growth in beef demand. First, reducing the emission intensity of manure methane through targeted

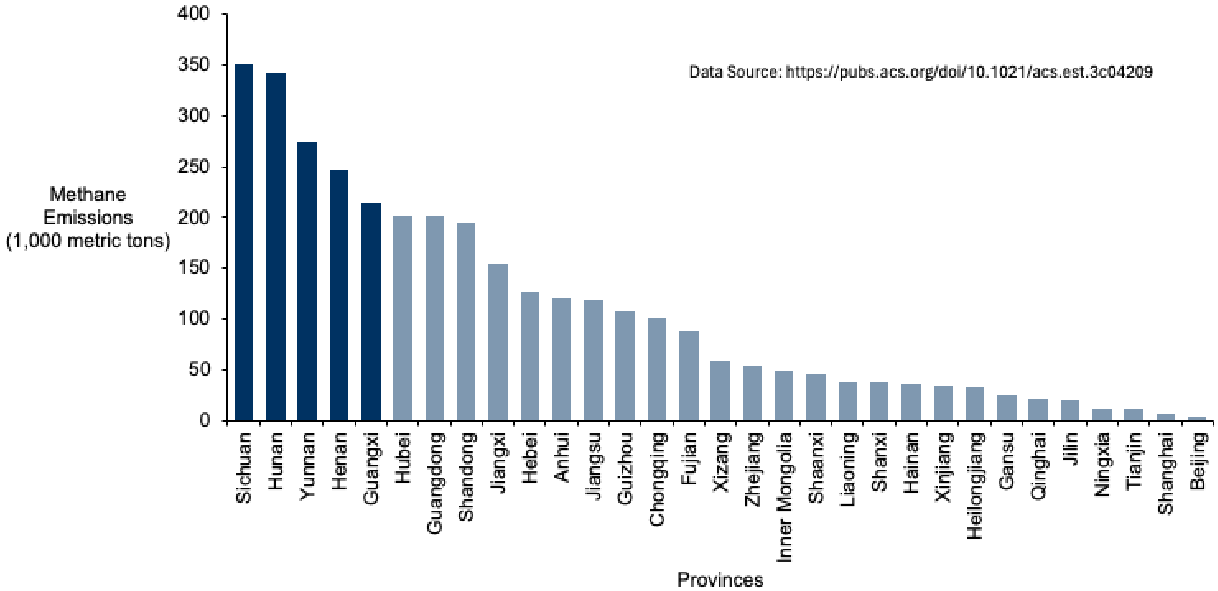
[120] (Duan et al., 2023)

investment and innovation is crucial. As mentioned, this can involve installing anaerobic digesters to capture methane for energy production and optimizing manure management practices to minimize methane release. This is particularly important for intensive cattle feeding systems, which satisfy beef demand but generate more manure methane emissions. Additionally, encouraging dietary changes can mitigate livestock manure methane emissions. Promoting sustainable, plant-based diets can reduce the overall methane footprint of beef production while also improving public health.[121] Finally, reducing food waste, especially for beef and dairy products, can slow increases in food production and reduce livestock manure methane. Combining these approaches can lead to substantial reductions in methane emissions while supporting sustainable beef production aligned with China's carbon-neutral future.

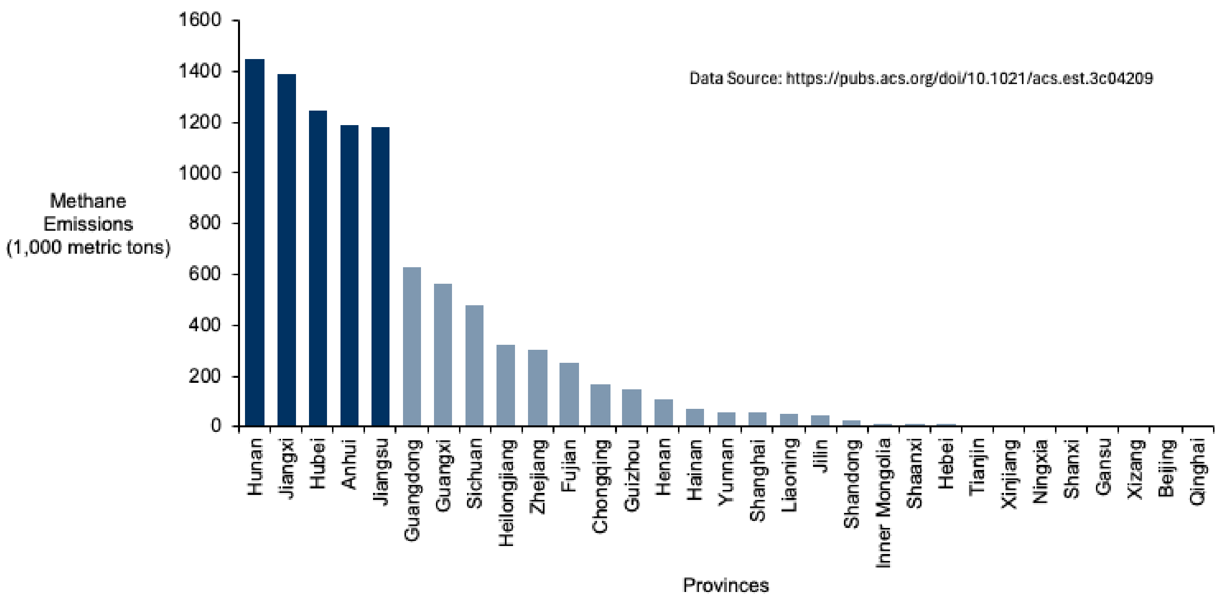
Regional Implementation Priorities

Agriculture varies across China, which necessitates a tailored approach to addressing variations in emission sources. Figure 6 shows methane emissions from manure management and rice cultivation for China's mainland provinces. Sichuan, Hunan, Yunnan, Henan, and Guangxi have the highest methane emissions from manure, while Hunan, Jiangxi, Hubei, Anhui, and Jiangsu have the highest methane emissions from rice. This data should inform priorities for government investment and policy support for different regions.

[121] (Academy of Global Food Economics and Policy, 2021)



(a)



(b)

Figure 6. Agricultural Methane Emissions in China's Mainland Provinces[122] *in 2020 (1,000 metric tons): (a) Manure Management; (b) Rice Cultivation*[123]

Beyond these provinces, it is also necessary to improve the capacity of China's western provinces to mitigate manure methane, as the livestock industry is expected to migrate to this area.[124] Compared to the rest of the country, China's western provinces have less agricultural infrastructure, human

[122] Data for Hong Kong, Macau, and Taiwan are not available.
[123] (Duan et al., 2023)
[124] (Duan et al., 2023)

resources, and financial resources. To support this region, China's government should invest in improving local capacity to deploy centralized manure treatment facilities and improve the efficiency of manure methane mitigation.

Reducing rice cultivation methane emissions in China's traditional rice-producing provinces like Hunan, Jiangxi, Hubei, and Anhui faces challenges due to waning interest in rice farming, as citizens seek higher-paying jobs in more economically developed provinces such as Guangdong and Jiangsu. To incentivize adoption of rice methane mitigation technology in these regions, it is crucial to explore strategies that not only reduce emissions, but also maintain or enhance rice yield and make its cultivation more profitable. The *Ecological Protection Compensation Regulation*,[125] recently introduced by China's government, emphasizes that the protection of arable lands should be compensated. This regulation presents a significant opportunity to boost the profitability of rice cultivation while promoting methane mitigation strategies such as water management. In addition, since southern and central China remain the primary regions for rice production, the ongoing promotion of water-saving rice varieties (e.g., Hanyou 73, Huhan 61) by local governments is needed, as these varieties are high-yield, low-cost, and able to reduce methane.[126] Despite this, adoption of water-saving rice varieties remains limited. In 2022, water-saving rice species grew on only 200 thousand hectares in China,[127] compared to a total rice planting area of about 29 million hectares. Overcoming this limitation will require targeted efforts and investments to (1) cultivate species adaptive to China's major rice-producing regions; (2) avoid impacting local biodiversity; (3) inform farmers of the economic and methane-mitigating potential of new varieties; (4) update guidelines and standards for farmers' planting practices; and (5) encourage seed companies to promote new species.[128]

Implementing a Comprehensive MRV System

An MRV system is crucial for both rice and manure methane mitigation for several reasons. First, it provides a structured framework for monitoring methane emissions accurately from agricultural activities. It is also essential for understanding emission trends, identifying hotspots, and evaluating the effectiveness of mitigation measures over time. A robust MRV system also facilitates transparent reporting of methane emissions, which is vital for meeting regulatory requirements and demonstrating progress toward emission reduction goals.

China's agricultural methane MRV systems are still in an early stage. Progress in establishing MRV systems for agriculture has been slow compared to other industries, and there remains a lack of specific guidelines for agricultural GHG verification and reporting.[129] China does include

[125] (State Council of the People's Republic of China, 2024)
[126] (L. Luo, 2018)
[127] (Ministry of Ecology and Environment, 2022a, p. 15)
[128] China's agricultural materials retailers often sell fertilizers, pesticides, and seeds together, with higher profits from fertilizers and pesticides compared to seeds. This creates a tension where if a species shows effectiveness in reducing fertilizer and pesticide use, retailers may lack an incentive to promote it (L. Hu et al., 2021).
[129] (Ministry of Ecology and Environment, 2022b; National Development and Reform Commission, 2013b, 2014, 2015)

agricultural GHG emission data in its *Third Biennial Update Report on Climate Change*, which provides insights into the country's overall GHG inventory. In the inventory, estimates of manure methane emissions rely on Tier 2[130] measures from the 2006 IPCC guidelines, indicating that detailed information was used for animal characteristics and manure management practices, but that limited country-specific methodologies or measurement-based approaches were developed for quantifying manure methane emission factors.[131] Estimates of rice methane were higher quality, as they were based on the CH4MOD model, a country-specific Tier 3 measure.[132]

China faces several challenges in establishing MRV systems for agriculture:

- ***Lack of legal and institutional support***. China's MRV system requires a comprehensive structure established through laws, regulations, and technical standards. This involves formalizing workflows, technical requirements, and the rights and responsibilities of stakeholders. At present, the structure has not been established and the reporting, accounting, and verification of methane emissions data from key emitters are not institutionalized, leading to challenges in complying with national carbon neutrality targets and preparing for methane MRV among localities and businesses due to institutional uncertainty.
- ***Gaps in data collection***. The absence of legal and technical standards results in data collection that relies on existing statistical methods and traditional data collection systems within enterprises. This type of data collection framework suffers from issues such as infrequent data updates, relatively simple statistical calculation methods and standards, and a lack of dynamic adjustments reflecting local circumstances. These inadequacies hinder the calculation and monitoring of China's agricultural methane emissions.[133]
- ***Limited micro-level studies***. Research on agricultural methane emissions monitoring has primarily focused on macro-level analyses at the national and provincial levels, with limited attention given to micro-level studies involving farmers and enterprises. While understanding agricultural methane emissions at the macro level is crucial for informing policy decisions, it is equally important to consider the direct impact of farmers' production decisions on emissions, which is crucial for acquiring accurate methane emission data and evaluating emission trends. Current research tends to prioritize macro-level emission calculations and empirical analyses while overlooking the micro-level activities of farmers and enterprises. Additionally, existing literature on spatial analyses of agricultural methane emissions often summarizes spatial differences without delving into underlying causes.[134]

Given the importance of MRV systems to agricultural methane mitigation, China should take the following actions to refine the existing system:

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[130] The 2006 IPCC guidelines for GHG inventories classify tiers based on methodological complexity, with typically three tiers provided. Tier 1 represents the fundamental method, Tier 2 denotes an intermediate level, and Tier 3 is the most complex and data-intensive tier (Intergovernmental Panel on Climate Change, 2006, p. 6).
[131] (Intergovernmental Panel on Climate Change, 2023)
[132] (Ministry of Ecology and Environment, 2023a)
[133] (Zhao et al., 2022)
[134] (Hu Y. et al., 2023)

- ***Establish comprehensive technical guidelines***. National departments should lead the work and collaborate with universities and research institutions to develop a robust methodological framework for calculating methane emissions. This is an important step and will serve as the foundation for the subsequent making of laws and regulations. This framework should align with scientific principles and agricultural practices in China and be based on IPCC guidelines for greenhouse gas emission inventory. Comprehensive methodologies, including lifecycle analysis and input-output methods, should be adopted to determine technical standards for agricultural methane emission estimation. Additionally, designating a government agency to oversee MRV systems for agricultural methane and fostering interagency collaboration are crucial steps in this process.
- ***Improve the transparency of the national GHG inventory***. Currently, the *Biennial Update Report on Climate Change* is the only official source of agricultural methane emission data in China, but details about methodology and data are not public, especially for manure methane. Releasing the methodology and data used for agricultural methane emission estimation in the national GHG inventory could encourage more research on methodology and help refine the existing methane estimation methodology and MRV systems.
- ***Establish an agricultural methane emission database based on multiple technologies***. A database could help integrate methane emission information from different sources, facilitate the operation of agricultural methane MRV systems, and serve as an important decision-making tool. Two steps are necessary for establishing such a database: (1) applying technologies such as remote sensing (aircraft and satellite), big data, and cloud computing for methane monitoring;[135] and (2) measuring methane emissions from different regions, different cultivation methods, and different types of livestock management, and then calculating emission factors that align with China's actual agricultural production.
- ***Improve the quality of third-party verification via regulation and capacity-building***. Introducing third-party verification is an important step in ensuring the data quality and credibility of MRV systems. To ensure the effectiveness of third-party verification, it is essential to standardize the operation of third-party organizations. Standardization involves ensuring independent verification and adherence to professional standards. Concurrently, efforts should focus on capacity-building to train a larger number of qualified professionals to perform third-party verification.
- ***Increase micro-level studies on farmers and local enterprises***. Implementing agricultural methane reduction policies hinges on actions taken by farmers and local enterprises. More studies on farmers' and enterprises' willingness to install MRV systems will provide useful feedback on the direction of MRV technology innovation and how to refine MRV technical guidelines. In addition, micro-level studies can provide on-the-ground methane data, which is useful in estimating methane emissions from individual sources and can be used to refine the methodology of MRV systems.

[135] (J. Zhang & He, 2022)

Conclusion and Discussion

There have been several positive developments in terms of mitigating China's agricultural methane emissions. Among these are the inclusion of methane reduction targets in recent policy updates and the launch of initiatives focusing on ecological farms and low-carbon compensation for methane reduction projects. Collaboration between national departments has been promising, as has been the implementation of pilot projects using furrow flooding, biochar, and other techniques. Even so, challenges persist. These primarily result from a lack of methane emission data and quantitative targets; inadequate regulatory frameworks; and limited availability of cost-effective mitigation technologies. Further, existing policies often lack systematic tracking and evaluation of methane reductions.

The release of its methane mitigation action plan in 2023 showed China's political will to address agricultural methane emissions. Implementing the action plan will require measures based on different agricultural driving forces in different regions, as well as the establishment of comprehensive MRV systems. Methane emission intensity is the most significant driver of China's agricultural methane emissions, and both technological innovation and policy support are needed to lower it. Technological innovation measures for rice methane mitigation include reducing technology costs; increasing the scale of mitigation technologies; developing water-management measures, especially for small farmers; and improving the collection and transportation system for rice straw. Meanwhile, large-scale, integrated manure management should be prioritized to improve the efficiency of manure methane utilization. On the policy front, three priorities for encouraging methane mitigation projects are increasing government financing; implementing climate-smart agricultural commodity programs; and integrating agricultural methane into China's voluntary carbon market.

Structural changes in China's livestock industry have also driven agricultural methane emissions. A surge in demand for beef has significantly increased the potential for methane emissions from manure management. In response, China should encourage dietary changes and reduce food waste.

Regional differences among China's provinces mean that different priorities should accompany the design and implementation of programs to mitigate agricultural methane. According to this report's analysis, Sichuan, Hunan, Yunnan, Henan, and Guangxi have the highest amount of manure methane emissions and should therefore focus on installing manure treatment facilities, such as digesters. These provinces should also attend to any negative environmental impacts these facilities may have on local communities, such as air and water pollution. Improving the capacity of manure methane mitigation in China's western provinces is also important, as the livestock industry is expected to migrate there. Notably, these provinces lack the agricultural infrastructure, human resources, and financial resources of China's other provinces. Meanwhile, Hunan, Jiangxi, Hubei, Anhui, and Jiangsu should focus on mitigating rice methane emissions. Even more importantly, China must explore comprehensive strategies that simultaneously reduce emissions, improve carbon sequestration, and increase rice production to effectively incentivize the adoption of rice methane-mitigating technology in these regions. Promoting water-saving rice species is also a valuable strategy but incentivizing adoption among farmers will require concerted effort.

Finally, establishing comprehensive MRV systems is crucial for mitigating China's agricultural methane emissions. Such systems are still in a nascent stage. By analyzing China's agricultural methane inventory, this report found that China uses a country-specific IPCC Tier 3 method for estimating rice methane and a less sophisticated IPCC Tier 2 method for estimating manure methane. China should enhance its MRV systems by taking the following actions: (1) establishing comprehensive technical guidelines for methane estimation; (2) improving transparency of the national GHG inventory by revealing the methodology and data used; (3) establishing an agricultural methane emission database; (4) improving the quality of third-party verification by regulating and capacity-building; and (5) increasing micro-level studies on farmers and local enterprises to assess policy effectiveness.

The future of rice and manure methane mitigation in China is promising. It is clear that China has the political will to mitigate agricultural methane, and there is potential to utilize rice and manure methane mitigation as a solution to a circular economy and energy security. Furthermore, the restart of China's voluntary carbon market can also provide incentives for rice and manure methane projects. However, there remains a need for comprehensive regulatory standards, inter-departmental collaboration, and increased research efforts to develop tailored methane mitigation strategies suited to China's agricultural landscape and emission patterns.

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