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Institute for Global Decarbonization Progress

THE AGRI-FOOD SYSTEM AND CARBON NEUTRALITY

AN ANALYSIS OF CHINA'S AGRICULTURE- AND FOOD-RELATED GREENHOUSE GAS EMISSIONS AND EMISSION REDUCTION PATHWAYS

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EXECUTIVE SUMMARY

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The agri-food system – which emcompasses activities ranging from agricultural production and food transport, to food consumption and food waste disposal – is tightly linked to climate change. On the one hand, changes in temperature and precipitation from global warming, as well as extreme weather events, can exacerbate the volatility of agricultural production. On the other hand, many agri-food system activities are major sources of greenhouse gas (GHG) emissions: the preparation of arable land and pasture, crop cultivation and livestock farming, food processing, packaging, transportation, retail, and cooking and the disposal of kitchen waste are all associated with GHG emissions of varying magnitude. Globally, agriculture and food-related GHG emissions already account for about one-third of carbon emissions.

Climate researchers have tended to split emissions from the agri-food system between its various stages, making emissions from each individual stage seem insignificant. Furthermore, emissions from each stage are often calculated within different industry categories, which means that total emissions from the agri-food system are often overlooked. But emissions from the different stages of the production and consumption sides of the agri-food system influence each other, and are subject to common drivers, including population growth, economic development, income levels and dietary habits. An effective agri-food system emissions reduction plan must view food production, transport, consumption and disposal as an organic whole.

To strengthen China's response to global climate change and achieve the long-term goal of carbon neutrality, it is necessary to have a clear understanding of its agri-food system's emissions and reduction possibilities. This report estimates China's agri-food system GHG emissions by source and type, examines existing and new potential reduction efforts, and outlines key pathways and priority measures to achieve carbon neutrality in the agri-food system.

Key Findings

GHG emissions from China's agri-food system will continue to grow in a business-as-usual scenario

GHG emissions from China's agri-food system would continue to grow under a scenario in which there is a continuation of existing mitigation measures, with total GHG emissions 30 percent higher in 2060 compared to the 2019 level. GHG emissions from agricultural production would continue to grow, while emissions from food processing, transportation, retail, cooking, and waste disposal would exhibit a slow downward trend after peaking, due in large part to energy efficiency improvements. GHG growth would mainly come from methane and nitrous oxide emissions. F-gases emissions would continue to grow until around 2040 and then slowly decline, while CO_2 emissions would begin to gradually decrease after 2030.

Deep-decarbonization would put agri-food emissions on a downward trend from 2020

Under a deep decarbonization scenario, with the adoption of all feasible mitigation actions based on international and domestic mitigation practices, GHG emissions from China's agri-food system would be on a gradual downward trend from 2020. They would decrease to 1.408 billion tons of CO_2e and 651 million tons of CO_2e by 2030 and 2060, respectively, which in 2060 would be 70 percent less than under the reference (business-as-usual) scenario. However, deep-decarbonization would still fail to achieve near-zero emissions.

GHG emissions reduction for the agri-food system calls for systematic change

Focusing only on reducing emissions from agricultural production will not achieve carbon neutrality in China's agri-food system. In 2050, only 37 percent of the mitigation potential in the agri-food system will come from agricultural production. New efforts should target the large mitigation potential in other stages of the agri-food system.

China's existing green development actions could unlock two-thirds of the mitigation potential in the agri-food system

Sixty-nine and sixty percent of mitigation potential in 2030 and 2050, respectively, will come from enhancing existing green development actions, including actions in green agriculture, clean energy promotion and the circular economy that are designed to address environmental pollution and protect public health. The remaining one-third will come from strengthening low-carbon actions, including low-carbon agricultural actions and incentivizing behavioral change in food consumption patterns.

TABLE ES-1. Major mitigation actions in the agri-food system

PRIORITY ACTIONS	MAJOR MEASURES	MITIGATION POTENTIAL IN 2050	MAIN OBSTACLES
AGRICULTURAL PRODUCTION			
Nitrogen fertilizer use reduction	Use of nitrification inhibitor and slow-release fertilizer, conservation tillage, knowledge-based nitrogen management	10%	Lack of strong economic incentives
Manure management	Biogas recovery	11%	Lack of economic incentives
Methane mitigation in rice fields	Irrigation management, dry direct seeding	6.6%	Lack of low-cost technology Implementation difficulty
Emissions mitigation in enteric fermentation	Animal breeding, Feed additives	3%	Lack of low-cost technology
Agricultural machinery energy-saving and electrification	Agricultural machinery energy efficiency improvement and electrification	5.8%	Lack of policy and standards guidance for agricultural machinery electrification
FARM TO TABLE			
Clean energy application in food processing	Energy efficiency improvements	5%	Lack of policy guidance
Low-carbon transportation	Transportation energy efficiency improvements, freight electrification, low-GWP refrigerants	7%	Lack of policy guidance
Plastic reduction and recycling	Recyclable packaging, biodegradable packaging materials	2.8%	Implementation difficulty
FOOD CONSUMPTION			
Cooking energy saving and electrification	Cooking energy saving and electrification	12.8%	Lack of economic incentives
Kitchen waste resource utilization	Waste sorting and kitchen waste resource utilization	5%	Lack of economic incentives for the scale development of waste recycling
Dietary shift and behavior change*	Plant-rich diets	-	Implementation difficulty

Note: * Dietary shift mainly refers to reducing animal-based food consumption and encouraging local food consumption, which can reduce emissions in agricultural production and food transportation. Considering the large uncertainty surrounding behavior change, quantitative analysis is not performed here. Numerous studies have shown that reducing animal food consumption has large emissions reduction potential, a dynamic that deserves greater attention.

Major mitigation actions in China's agri-food system

Based on the 2050 GHG reduction potential under the deep decarbonization scenario, we identify the following ten priority actions and the main obstacles they are facing.

Policy Suggestions

- **Develop an integrated carbon neutrality strategy for the agri-food system**

  Since food production and consumption involve multiple sectors – agriculture, transportation, industry and waste – an integrated carbon neutrality strategy for the agri-food system as a whole can provide a comprehensive approach to reduce GHG emissions, help coordinate cross-sector mitigation actions and promote stakeholder participation.

- **Establish a GHG emissions database for the agri-food system to support scientific decision-making and behavioral change**

The database should include data on GHG emissions from the agri-food system classified by stage and by gas, as well as environmental data on associated activities. Reliable GHG emissions data can provide support for mitigation policies in the agri-food system, and environmental and carbon data labelling can facilitate behavioral change. China's 2021 Updated National Determined Contribution (NDC), which proposes gradually establishing a non-CO_2 GHG emissions inventory system, as well as a policy framework and management system for non-CO_2 GHG emissions, can also provide policy support for agri-food emissions data collection and analysis. China's work on product carbon labeling could also extend to the agri-food system and include carbon information in the existing labelling systems for ecological food and green food.

- **Strengthen existing green and low-carbon actions in the agri-food system to achieve further GHG mitigation, especially methane reduction**

Numerous policies have been created to promote green agricultural development both in China's NDC and domestic policy documents, such as reduction of chemical fertilizer and pesticide use, collection and biogas recovery, promotion of organic fertilizers, and promotion of knowledge-based N management and green agricultural machinery. Optimizing existing policies and measures, especially by strengthening methane reduction in existing actions, can not only mitigate agricultural pollution, protect agricultural resources, and improve the quality of agricultural products, but also reduce GHG emissions with cost-effective measures.

- **Promote energy efficiency and low-carbon transformation in the agri-food system**

GHG emissions from energy consumption at different stages of the agri-food system, such as farm machinery, food processing, transportation and cooking, cannot be ignored. It is recommended to enact relevant policies to accelerate the electrification of agricultural machinery, including market-driven adoption of electric tractors, mini-tillers, and lawnmowers. Priority should be given to the use of renewable energy sources, particularly in the replacement of clean cookstoves in rural areas, with government subsidies and incentives to encourage the widespread adoption of high-efficiency household appliances. Transitioning to green and electric transportation in the food cold chain and freight logistics can also effectively reduce carbon emissions from conventional energy consumption.

- **Promote innovative agricultural practices such as community-supported and regenerative agriculture**

Different types of sustainable agriculture should be explored to improve the resilience of the agri-food system in the face of resource scarcity, environmental pollution and climate change. For example, in addition to industrial agricultural production, given China's smallholding farmer dominated agriculture, policymakers should promote community-supported agriculture, which can provide healthy food for consumers and financial support for producers. Another example is promotion of regenerative agricultural practices such as conservation tillage and cover crops to improve soil health. In addition, development of mitigation technologies in the food sector requires more private capital to promote technology adoption at scale, while commercialized mitigation technologies and practices require government support to reduce the cost of technology adoption.

Consumers, as the end users of food, have a decisive influence on the scale and structure of food production and the way food is served, making changes in consumer behavior an important part of the equation. The promotion of initiatives such as food waste reduction and dietary shift, for example, can mitigate emissions in the agri-food system. Importantly, policy design needs to consider the impact on disadvantaged groups, ensure consumer access to affortable, safe and healthy food, and make the transformation of the agri-food system more inclusive.

1. BACKGROUND

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This section provides a general overview of the connection between climate change and agri-food systems, noting that agri-food systems are at the same time vulnerable to climate change and a source of greenhouse gases (GHG). The green and low-carbon transformation of agri-food systems can lead to GHG emission reductions, while also pushing forward other sustainable development goals.

1.1. Climate change and the agri-food system

The agri-food system, ranging from agricultural production, food processing, packaging, transportation, and retail to food consumption, is closely linked to climate change (Crippa et al., 2021; Niles et al., 2017; Poore & Nemecek, 2018; Rosenzweig et al., 2020; Tubiello et al., 2021; Vermeulen et al., 2012). On the one hand, agricultural activities such as crop production and livestock farming are at enormous risk from the effects of climate change. Changes in temperature and precipitation from global warming, as well as extreme weather events, exacerbate the volatility of agricultural production and can impact the overall production potential (Y. Li et al., 1997; Woetzel et al., 2020). On the other hand, many activities in the agri-food system are major sources of GHG emissions, from the preparation of arable land and pastures, crop cultivation and livestock farming, to food processing, packaging, transportation, and retail, and including cooking and the disposal of kitchen waste (Niles et al., 2017; Vermeulen et al., 2012).

However, because total emissions from the agri-food system are split between its various stages, the emissions from each individual stage become insignificant when compared with those from other major emitting sectors. Furthermore, emissions from each stage are often calculated within different industry categories, which means that too often the total emissions from the agri-food system are overlooked (Clark et al., 2020; Tubiello et al., 2021). Since emissions from the different stages of the production and consumer sides of the agri-food system mutually influence each other, and are subject to common drivers, including population growth, economic development, income levels and dietary habits, splitting emission control measures between different sectors, such as agriculture, transportation and industry, is not an effective way to establish an agri-food system emissions reduction plan (Niles et al., 2017; Rosenzweig et al., 2020). Therefore, to maximize the system's contribution to climate mitigation efforts, it is necessary to view agriculture, food production and consumption as an organic whole.

According to the IPCC's *Sixth Assessment Report*, in the 2010-2019 period global GHG emissions from the agricultural sector, including those arising from land use, accounted for between 13 percent and 21 percent of total global emissions (IPCC, 2022). However, if agriculture as well as food production and consumption are taken as a whole, with indirect emissions from food production, processing and consumption included, then globally, agriculture and food-related GHG emissions already account for about one-third of global carbon emissions (Crippa et al., 2021). This makes the proper management of the agri-food system crucial to global climate security.

The green and low-carbon transformation of agri-food systems can also push forward sustainable development goals like biodiversity protection, social equity and public health. Reducing the overuse of fertilizers and pesticides in agricultural production and changing production methods, such as monoculture and intensive farming, can reduce their damage to ecosystems (Benton et al., 2021). Community-supported agriculture allows consumers to connect directly with agricultural producers, improving food safety and contributing to social equity. The promotion of low-sugar, low-fat dietary guidelines is not only beneficial to public health, but also reduces GHG emissions by reducing animal-based food consumption (Tilman & Clark, 2014; Zang et al., 2018).

2. CURRENT STATUS AND CHALLENGES OF GREENHOUSE GAS EMISSIONS FROM CHINA'S AGRI-FOOD SYSTEM

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This section reviews previous analyses of GHG emissions from agri-food systems, describes iGDP's assessment of GHG emissions from China's agri-food system, and makes note of the ongoing socio-economic changes in China that are helping to drive agri-food system emissions.

2.1. Main agri-food system emissions sources

There have been numerous analyses of GHG emissions from agri-food system activities (Crippa et al., 2021; H. Li et al., 2016; Niles et al., 2017; Poore & Nemecek, 2018; Tubiello et al., 2021). Vermeulen et al. divide food-related GHG emissions into three stages: 1) food production preparation, such as the manufacture of fertilizers, pesticides and feed; 2) food production, which includes direct emissions from agricultural production, such as nitrous oxide from the use of nitrogen fertilizers, methane emissions from livestock and poultry farming, and indirect emissions during production, including GHG emissions from the conversion of forest land to arable land or grassland for food production; and 3) post-food production, which covers emissions generated during food processing, packaging, transportation, retail and consumption (Vermeulen et al., 2012).

Based on data from the EDGAR-Food database, Crippa et al. divide GHG emissions from the food sector into eight stages, from food production to consumption, analyzing emission sources in each stage. The stages in order are: change in land use type, food production, processing, packaging, transportation, retail, consumption and food end-of-life processing. (Crippa et al., 2021). The Poore and Nemecek study takes a similar approach, but due to limited data availability, it excludes cooking and food waste from its analysis of GHGs caused by food production and consumption (Poore & Nemecek, 2018). Tubiello et al. divide food system emissions into changes of land use, farm production, and those emitted by the energy, industry and waste sectors associated with the production and consumption of food (Tubiello et al., 2021). Li and Niles et al. analyze greenhouse gas emissions from farm production to end-user food consumption and disposal as the main GHG emissions from the food system (H. Li et al., 2016; Niles et al., 2017). Based on these analyses and data availability, the GHG emissions from the agri-food system discussed in this report largely cover the main emission sources from agricultural production, processing, packaging, transportation, and retail to consumption. Major GHGs covered include carbon dioxide, methane, nitrous oxide and fluorinated greenhouse gases (F-gases) (mainly hydrofluorocarbons [HFCs] used in refrigeration equipment). The Global Warming Potential (GWP) is used to calculate the various greenhouse gases in terms of their carbon dioxide equivalent (CO_2e). This report broadly classifies the main GHG emissions from the agri-food system into the following seven stages (as shown in Table 1):

- **Agricultural production:**
  - GHGs emitted during the production, processing and transportation of agricultural inputs, such as fertilizers, pesticides and agricultural films, as well as from energy consumption by agricultural machinery,
  - Methane and nitrous oxide emitted during the cultivation of crops (rice, wheat, etc.),
  - GHGs emitted during animal-based food production, such as methane emissions from intestinal fermentation in livestock and poultry farming, and methane and nitrous oxide emissions from livestock and poultry manure.
- **Food processing:** Mostly energy consumption from processing and GHG emissions from wastewater treatment.
- **Food packaging:** Energy consumption and GHG emissions from the production of packaging materials such as plastics, aluminium, steel and glass.
- **Food transportation:** Energy consumption during transportation and storage and F-gases emissions from refrigerants in the cold chain transportation of fresh food.
- **Retail:** Energy consumption from retail and F-gases emissions from refrigerants.

TABLE 1. Scope of research on agri-food system GHG emissions

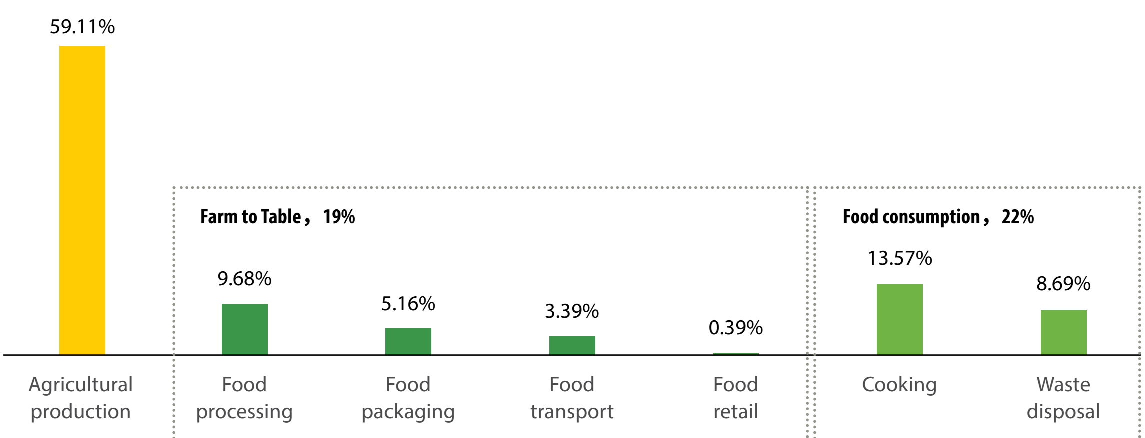
KEY STAGES IN THE AGRI-FOOD SYSTEM	MAIN GREENHOUSE GASES			
	CO_2	CH_4	N_2O	F-gases
Agricultural production	√	√	√	
Farm to table: food processing	√			
Farm to table: food packaging	√			
Farm to table: food transportation	√			√
Farm to table: retail	√			√
Food consumption: cooking	√			
Food consumption: kitchen waste disposal	√	√		

- **Cooking:** Energy consumption and emissions from cooking food in restaurants and homes.
- **Kitchen waste disposal:** Energy consumption from the transportation and disposal of food waste from restaurants and home kitchens, as well as methane and carbon dioxide emissions from waste disposal.

2.2. The current emissions status of China's agri-food system

Based on publicly available data and research on agri-food systems (see Table 1), this report estimates that in 2019 GHG emissions from China's agri-food system reached 1.65 billion tonnes of CO_2e, accounting for about 14 percent of the country's total GHG emissions that year. When comparing the different stages of the agri-food system, agricultural production has the highest emissions, accounting for approximately 59 percent of GHG emissions from the entire agri-food system, followed by food consumption at 22 percent and farm to table at 19 percent.

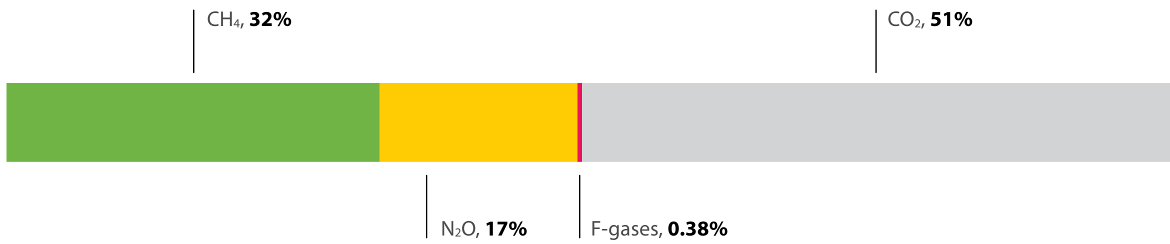
FIGURE 1. Percentage of GHG emissions in the agri-food system by stage in China (2019)



Data source: iGDP estimate

When categorized into different types of GHG, CO_2 accounts for 51 percent of emissions from China's agri-food system, while the remaining 49 percent of non-carbon dioxide GHGs are mostly methane (CH_4), nitrous oxide (N_2O) and F-gases. Among these, methane accounts for the highest proportion, the majority coming from the rice cultivation and livestock and poultry farming within the agricultural production component of the agri-food system.

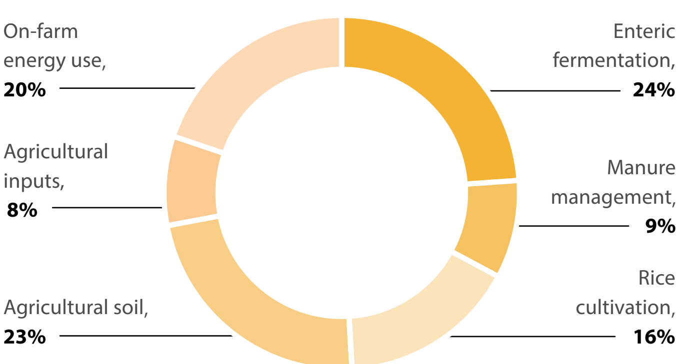
FIGURE 2. China's agri-food system GHG emissions by gas (2019)



Data source: iGDP estimate

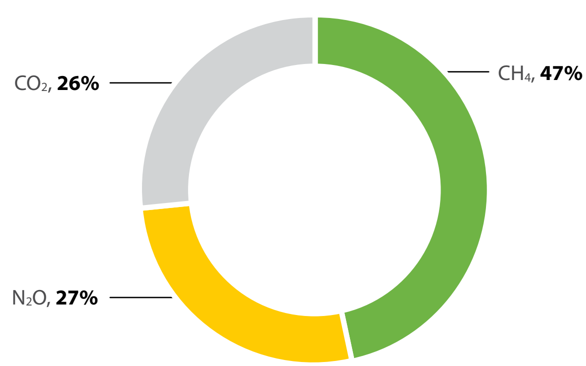
The main emission sources and gases from the agricultural production component of the agri-food system are shown in Figure 3 and Figure 4 below. This report estimates that in 2019 greenhouse gas emissions from agricultural production came to around 970 million tonnes of CO_2e, of which emissions from livestock and poultry intestinal fermentation accounted for the largest share at 24 percent. Next was energy consumption, mainly from the use of nitrogen fertilizer (23%) and agricultural machinery (20%). When categorized by different types of GHGs, the greatest share comes from methane, accounting for about half of all agricultural production emissions.

FIGURE 3. Agricultural GHG emissions in China by source (2019)



Data source: iGDP estimate

FIGURE 4. Agricultural GHG emissions in China by gas (2019)



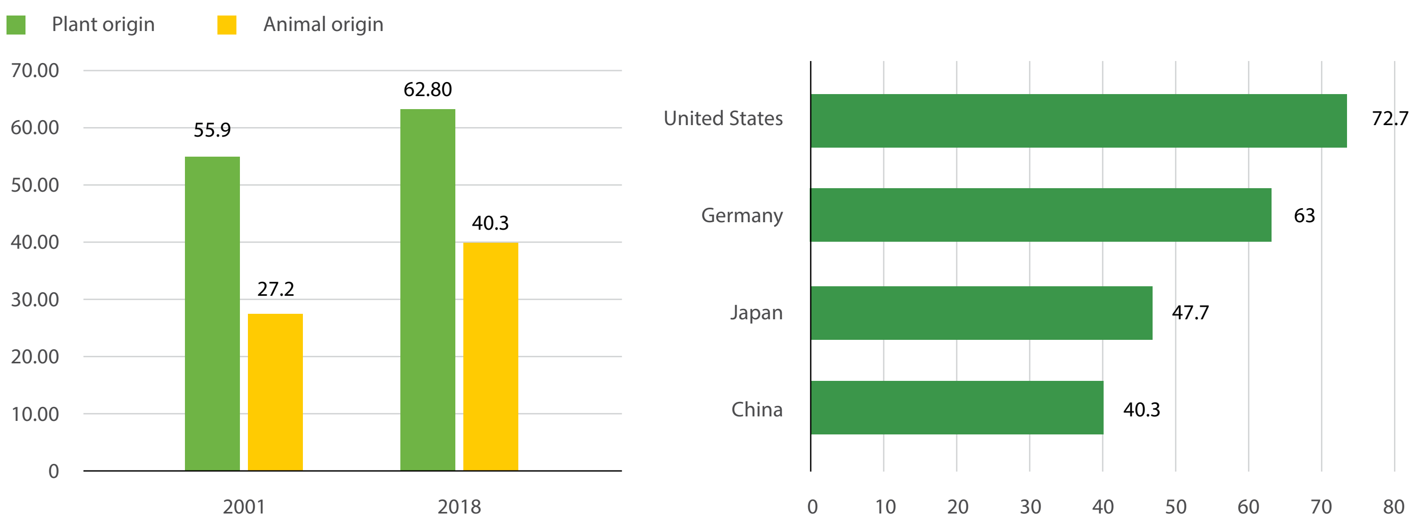
Data source: iGDP estimate

2.3. Challenges facing China's agri-food system emissions

Changes in population, economic development and dietary structure in China have led to changes in the scale, types and style of food consumption. These changes have also had an impact on the scale and structure of agricultural production and the food supply mode. China's agri-food system's GHG emissions are changing alongside these adjustments, and may see further increases going forward.

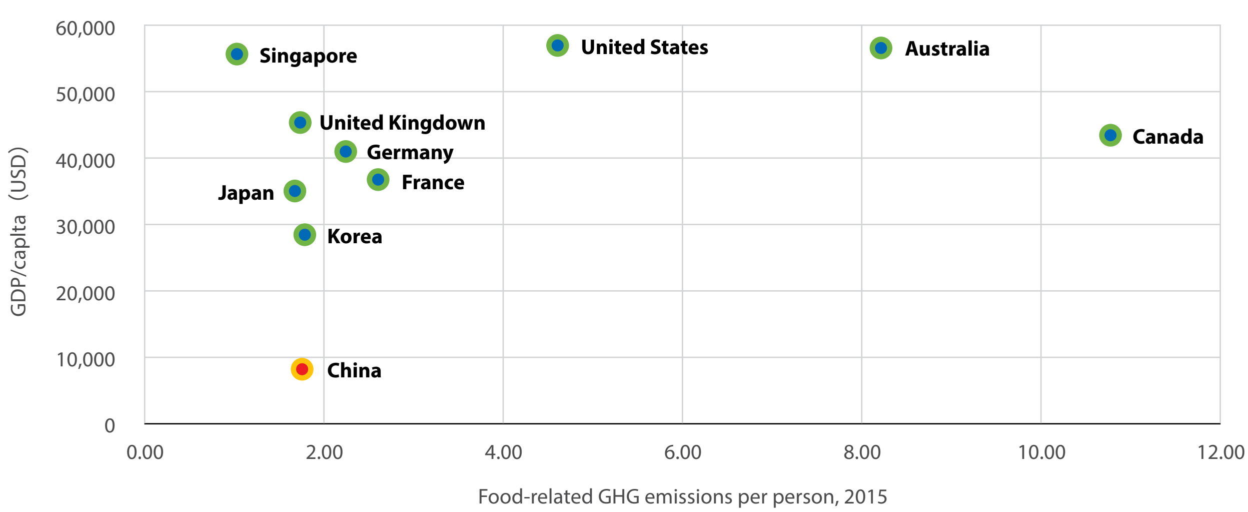
Using comparable estimation methods, China's 2015 per capita agri-food system GHG emissions were close to those from major developed countries such as the United Kingdom, Japan and Germany, while China's per capita GDP was close to, but yet to reach, the lower limit of developed countries (Figure 5). Along with economic development, Chinese consumption levels are rising and there is growing demand for more varieties and better quality of food. For example, China's per capita protein intake is still at a low level compared to some developed countries (Figure 5). If higher protein intake in the future comes from animal-based food consumption, this could greatly increase greenhouse gas emissions, posing a challenge to the effort to achieve carbon neutrality within the agri-food system and for food safety (Bai et al., 2018; H. Li et al., 2016; L. Ma et al., 2019).

FIGURE 5. Daily protein supply in China and comparison of animal protein supply (g/person/day) between China and other countries (2018)



Data source: FAO, 2018

FIGURE 6. Per capita agri-food system GHG emissions: China vs. major developed countries (2015)



Data source: EDGAR Food Database and the World Bank

3. SUMMARY OF CHINA'S POLICIES TO REDUCE GREENHOUSE GAS EMISSIONS IN THE AGRI-FOOD SYSTEM

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This section describes policies that indirectly promote GHG emission mitigation in China's agri-food system, existing efforts that directly target these emissions, and identifies new emission reduction opportunities.

3.1. Policy actions leading to GHG emission reductions in the agri-food system

Agricultural production and food security are long-standing policy priorities in China. Policymakers have promoted sustainability in China's agricultural industry and rural areas with strategies and policies for green agricultural development, soil conservation, rural revitalization and food security. They have also introduced emission reduction measures targeting food processing, transportation and consumption, including industrial energy conservation, green low-carbon transportation and waste management.

Since 2004, the Central Committee of the Communist Party of China and the State Council have issued the annual No. 1 Central Document, which prioritizes agriculture, rural areas and farmers, laying out agricultural and rural work arrangements. The 18th *No. 1 Central Document*, issued in 2021 and titled "Opinions of the Central Committee of the Communist Party of China and the State Council on Comprehensively Promoting Rural Revitalization and Accelerating Agricultural and Rural Modernization," identified green agricultural development as one of the key measures to further agricultural modernization. It proposed maintaining a red line of 1.8 billion acres of arable land, as well as measures such as encouraging conservation tillage, reducing the use and improving the effectiveness of fertilizers and pesticides, making use of livestock and poultry manure, and improving oversight of agricultural product quality and food safety[1].

China's large population and limited arable land have put food production at the core of its policy agenda, and food security is seen as critical to national security. The 2019 *China Food Security White Paper* emphasized that China should adhere to the principle of ensuring basic self-sufficiency in food and implement the strictest measures to protect its arable land[2]. Policies such as the *National Sustainable Agricultural Development Plan (2015-2030)* and the *National Rural Revitalization Strategic Plan (2018-2022)* encourage sustainable agricultural development from different angles.

TABLE 2. Overview of main emission reduction actions in the agri-food system

	EMISSION REDUCTION ACTIONS	POLICY INSTRUMENTS
Agricultural production	• Encourage more effective and reduced use of chemical fertilizers and pesticides, and replacement with organic fertilizers; build a long-term effective mechanism to replace chemical fertilizers with organic fertilizers for the cultivation of fruit, vegetables and tea; and provide subsidies for the purchase and use of organic fertilizers. • Encourage the recycling of agricultural films and the use of environmental-friendly biodegradable films. • Propose farmland methane emissions control; breed high-yield, low-emission crop varieties, and improve water and fertilizer management. • Improve agricultural carbon sequestration capacity through sound farmland management practices. • Improve the use of livestock and poultry manure. • Encourage low-protein daily feed, whole plant-silage, and high-yield, low-emission livestock and poultry breeds. • Farmland carbon sink initiatives. • Encourage the digitalization of and smart technology use with crop and livestock farming and fisheries. • Encourage the use of green agricultural machinery, support the inclusion of agricultural green development machinery and smart equipment into agricultural machinery purchase subsidies.	*National Agricultural Sustainable Development Plan (2015-2030)* *Opinions on Accelerating the Prevention and Control of Pollution from Agricultural Films* *13th Five-Year Plan for the Control of Greenhouse Gas Emissions* *14th Five-Year National Agricultural Green Development Plan* *Improvement and Protection Plan for Farmland Quality* *Opinions on Comprehensively Promoting Rural Revitalisation and Accelerating Agricultural and Rural Modernisation* *Development Plan for Digital Agriculture and Rural Areas (2019-2025)* *Opinions of the Central Committee of the Communist Party of China and the State Council on Fully, Accurately and Comprehensively Implementing the New Development Concept and Achieving Peak Carbon and Carbon Neutrality* *Action Plan for Carbon Dioxide Peaking Before 2030* *Implementation Plan for Emissions Reduction and Carbon Sequestration in Agriculture and Rural Areas*

1. No. 1 Central Document (2021). http://www.gov.cn/zhengce/2021-02/21/content_5588098.htm
2. "Food Security in China" White Paper. http://www.gov.cn/zhengce/2019-10/14/content_5439410.htm

TABLE 2. Overview of main emission reduction actions in the agri-food system

	EMISSION REDUCTION ACTIONS	POLICY INSTRUMENTS
Farm to Table	• Encourage green packaging, aiming for the discontinuation of secondary packaging for all e-commerce express shipments by 2025, with the application scale of recyclable courier packaging reaching 10 million units. • Develop the green and low-carbon transportation of agricultural products. • Improve the energy efficiency of the food processing industry. • Cut the production and consumption of HFCs.	*Guiding Opinions on Accelerating the Transformation and Development of China's Packaging Industry* *14th Five-Year Plan for Circular Economy Development* *Opinions on Accelerating the Development of Cold Chain Logistics to Ensure Food Safety and Promote Consumption Upgrading* *14th Five-Year National Agricultural Green Development Plan* *Kigali Amendment* *14th Five-Year Plan for the Modern Energy System*
Food consumption	• Sort household waste and use kitchen waste as a resource. • Reduce food waste, and draw up and revise relevant national, industry and local standards to minimize and prevent waste to the maximum extent possible. • Adjust people's diets by encouraging healthy eating habits with a diverse range of foods.	*Action Plan for Household Waste Separation System* *Law of the People's Republic of China on Prevention and Control of Environmental Pollution by Solid Waste* *Law of the People's Republic of China on Countering Food Waste* *China Food and Nutrition Development Outline (2014–2020)* *Dietary Guidelines for Chinese Residents*

China has also issued policies and measures in industrial sectors related to food production and consumption, such as agriculture, transportation and waste management. Although the primary goals of these actions have not been to reduce GHG emissions, they are making a positive contribution to carbon reduction in the agri-food system. The table below summarizes these policies, organized by the main emission sources for different components of the agri-food system.

BOX 1. Implementation plan for emissions reduction and carbon sequestration in agriculture and rural areas

Emissions reduction and carbon sequestration in agriculture and rural areas are important measures and hold great potential for helping China achieve its dual-carbon goal. The Ministry of Agriculture and Rural Affairs and the National Development and Reform Commission issued the *Implementation Plan for Emissions Reduction and Carbon Sequestration in Agriculture and Rural Areas* in June 2022 as an important part of China's 1 + N policy system. This was China's first comprehensive strategy to address climate change in the agricultural sector. The Plan proposes six tasks and ten actions to implement the dual-carbon strategy within the agricultural sector. The six tasks are: energy saving and emissions reduction in crop farming; emissions and carbon reduction in livestock farming; emissions reduction and increasing the carbon sink potential in fisheries; expansion of the carbon sequestration of farmland; energy saving and emissions reduction for agricultural machinery; and substitution with renewable energy. The ten actions are: reducing methane emissions from paddy fields; reducing use and increasing efficiency of fertilizers; reducing emissions from livestock and poultry farming; reducing emissions in, and increasing the carbon sink potential of, the fisheries sector; using green and energy-saving agricultural equipment; improving the carbon sequestration capacity of farmland; reusing and recycling straw; substituting with renewable energy; support from technological innovation; and building monitoring mechanisms. The goal is to accelerate the development of resource-saving and environmentally-friendly agricultural and rural industrial structures, production methods, lifestyles and spatial patterns, and to support the national carbon peaking and carbon neutrality goals.

BOX 2. Anti-Food Waste Law

The Anti-Food Waste Law of the People's Republic of China was formally implemented on 29 April 2021, with the aim to prevent food waste, ensure national food security and promote sustainable socio-economic development. The 32 Articles of this law outline definitions, principles and requirements for countering food waste, the responsibilities of government and other entities such as food production/operations and food and beverage service operations, incentives and restrictive measures, and legal liabilities. The key points are:

- Food producers and operators: improve the conditions of food storage, transportation and processing, reduce storage and transportation losses; apply stricter daily inspections, categorized management and special handling of near end-of-shelf life food products.
- Food and beverage service operators: establish sound food procurement, storage and processing management systems; proactively issue food waste prevention tips; do not mislead consumers into ordering excessive amounts of food; provide small portions, etc.
- Industry associations and the public: promote and popularize ways to prevent food waste, including the "Clean Plate Campaign"; individuals should adopt socially responsible, healthy, sensible and green consumption habits.

Few countries have used legislation to reduce food waste. This law highlights China's determination to reduce food waste and ensure food safety. It supports healthy traditional lifestyles during a period of social transformation in China and aims to curb waste.

3.2. Agri-food system emission reduction actions and synergies

As previously mentioned, not all actions that help in reducing greenhouse gas emissions within the agri-food system have the primary goal of combating climate change – much emission reduction comes from their synergistic effects. For ease of analysis, this report divides the mitigation actions in Table 1 into two broad categories based on their overarching policy objectives: green development actions and low-carbon agriculture actions.

- **Green development actions:** these encompass measures and actions where primary policy objectives prioritize other socio-economic and sustainable development goals, in particular agricultural security, environmental protection, energy conservation, low-carbon transformation and public health, while also including the reduction of greenhouse gas emissions. While the initial policy objective was not to tackle climate change, these actions have been intensified under efforts to achieve carbon peaking and carbon neutrality. Green development actions mainly cover such actions as environment-friendly agriculture, green and low-carbon energy systems, and the circular economy. Specific actions include:
    - Environment-friendly agriculture: this mainly includes actions with the primary objectives of reducing air, water and soil pollution arising from agricultural production and ensuring food security.
    - Green low-carbon energy systems: this mostly includes actions taken by China to promote the green and low-carbon transformation of the energy system that are synergistic with efforts to improve energy efficiency and the decarbonization of the agri-food system.
    - Circular economy: the main focus is on actions with the primary objective of conserving resources, recycling and reusing, which also help to reduce emissions within the agri-food system.

- **Advanced low-carbon actions:** this refers to measures and actions to reduce GHG emissions in the agri-food system whose primary objective is to combat climate change and which take into account carbon neutrality requirements — that is, controlling GHG emissions. For example, China has proposed actions and measures related to emissions reduction in the agri-food system in its response to climate change, which were published in *China's Achievements, New goals and New Measures for Nationally Determined Contributions and Implementation Plan for Emissions Reduction and Carbon Sequestration in Agriculture and Rural Areas.*

The table below summarizes the above policies with respect to actions that reduce greenhouse gases and lists their primary policy objectives.

TABLE 3. Overview of actions that have reduced GHG emissions in the agri-food system, categorized by objective

EMISSIONS REDUCTION ACTION CLASSIFICATION	KEY MEASURES	PRIMARY OBJECTIVE	STAGE IN AGRI-FOOD SYSTEM		
			AGRICULTURAL PRODUCTION	FARM TO TABLE	FOOD CONSUMPTION
ADVANCED LOW-CARBON ACTIONS					
Low-carbon agricultural production	Emissions reduction in rice cultivation	Greenhouse gas emissions reduction	√		
	Low-carbon, emissions reduction in livestock and poultry farming	Greenhouse gas emissions reduction	√		
	Farmland carbon sinks	Carbon sequestration	√		
Green refrigeration	Refrigerant emissions reduction in the food cold chain	Greenhouse gas emissions reduction		√	
GREEN DEVELOPMENT ACTIONS					
Environment-friendly agriculture	Resource utilization of livestock and poultry manure	Water pollution reduction	√		
	Improved efficiency and reduction in chemical fertilizer and pesticide use, replacement with organic fertilizer	Soil conservation, food security	√		
	Recycling of agricultural films	Solid waste pollution reduction	√		
Clean and modern energy systems	Reducing energy consumption and emissions in agriculture and rural areas	Air pollution reduction	√		
	Reducing energy consumption and emissions from food processing	Industrial energy saving, air pollution reduction, greenhouse gas emissions reduction		√	
	Reducing energy consumption in food transportation and retail	Transportation energy saving, air pollution reduction, greenhouse gas emissions reduction		√	
	Reducing energy consumption in cooking	Air pollution reduction			√
Circular economy	Recycling and reusing of food packaging	Solid waste pollution reduction		√	
	Kitchen waste management, cutting food waste	Solid waste pollution and air pollution reduction			√

4. EMISSION REDUCTION PATHWAYS FOR CHINA'S AGRI-FOOD SYSTEM

This section identifies mitigation opportunities that can be further promoted based on existing domestic policies, and both domestic and international mitigation practices and technologies.

4.1. Agricultural production

Methane emissions reduction from rice farming

- **Water management in paddy fields:** Since the moisture status of paddy fields affects greenhouse gas emissions, the overall greenhouse gas emissions of paddy fields can be lowered by improving water management (Zhang et al., 2012). Methane emissions can be significantly reduced by draining water one or more times during the rice growing season, compared to conventional irrigation which requires maintaining a certain depth of water. Changing from flooding irrigation to wetting or intermittent irrigation can reduce methane emissions by 47% and 39%, respectively (Mi et al., 2016). In addition, the use of alternate wetting and drying irrigation with slow-release fertilizers, nitrification inhibitors, and other measures can cut methane emissions by 28% to 49% (Zhou et al., 2020).

- **Adjust tillage practices to reduce tillage intensity:** Compared to minimum tillage or no tillage, tilling leads to greater decomposition of organic matter and facilitates methane production and emission (E. Ma et al., 2011). Replacing deep tillage with shallow rotary tillage can lower methane emissions by 32%.

- **Adjust rice farming practices and promote dry direct rice seeding:** Since the direct seeding of rice means less time that the paddy field needs to be in contact with water, it avoids methane emissions from the decomposition of organic matter in flooded soil conditions by methanogenic bacteria. Since this also means a reduced need for water resources and manpower, it is also a cost-effective emissions reduction measure (Ahmed et al., 2020). Studies that have looked into encouraging the move to dry rice from flooded rice cultivation in China have shown that in addition to saving water, it can also reduce GHG emissions (W. Wang & Nie, 2018). However, compared with traditional rice cultivation, dry direct seeding of rice faces problems including susceptibility to lodging, poor growth and overgrown weeds. Therefore, when recommending it, it is also important to promote the use of suitable dry rice varieties and provide guidelines on how to nourish the plants and manage weeds as well as appropriate sowing instructions (H. Liu et al., 2014; W. Wang & Nie, 2018).

- **Select suitable rice varieties:** Selecting rice varieties with a low infiltration rate and efficient nitrogen utilization can reduce emissions. Selecting suitable rice varieties can reduce methane emissions by 20 to 50 percent (Zou et al., 2011).

BOX 3. Climate-friendly rice cultivation in China

As one of China's main food crops, rice is widely grown in different regions of the country. During rice cultivation, methane is produced from the anaerobic decomposition of organic matter in flooded soil, which is a major source of GHG emissions in China's agricultural sector.

In a village in the Jianyang region of Sichuan Province, farmers are growing rice using covering, no-tillage and furrow flooding. Before planting the rice, farmers employ no-tillage to minimize disturbing the soil. During planting, they employ furrow flooding to reduce the time the paddy field is flooded, while using rapeseed cake as a substitute for chemical fertilizer and a layer of local rapeseed hulls to help increase the temperature and maintain moisture levels. In addition to reducing methane emissions from rice farming by changing sowing and irrigation methods, scientific and technological improvements are also being explored. The smart farming system built by the China National Rice Research Institute (CNRRI) and Alibaba Cloud is based on CNRRI's rice growth model. Digital technologies, such as cloud computing and the Internet of Things, allow farmers to connect to water level sensors to precisely manage irrigation and drainage. Studies have found that this type of smart farmland management reduces water use by 30 to 50 percent and methane emissions by 30 percent compared with traditional models3.

1. "Rice Can Also Reduce Carbon Emissions! A Low-Carbon Experiment in the Fields: How to Build a Closed Loop of Technology, Cost, and Carbon Trading?" *Daily Economic News*.

Reduce chemical fertilizer use and promote organic fertilizers

- **Soil-testing formula fertilization:** The appropriate application of fertilizers based on soil nutrient requirements avoids the overuse or underuse of fertilizers, thereby reducing nitrous oxide emissions from nitrogen fertilizer application. China started its soil-testing formula fertilization program in 2005 and has promoted it as a key technology to reduce chemical fertilizer use while increasing its efficiency. Various studies have also demonstrated its significant potential in reducing nitrous oxide emissions from farmland (Luo et al., 2019; Nayak et al., 2015).

- **Use of slow-release fertilizers and nitrification inhibitors:** The nitrogen in nitrogen fertilizers is used by microorganisms in the soil in the processes of nitrification and denitrification, generating nitrous oxide emissions. By using slow-release fertilizers, nitrogenous gases are released more gradually, reducing nitrous oxide emissions by 20 to 40 percent, while the use of nitrification inhibitors cuts nitrous oxide emissions by 11 to 60 percent (Zou et al., 2011). In addition, technical training, and management programs for farmers on fertilizer application can also enhance emissions mitigation. In a training program to improve agricultural management and technology involving more than 20 million farmers in China from 2005-2015, the development of locally tailored farmland improvement programs not only reduced fertilizer use and increased yields, but also mitigated GHG emissions, for example by about 14 percent and 21 percent for rice and wheat, respectively (Z. Cui et al., 2018).

- **Promote use of organic fertilizers:** Organic fertilizer application can regulate microbial activity in the soil and reduce nitrous oxide emissions from farmland by 14 to 30 percent (Zou et al., 2011). Existing measures for using livestock and poultry manure also offer room to encourage the development of organic fertilizers.

BOX 4. Technology-assisted soil testing

Excessive fertilizer use leads to a range of environmental problems, including water pollution and the release of N_2O emissions from farmland soils; it also leads to a decline in soil organic matter, soil acidification and soil hardening, thereby reducing soil fertility. Responding to the overuse of chemical fertilizer, China launched it soil-testing formula fertilization initiative in 2005, which involves the appropriate use of fertilizers based on soil nutrient requirements to avoid the overuse of fertilizers and low fertilizer utilization rates.

With the support of the Ministry of Agriculture, in 2014 Sinofert launched smart fertilizer service stations nationwide to carry out accurate soil testing and fertilizer distribution, through smart fertilizer dispensers[4]. Both large and small-scale growers can use the application software connected to internet-enabled smart fertilizer terminals. After entering planting data and providing soil samples, the fertilizer dispenser can perform a quick soil assessment and send the results to the cloud. Based on the results of the soil assessment, the cloud server calculates a plan for planting, the required fertilizer formula and price, ultimately generating an order which is sent to the farmer's phone[5]. The order goes directly from the factory to the farmer, saving costs by avoiding any distribution mark-up. Calculations show that smart fertilizer distribution systems can directly reduce fertilizer usage and cost by 10 to 30 percent, while increasing crop yields by more than 5 percent and helping farmers boost incomes by more than 10 percent.[6]

4. "Joint Efforts to Reduce Waste and Create an Efficient New Chapter", Farmer's Daily (2016). http://www.sinofert.com/s/4368-12223-56364.html
5. "Precision Farming: Smart Fertilization via Mobile Control", China Business Network (2016). https://www.yicai.com/news/5003423.html
6. "Soil Testing and Fertilization: One-Click Ordering for Precision Fertilization via Mobile Control". Farmer's Daily. http://www.sinochem.com.cn/s/1375-5662-19811.html

Enhance carbon sequestration of farmland

Increase soil organic carbon (SOC) content: On-farm SOC is the foundation of agricultural soil fertility, and it is also a carbon pool that can be adjusted over a relatively short time period (Zhao et al., 2018; Zou et al., 2011). A number of farmland management measures, including conservation tillage, straw return and nitrogen fertilizer management, can reduce disturbance of the soil's physical properties, minimize SOC loss and improve organic carbon stability, thus increasing carbon stock in farmland (Shi et al., 2012). Experimental studies on Chinese farmland show that 1) conventional tillage + straw returning to field, 2) no-tillage and 3) no-tillage + straw returning to field could increase SOC content of farmland with annual carbon sequestration rates of 0.22 g/kg, 0.35 g/kg and 0.52 g/kg, respectively (Zhao et al., 2018). With further promotion of reasonable farm management practices including straw returning to field, organic fertilizer and no-tillage, the organic carbon stock of Chinese farmland can increase from 0.48 to 0.63 percent per year (Tao et al., 2019). If these farmland management measures are promoted under reasonable economic and technological conditions, the carbon sequestration potential may reach 30-50 million tonnes per year, or 0.25-0.4 t/hm2 per year (Cheng & Pan, 2016).

BOX 5. Conservation tillage promotion

The black soil region in Northeast China produces one quarter of the country's total food, making it critical to national food security. However, unsound farming practices have drastically reduced the organic matter and productivity of the black soil. The *2005 No. 1 Central Document* elevated conservation tillage development to a national policy.

In 2007, the Chinese Academy of Sciences set up the "Conservation Tillage Research and Development Base of the Chinese Academy of Sciences" in conjunction with the Agricultural Technology Promotion Station and the Soil Fertilizer Work Station in Lishu county, Jilin Province. Over the course of fifteen years of research and observation, researchers explored a set of technical models and support equipment, called the "Lishu Model." Conservation tillage can be effective in preventing soil degradation. The Lishu pilot project found that soil organic matter increased from 22.5g/kg to 24g/kg between 2007 and 2018. Straw mulching also increases the accumulation and activity of nutrients such as nitrogen, phosphorus and potassium in the cultivated layer, and increases the capacity to supply soil nutrients. Improvements were found in soil structure and soil biodiversity and increased the soil's ability to retain water and resist drought[7]. In 2020, the area of black soil under conservation tillage in Northeast China reached 2.69 million hectares (40 million mu). As well as reducing emissions and bringing environmental benefits, conservation tillage can also increase yields and incomes. In 2017, the Lishu pilot site produced an increase in yields of about 1,000kg/ha, increasing revenues by about 1,400 yuan. Conservation tillage also increased the nitrogen fertilizer utilization rate by 4.7 percent. Reductions in chemical fertilizer use, frequency of farm machinery use, fuel consumption and labor costs resulted in an average saving of 1,650 yuan per hectare[8].

7. "Ao Man, Zhang Xudong, Guan Yixin (2021). Research and Practice of Protective Tillage Technology in Northeast Black Soil, *Journal of the Chinese Academy of Sciences,* 36(10): 1203-1215.

8. Ibid.

Resource utilization of livestock and poultry manure: fertilizer production and biogas recovery

- **Optimize management of livestock and poultry manure:** Sound management can effectively reduce greenhouse gases emitted during the storage of livestock and poultry manure. For example, adding 10 percent biochar or bentonite clay to pig manure in storage can reduce nitrous oxide emissions by 19.8 and 37.6 percent, respectively (Lei et al., 2019).

- **Use livestock and poultry manure as fertilizer:** One of the main practices in managing China's livestock and poultry manure is simple composting and direct application to farmland. Studies have shown that turning and forced aeration during aerobic composting can reduce methane and nitrous oxide emissions. In addition, by adding biochar to pig manure compost, methane and nitrous oxide emissions were reduced by 19 and 37.5 percent, respectively (Zhu et al., 2020).

- **Using livestock and poultry manure as an energy source:** Biogas produced from the anaerobic fermentation of livestock and poultry manure can be recovered by building a biogas plant. By connecting this biogas up to the energy grid or converting it into biofuel for energy generation, methane emissions can be reduced. Various studies have shown that if biogas is collected from the anaerobic fermentation of livestock and poultry manure, GHG emissions can be significantly reduced (Yu et al., 2015; Zhu et al., 2020). For example, a biogas project in one pig farm in Southern China with an annual output of 10,000 animals can reduce approximately 781 tonnes CO_2e (Yu et al., 2015).

BOX 6. Resource utilization of livestock and poultry manure

China has been actively promoting policies and regulations that encourage resource utilization of livestock and poultry manure. With the development of large-scale and intensive livestock and poultry farming, there is now the need for a model of centralized collection and resource utilization of manure and other agricultural waste by third-party companies.

The Zhenghe Environmental Protection Group, a manure management company in Jiangxi Province, has set up the "N2N" green environmental circular agriculture model. By collecting and treating manure from "N" upstream livestock farms, it can then provide biogas for power generation and supply "N" downstream crop farms with organic fertilizers, thus helping to build a green circular industry chain, while solving the environmental problem associated with manure contamination. The company's facility is located in the Ecological Agricultural Science and Technology Park in Liuhu town, Nanchang city, the facility collects and transports manure from 229 large-scale livestock farms and toilets in the nearby area. Annually, it handles 300,000 tonnes of manure, generating 5 million cubic metres of biogas and generating 10 million kWh of electricity. It produces 20,000 tonnes of various solid organic fertilizers, 260,000 tons of biogas slurry and 1,000 tonnes of soil conditioners. In one year, the amount of biogas it generates can save 7,400 tonnes of standard coal and 18,000 tonnes of carbon emissions[9].

9. Expert Interview

Feed management: adjust feed structure and feed additives

- **Adjust feed structure:** The use of good feed varieties can improve livestock digestion while reducing methane emissions (Sun et al., 2018; Yu et al., 2015; Zhang et al., 2012; Zou et al., 2011). For example, processing coarse feed materials through methods such as silaging, microstorage or ammoniation can reduce methane production (Na et al., 2011; Sun et al., 2018). Silage treatment of coarse feedstuffs can reduce methane emissions by 6-8% (Na et al., 2011). Appropriate addition of protein feeds can reduce the rate of rumen nutrient degradation, improve intestinal absorption of nutrients and inhibit rumen fermentation, thereby reducing methane emissions (Sun et al., 2018). Changing the concentrate-to-forage ratio of an animal's diet can affect methane emissions. A diet with a 60:40 concentrate-to-forage ratio produced 21 percent less methane than a diet with a 40:60 concentrate-to-forage ratio when the fodder all comes from maize stover silage (Na et al., 2011).

- **Add feed additives:** Adding allicin or tea saponin to feed can inhibit microbial fermentation in the rumen, reducing methane emissions by over 70 and 16 percent, respectively (Zou et al., 2011). The use of methane inhibitors can reduce methane production by about 25 percent (Zhang et al., 2012). Recent studies and experiments have shown that adding small amounts of red seaweed to beef cattle feed not only improves feed conversion, but also reduces methane emissions from enteric fermentation by 69.8 to 80 percent without compromising beef quality (Roque et al., 2021). Mitigation is therefore promising if applications are made going forward.

BOX 7. Change dairy cattle diets to reduce methane emissions

Planting a salt-tolerant crop, such as sweet sorghum, in saline soil and mixing it with corn to make silage for livestock farming, can improve land use and alleviate pasture shortages while boosting the feed absorption rate and reducing methane emissions.

This method is being applied on 5,000 mu of saline soil in northern Jiangsu Province. Dairy cattle feed is mostly made up of silage maize, but due to poor yields of maize from the local saline soil, in the past livestock farmers used to face grass shortages. Now, farmers intercrop sweet sorghum and silage maize, which are suitable for the varied levels of salinity found on local coastal land. After mixed harvesting, the crops are combined and ensiled, then sent to breeding farms. After the required nutritional supplements are added, this becomes the daily feed for dairy cattle. Silage handled this way is high in digestible nutrients and can improve milk quality[10]. Data show that using this intercropping sweet sorghum and silage maize model can give farmers an income of about 3,000 yuan per mu, an increase of 24 percent profit per mu, 11 percent higher milk production and all with lower methane emissions[11].

10. Zhang Ye (2022). Sweet Sorghum Paired with Green Corn: How to Build a Closed Loop of Technology, Cost, and Carbon Trading on Salt-Alkali Land? Science and *Technology Daily*, http://digitalpaper.stdaily.com/http_www.kjrb.com/kjrb/html/2022-12/12/content_545946.htm?div=-1

11. Ibid.

Agriculture digitalization: encourage precision in agricultural production and management

- **Promote precision agricultural technology:** The use of information and smart technologies to determine accurate data on factors that impact crop growth, such as weather and demand for crops as well as the sound use of resources, can improve agricultural production efficiency and reduce greenhouse gases (Balafoutis et al., 2017). One example is the use of variable rate fertilizer application, which can reduce emissions by 5 percent through precision fertilization (Balafoutis et al., 2017). An additional 10 percent reduction in GHG emissions can be achieved through the use of an automatic steering system with no-tillage or minimum tillage practices (Cillis et al., 2018). Precision farming is widely used in countries that have large-scale farms, such as the United States and Canada, but it is also popular in areas with scattered farm plots such as Japan. In China, precision farming pilots have mostly taken place in regions that have large-scale farms, such as Xinjiang, Heilongjiang and Jilin (Fang & Li, 2018). In the future, with technological improvements and research and development, it can be introduced to more regions.

BOX 8. Use of precision farming for chemical fertilizers and pesticides use reduction

With the rise of smart agriculture, information technologies such as big data and remote sensing drones have been adopted by farmers to help with precision planting and management of farmland and crops. For example, sensors can be used to collect soil and crop information as well as environmental data such as weather and temperature. These data are processed via big data analysis, yielding recommendations on tasks such as planting, irrigation and fertilization to improve yields and save energy.

One example of smart fertilization is a high-standard unmanned planting demonstration farm in Bufeng town, Yancheng, Jiangsu Province[12]. The 5,000-mu farm uses XAG's smart agricultural equipment, and is run by a three-person management team. Prior to planting, a remote sensing drone is used to map the farmland on a horizontal plane to obtain high-resolution maps. Based on these maps, farmland profiles are created in the system to carry out precision management of land plots. Remote sensing drones can be used in conjunction with AI models to analyze rice plant growth, identify seedlings, and monitor pests and diseases during the growth period[13]. In addition, drones can replace manual labor for precision fertilizer and pesticide application in the paddy fields. In Bufeng, smart agriculture has led to a 10 percent reduction in pesticide and fertilizer use per unit area on the farm compared to traditional farming models, while yields have risen by about 10 percent[14].

12. Sen Ning (2023). The Three Post-90s Generation Farmers Manage 5,000 Acres of Farmland in Jiangsu: Cultivating, Managing, and Harvesting Using Smart Agriculture Systems, *The Paper*. https://m.thepaper.cn/newsDetail_forward_19944206

13. Ibid.

14. XAG (2022), Extreme Vision Technology Corporate Social Responsibility Report 2022.

Energy saving and emission reduction in agricultural machinery

Improve energy efficiency of agricultural machinery: The energy consumption of agricultural machinery, such as that used in crop planting or livestock production, is a major source of carbon emissions from farming. Approximately 30 to 40 percent of China's total diesel consumption comes from the agricultural sector. Studies have shown that a 10 percent increase in the efficiency of agricultural machinery can reduce 9 to 10 million tonnes of carbon emissions annually (Zou et al., 2011). Emissions reduction in agricultural machinery relies on existing purchase subsidy policies to enhance machinery efficiency by measures including phasing out energy-intensive equipment and optimizing agricultural machinery (Dou, 2018; X. Liu et al., 2012).

- **Electrification of agricultural machinery:** Promoting the development of new-energy agricultural machinery can reduce emissions from the fossil fuel combustion. Despite the late domestic start, there is significant room for the application and promotion of electric agricultural machinery, including electric tractors, micro tillers, and lawn mowers in China, where there is limited land and a large population. In the future, as costs come down and pollution from batteries can be better controlled, the electrification of small and medium-sized agricultural machinery shows great potential for replacing traditional machinery (J. Wang et al., 2019).

BOX 9. Electrification of agricultural machinery in China

With the increasing mechanization of agriculture, the use of diesel fuel in farming machinery is on the rise. The shift towards electrification of agricultural machinery offers the potential to reduce diesel consumption and, in turn, lower carbon emissions and environmental pollution. As China advances its goals of green and low-carbon development and modernizing agriculture and rural areas, the exploration of electrifying farm machinery is accelerating.

In recent years, numerous domestic enterprises have initiated research and development efforts for electric tractors. In 2020, the National Agricultural Machinery Equipment Innovation Center introduced the country's first hydrogen fuel cell electric autonomous tractor[15]. Huanghe Jinma Tractor Factory, a subsidiary of Jiangsu Yueda Group, introduced two electric tractors in 2021: the YL254ET, suitable for light-duty operations in greenhouses and orchards, and the YU1004, designed specifically for paddy field plowing, sowing, and field management. Both of these electric tractors have entered small-scale production and are being used in practical applications[16]. Another company involved in the development of electric tractors is the Gansu-based Zhulong Machinery Manufacturing Co., Ltd. This company has developed a range of electric agricultural implements for the hilly and mountainous terrain in Gansu, including electric wheat seeders, electric cultivators, and electric fertilizer spreaders. They have established testing and demonstration sites in areas such as Dingxi and Linxia to carry out trials and demonstrations[17]. The electric soybean-corn integrated seeder, produced by the company in 2022, has received positive feedback in the market[18].

14. Tian Yilong & Chen Hui. (2020). 5G+ Hydrogen Fuel Electric Tractor Unveiled in Henan Province. *Henan Daily*. http://iot.china.com.cn/content/2020-06/18/content_41190201.html

14. Liu Qi. (2022). Hybrid tractor from National Agricultural Equipment Innovation Center rolls off the production line, China's tractors enter the electric era ahead of schedule. *35 Dou*. https://m.jiemian.com/article/7840604.html

14. Feng Zhengrui & Zhao Lan. (2022). Analysis of the technical advantages of electric agricultural machinery and suggestions for future work. *Agricultural Mechanization Information Network of China*.http://www.amic.agri.cn/secondLevelPage/info/31/147178

14. Ibid.

4.2. Mitigation opportunities: Farm-to-table

Green packaging: reduce food packaging and improve recycling

Reducing emissions from food packaging requires the simplification of packaging, using environment-friendly materials and improving the recycling of packaging (X. Yang & Cao, 2012). China's existing policies, including the New Plastic Ban and green packaging, have identified green packaging as the development direction for the packaging industry.

- **Simplify packaging and use biodegradable bio-based materials:** A study of GHG emissions from food packaging materials showed that cartons emit significantly less than plastic and glass on a per-serving basis, and single-serve food packaging emits significantly more than multi-serve packaging (Fresán et al., 2019). Cartons cannot completely substitute for other food packaging, and their wide-use also leads to more carton production and associated energy and water consumption and GHG emissions. Using pulping made from agricultural waste such as rice straw and wheat straw as packaging material can reduce CO_2 emissions by about 50 percent while preserving forests (X. Yang & Cao, 2012).

- **Recycle and reuse packaging materials:** For beverage packaging materials, mainly glass and aluminum cans, GHG emissions come primarily from the production stage, but through recycling management and reuse, the emissions of the material production can be reduced by 70 to 80 percent (Simon et al., 2016). With the prevalence of take-out food in China, an analysis of the environmental impact of take-out food packaging shows that while replacing plastic food containers with paper ones can reduce carbon emissions by 49 percent, it also generates a large amount of carton waste. The adoption of a shared container model, where reusable and recyclable containers are employed to replace traditional ones and all tableware is returned by consumers to a specified collection point for cleaning, would result in a 97 percent reduction in carbon emissions and a 67 to 93 percent reduction in other environmental pollutants (Y. Zhou et al., 2020).

BOX 10. Plastics food packaging reduction action

The production and consumption of plastics, as well as its end disposal, exacerbate plastic pollution and emit significant amounts of GHGs. Some companies have started to take action to reduce and reuse plastic packaging.

A firm called *Shuangti* has come up with a way to reuse food containers in colleges and universities to tackle disposable plastic waste generated by takeout food. They have set up on- and off-campus takeout platforms to collect and clean reusable food containers. As of December 2021, *Shuangti* reusable food containers had been used an average of 63 times. Studies found that when compared with a disposable container, the environmental load from the production and use (i.e., reusing, washing and sterilization) of an individual reusable container is higher. However, if the number of recycling times can reach 6-8 times, it can be comparable to the performance of disposable plastic lunch boxes with the same function or specification in terms of the overall environmental impact due to the reduction of waste generation. In the scenario of 63 uses, each use of a reusable container can save 91g CO_2e[19]. Shuangti estimates that each reusable food container can be used for one and a half to two years, and can be reused at least 150 times[20].

19. "Breaking Free from Plastic Restraints: Research Report on Circular Economy and Environmental Benefits of Takeout Food Containers." http://www.plasticfreechn.org.cn/upload/ueditor/20220511/202205111144068741.pdf

20. "The Challenges of Reducing Plastic Use in Takeout: Discoveries in 35 Million Takeout Orders", *Southern Weekend* (2022). https://new.qq.com/rain/a/20220602A0857A00

Green cold chain: promote low GWP refrigerants and light freight electrification

Although the expansion of cold chain logistics can extend the shelf life of perishable food and therefore reduce food waste caused by food spoilage, the use of high GWP HFCs refrigerants (e.g. HFC-134a, HFC-404A, HFC-407C, HFC-507A, etc.) brings about significant F-gases emissions. A study focused on replicating the cold chain development models of North America and Europe in sub-Saharan Africa shows that when additional cold chains still use high GWP refrigerants, emissions from refrigerant leakage remain even higher than those from the food waste avoided by cold chain use (Heard & Miller, 2018). Therefore, it is still necessary to promote low GWP refrigerants in cold chain logistics.

Furthermore, control of HFC production and consumption under the Kigali Amendment, which has been ratified by China, will also advance the promotion and application of environmental-friendly low GWP refrigerants. HFC refrigerants currently still predominate in the refrigeration equipment used in cold storage, cold cabinets and refrigerated trucks in China's fresh food cold chain logistics. In the future, the R&D and promotion of low GWP refrigerants, represented by ammonia (R717), carbon dioxide (R744), propane (R290), and HFOs synthetic refrigerants, will provide an alternative to HFC refrigerants.

- **Promote ammonia refrigerant R717 in large-scale cold storage:** Although different refrigeration systems and refrigerants are adopted in cold storages under different temperatures, the main refrigerants used in Chinese cold storage are R22, R404A, R507A and R717, the first three of which are HFCs. About half of the newly-built cold storage units in China after 2013 are still using R507A, another 30 percent use refrigerants blended with R744, and 15 percent use R717 (Gao et al., 2021). Although R717 has leakage risk, it can be rapidly applied and promoted after technical measures are taken to reduce the charging amount of the refrigerating system and to ensure its safe operation (Y. Yang & Fan, 2020).

- **Promote clean energy and low GWP refrigerants in refrigerated transportation:** The increasing demand for fresh food has led to the rapid development of cold chain logistics, with the number of refrigerated trucks rising from 75,000 in 2014 to 180,000 in 2018, and sustaining an upward trend as the market expands (Dong et al., 2021). Currently 90 percent of refrigerated trucks rely on mechanical refrigeration systems, mainly diesel (Wu, 2020). Among refrigerants for refrigerated trucks, R134a is dominant for medium temperature refrigeration and R404A for low temperature refrigeration, both of which belong to high GWP HFCs refrigerants (Gao et al., 2021). If a low GWP refrigerant, such as R744, is used in refrigerated vehicles, the fuel consumption and direct carbon footprint are significantly reduced compared to R134a under the same cooling capacity (Wu, 2020). Research has also shown that the use of energy-efficient and environment-friendly refrigerants can reduce the carbon emissions of refrigeration systems in refrigerated vehicles by 48 to 100 percent, and that reducing the running time and weight of the refrigeration system, and employing clean energy, can reduce the total carbon footprint of refrigerated vehicles by 16.5 to 63.4 percent (Wu, 2020).

- **Promote CO_2 (R744) refrigerants in supermarket refrigerators:** R22 and R404A are the main refrigerants used in China's supermarkets, accounting for 51 and 32 percent, respectively (Gao et al., 2021). The future alternative refrigerants are mainly CO_2 refrigerants (R744), which have been adopted by 29,000 supermarkets in Europe and 5,000 supermarkets in Japan (Gao et al., 2021). The disadvantage of this refrigerant is that energy efficiency will be reduced at high temperatures. Studies of CO_2-based refrigerants in Chinese supermarkets have shown an emissions reduction potential of 13 to 53 percent by replacing conventional refrigerants. Their promotion in northern Chinese cities appears to be more cost effective regarding technical factors (Cui et al., 2020). However, with technological improvements, there is still potential for replication in other regions of China.

BOX 11. The first mile to keep agricultural products fresh – mobile cold storage

Development of cold chain transportation can reduce losses and waste from not promptly preserving freshly-harvested produce. Therefore, the development of cold chain infrastructure should be the first step in handling agricultural products.

The development of cold-chain transportation of agricultural products can reduce the loss and waste of freshly harvested agricultural products that are not preserved in a timely manner. Therefore, developing cold-chain infrastructure for the first mile of agricultural production should not be overlooked.

China's largest asparagus farming complex is located in Lianshui, a county-level city in Jiangsu province, which produces 30 percent of domestic asparagus. To preserve the freshness of asparagus, which is not easy to store, the local power supply department has set up a mobile cold storage for pre-cooling the asparagus after it is picked but before it can be delivered to cold storage[21]. In order to avoid the aging of asparagus after picking under high temperature, State Grid Lianshui County Power Supply Company provided mobile cold storage for asparagus growers[22]. The mobile cold storage units can be driven directly to the farm to quickly lock in the freshness of the newly picked asparagus. Placing asparagus in the mobile cold storage within 10 minutes of harvesting can reduce losses by 20 to 30 percent and extend the freshness period of pre-cooled asparagus by about three days[23].

The area of the mobile cold storage is about 10 square meters, which is installed on a pure electric flatbed truck and powered by a set of UPS (Uninterruptible Power Supply) power supply. The UPS power supply can be used to cool a two hp compressor in the refrigerated compartment for about one hour, and there are one or two sets of backup battery packs at the same time. The vehicle and batteries can be recharged on a daily basis using a 200-volt power supply[24].

4.3. Food consumption emission reduction opportunities

Resource utilization of kitchen waste: biogas recovery from anaerobic digestion

Methane produced from catering and food waste disposal is the main greenhouse gas emitted during food consumption. Existing policies and technologies provide opportunities for emissions reduction from kitchen waste.

- Household waste sorting promotes kitchen waste recycling: Under China's ongoing policy measures to separate household waste and recycle kitchen waste, the amount of mixed waste that ends up in landfill or incineration, as well as the resulting methane emissions, can be reduced if kitchen waste is sorted separately for treatment and disposal. Also, resource utilization of kitchen waste can reduce GHG emissions if the sorted kitchen waste can be treated by conversion to feed, anaerobic digestion or aerobic composting. Taking the ongoing food waste separation as an example, research shows that every 20 percent increase in the food waste sorting rate leads to an additional 5 to 7 percent reduction of carbon emissions from household waste (H. Li et al., 2021).

- Biogas recovery through anaerobic digestion of kitchen waste: For different food waste treatment modes, anaerobic digestion and aerobic composting have shown greater potential for recycling and have been promoted in Europe and the

21. "Asparagus is Grown Fresh in the Fields with Mobile Refrigeration Units". Lianshui News (2022). http://www.lianshui.gov.cn/col/888_535372/art/16592832/1661473369941zq5m3ixU.html

22. "Mobile Refrigeration Units Arrive in the Fields to Keep Asparagus Fresh During Hot Weather". Renminhao (2022). https://rmh.pdnews.cn/Pc/ArtInfoApi/article?id=30629111

23. "A 'Refrigerator' in the Fields! Asparagus is Harvested Ahead of Time in Hot Weather". Hubei News (2022). http://news.cnhubei.com/content/2022-08/23/content_15000843.html

24. "Mobile Refrigeration Units Arrive in the Fields to Keep Asparagus Fresh During Hot Weather". Renminhao (2022).

U.S. (K. Wang et al., 2020). In the carbon emission analysis of food waste in these two treatment modes, the carbon reduction effect of anaerobic digestion is more significant, ranging from 65 to 209 kg CO_2e/t. The net carbon emissions from aerobic composting of food waste are 165 kg CO_2e/t due to more GHG leakage during aerobic composting (H. Li et al., 2021). In China, many currently operating kitchen waste treatment projects have been using anaerobic digestion. However, due to the complex composition of kitchen waste, the application of anaerobic digestion for kitchen waste still faces problems such as low biogas production and high operating costs (K. Wang et al., 2020). Nevertheless, there is potential for market application if efficient and stable operation can be achieved. There is still a large gap in China's kitchen waste treatment. Even if the kitchen waste treatment projects in the 13^{th} Five-Year Plan are completed and put into operation as scheduled, the kitchen waste treatment rate will only be 20 percent. Therefore, there is considerable mitigation potential with the improvement of kitchen waste treatment capacity and anaerobic digestion technology.

BOX 12. Biogas recovery from kitchen waste [25]

There are multiple ways for biogas to be recovered from kitchen waste treatment, including power generation, cogeneration, or purification and upgrading as vehicle fuel. But given the complex composition of kitchen waste, there are limited options for using solid or liquid digestates. Therefore, the newly built treatment projects need to consider the treatment costs and the application scenarios of these digestates.

A kitchen waste treatment project located in the village of Dongnanshe in Taiyuan, Shanxi Province, covers an area of 11.4 acres and has a treatment plant with a daily treatment capacity of 500 tons. The first phase of project, which was put into trial operation in 2017, collected kitchen waste in six districts of Taiyuan and Qingxu counties with daily treatment capacity of 200 tons.

The project was built under a BOT (Build-Own-Transfer) model, with a franchising period of 30 years. Operated by Taiyuan Tianrun Bioenergy Company, the total project investment is RMB 311 million yuan. According to the franchise agreement, the local government pays RMB 309 yuan per ton for kitchen collection and treatment.

The project is currently in operation with a daily restaurant waste collection and treatment capacity of over 200 tons and annual biogas output of over 6 million m^3, which is upgraded to bio natural gas. Another major product is raw oil from oil-water separation. The liquid digestates from kitchen waste treatment are transported to a wastewater treatment plant and solid digestates are transported to an incineration plant in an industrial park.

25. "Good Practices for Urban Solid Waste and Municipal Sludge Treatment in China", iGDP (2021)

Dietary shift: promote dietary guidelines

A well-balanced diet is not only good for public health, it also helps with reducing GHG emissions (Jarmul et al., 2020; Tilman & Clark, 2014). For example, a diet rich in vegetables, grains, and fruits with a reasonable control of meat consumption can reduce the risk of diabetes, cancer, and cardiovascular disease, and mitigate GHG emissions by 30 to 55 percent (Tilman & Clark, 2014)

- **Promote dietary guidelines:** China has published the China Food and Nutrition Development Outline (2014-2020) and regularly updates the Dietary Guidelines for Chinese Residents, both of which promote healthy diets for the public. The Outline shows that appropriate control of meat consumption based on the promotion of a diversified dietary structure has a mitigation potential of 0.53-222 million tons of CO_2e per year (Song et al., 2017). A 2021 report published by AGFEP shows that in a baseline scenario without any dietary recommendations, trends in China's dietary structure will lead agricultural GHG emissions to increase by 85.44 million tons or 12 percent in 2030 compared to 2020 (AGFEP, 2021). If the Chinese Food Pagoda and the EAT-Lancet healthy diets were followed, in contrast, dietary restructuring would reduce agricultural GHG emissions by 146-202 million tons, or 18 to 25 percent, in 2030 compared to the baseline scenario (AGFEP, 2021). It is important to note that any dietary restructuring to reduce GHG emissions must also maintain nutritional health.

BOX 13. East Asian healthy diet model – the Jiangnan diet

Dietary patterns vary across China due to geography, climate and culture. To promote better nutrition and prevent chronic diseases through balanced diets, the Chinese Nutrition Society regularly publishes dietary guidelines for the public. In the 2022 edition of the guidelines, the diets of the Jiangnan region of China, represented by Zhejiang, Shanghai and Jiangsu, are promoted as one of the 'East Asian Healthy Dietary Patterns.'

The *Scientific Research Report on Dietary Guidelines for Chinese Residents (2021)* describes the Jiangnan diet as one that is based on rice, with a higher intake of fish and shrimp, a lower intake of pork, and lightly cooked with less oil and salt. People who follow this diet have a greater life expectancy and a lower risk of diseases such as obesity, type 2 diabetes and metabolic syndrome[26].

The Jiangnan diet has also been described as the "five more and three less" diet: specifically, more white meat (such as chicken, duck, goose and fish), more nuts, more whole grains, more fruits and vegetables and more steaming; less deep frying, less sugary and rich food, and less refined rice[27].

26. "Scientific Research Report on the Chinese Resident Dietary Guidelines." China Nutrition Society (2021).

27. "Why is Jiangnan Cuisine Known as 'China's Healthiest Diet'"? *The Paper* (2021). https://m.thepaper.cn/newsDetail_forward_12508999

Food waste reduction: promote green consumption

Reducing consumer food waste not only reduces GHG emissions from disposing of food waste, but also reduces the demand for food production and resulting emissions. An analysis of food loss and waste in China showed that between 2014 and 2018 the country's average annual GHG emissions due to food loss and waste came to about 464 million tonnes of CO_2e, with more than 200 million tonnes of CO_2e coming from food waste at the consumption level (Xue et al., 2021). The analysis also shows that a 50 percent reduction in food waste at the consumption level is equivalent to a 50 percent reduction in food loss and waste at the retail level of food production and transportation. Greenhouse gas emissions based on different dining scenarios also show that that the highest GHG emissions per person per meal are wasted in restaurants, followed by cafeterias, takeaways, and then dining at home (Tsinghua University School of Environment et al., 2023). Therefore, actively promoting anti-food waste practices among individuals and food service sector can sustainably reduce the resulting emissions. Efforts in this direction include the "Clean Plate Campaign," which has been running since 2013, as well as restaurants and takeaway platforms beginning to include smaller portion options in recent years.

BOX 14. Business innovation to reduce food waste

Shelf life was created along with the food industry, and near-expired food is food that is about to reach the expiration date but has yet to expire. In principle, the quality of food is guaranteed as long as it is within its expiration date, but near-expired food is nevertheless difficult to sell and often ends up being discarded. With the rise of sustainable consumption, Hotmaxx is one of several companies and supermarkets that are reducing food waste from near-expired food products.

Since its establishment, Hotmaxx has been helping consumers develop sustainable consumption concepts and lifestyles by leveraging the turnover of surplus resources. In 2021, more than 400 Hotmaxx outlets across the country served a total of more than 13 million customers and circulated more than 300 million items, directly reducing more than 70,000 tonnes of food waste, equivalent to saving about 140,000 tonnes of carbon emissions[28]. In August and September 2022, Hotmaxx partnered with DBS Bank in holding a Zero Waste Month, when they connected offline stores with social media platforms, and invited seven bloggers with 5 million followers and 100 Key Opinion Consumers (KOCs) to promote the idea of "No Food Waste" to consumers. More than 40,000 people participated in the event, saving more than 122 tons of food from being wasted, equivalent to reducing 243.8 tons of GHG emissions[29].

28. "HotMaxx Leading Low-Carbon Consumption, Creating a Better Life". Qilu Evening News (2022).

29. Ibid.

5. GREENHOUSE GAS EMISSION SCENARIOS FOR CHINA'S AGRI-FOOD SYSTEM

照片： Marta Markes on Unsplash

This section describes three scenarios that illustrate alternative emissions and mitigation trajectories for China's agri-food system. The three scenarios vary in terms of policy ambition and mitigation practices.

5.1. Three scenario settings

- Reference Scenario (RS): In this scenario, GHG emissions from the agri-food system are estimated based on China's current pathway for economic and social development and green low-carbon transition.
- Enhanced Action Scenario (EAS): This scenario maps out a mitigation pathway with the continuation and enhancement of green and low-carbon actions that have already been implemented, as well as cost-effective mitigation actions that have not yet been adopted.
- Deep Decarbonization Scenario (DDS): This scenario describes a deep decarbonization pathway with the adoption of all feasible mitigation actions based on international and domestic mitigation practices. It includes actions that go beyond ones in EAS and includes, 1) higher-cost mitigation practices, 2) low-cost mitigation actions at a greater speed and coverage, and, 3) mitigation actions from behavioral changes on the consumption side.

TABLE 4. Key assumptions for GHG emission scenarios for China's agri-food system

EMISSIONS SOURCE	REFERENCE SCENARIO		ASSUMPTIONS FOR EAS	ASSUMPTIONS FOR DDS
	EMISSIONS UNDER RS IN 2030 (%)	EMISSIONS UNDER RS IN 2060		
Agricultural production	57.2%	68.7%	• Emission reduction from livestock farming: promote biogas recovery from livestock and poultry manure and large-scale livestock farming; promote animal breeding, and use of feed supplements including tea saponins and probiotics. • Emission reduction from rice cultivation: improve irrigation management, i.e., alternate wetting and drying irrigation. • Emission reduction from farmland: advance soil testing-based fertilizer use and conservation tillage. • Emission reduction from agricultural inputs: promote biodegradable agricultural films and adjust nitrogen fertilizer production in response to the decline in nitrogen fertilizer use. • Emission reduction from agricultural energy consumption: improve the energy efficiency of agricultural machinery.	• Emission reduction from livestock farming: consider dietary shift based on the EAS; adopt supplement feed with tea saponin, probiotics and lipids. • Emission reduction from rice farming: improve irrigation management and promote dry direct seeding of rice. • Emission reduction from farmland: promote the use of slow-release fertilizers and fertilizer enhancers based on the EAS. • Emission reduction from agricultural inputs: increase efforts to promote biodegradable agricultural films, further improve the energy efficiency of pesticide and fertilizer use per unit. • Emission reduction from agricultural energy consumption: improve the energy efficiency and promote the electrification of agricultural machinery.
Food processing	8.7%	5.2%	• Improve energy efficiency in food processing.	• Improve energy efficiency and energy substitution in food processing.
Food packaging	5.8%	5.6%	• Use biodegradable materials for plastic packaging. • Encourage the replacement of plastic food containers with paper cartons. • Improve the recycling of paper cartons.	• Advance the use of biodegradable materials in plastic packaging, encourage the use of recycled plastics for food containers. • Improve recycling rates for cardboard boxes and use a higher proportion of wastepaper for packaging.

TABLE 4. Key assumptions for GHG emission scenarios for China's agri-food system

EMISSIONS SOURCE	REFERENCE SCENARIO		ASSUMPTIONS FOR EAS	ASSUMPTIONS FOR DDS
	EMISSIONS UNDER RS IN 2030 (%)	EMISSIONS UNDER RS IN 2060		
Food transport	5.7%	4.5%	• Improve the energy efficiency of transportation. • Promote low GWP refrigerants in cold chain.	• Increase the proportion of food transportation that is electrified, improve energy efficiency and promote the electrification of light freight transport. • Continue to promote low GWP refrigerants in the cold chain.
Food retail	0.4%	0.3%	N/A	N/A
Food cooking	13.7%	10%	• Improve the energy efficiency of cooking.	• Further optimize the energy use structure for cooking.
Kitchen waste disposal	8.5%	5.7%	• Promote a higher waste sorting rate and resource utilization of food waste. • Incinerate food waste to generate energy.	• Further improve resource utilization of food waste based on the EAS. • Incinerate food waste to generate energy.

5.2. Key findings

1. GHG emissions from China's agri-food system will continue to grow in the reference scenario

In the reference scenario, GHG emissions from China's agri-food system continue to grow under existing mitigation measures, and total GHG emissions are 30% higher in 2060 compared to the 2019 level. GHG emissions from agricultural production continue to grow, while emissions from food processing, transportation, retail, cooking, and waste disposal show a slow downward trend after peaking, due in large part to energy efficiency improvements.

GHG growth mainly comes from methane and nitrous oxide emissions, which continue to grow in this scenario. Between 2019 and 2060, CH_4 emissions increase from 519 million tons of CO_2e to 1 billion tons, while N_2O emissions increase slowly from 273 million tons of CO_2e to 330 million tons. In addition, F-gases emissions continue to grow until around 2040 and then slowly decline. CO_2 emissions, however, begin to gradually decrease after 2030.

TABLE 7. Projected GHG emissions by agri-food system component under the reference scenario (Mt CO_2e)

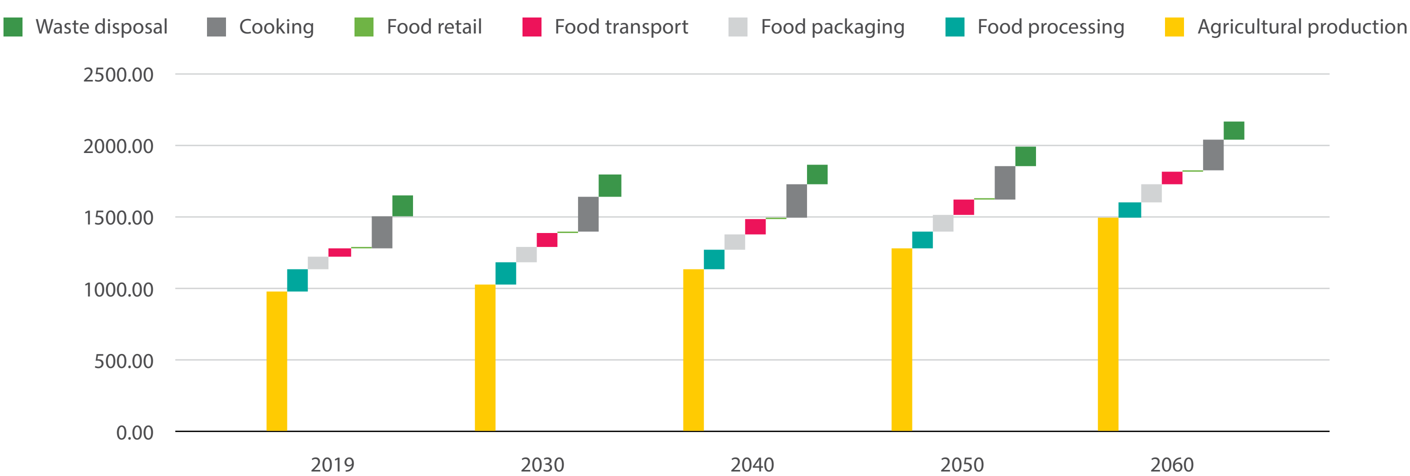
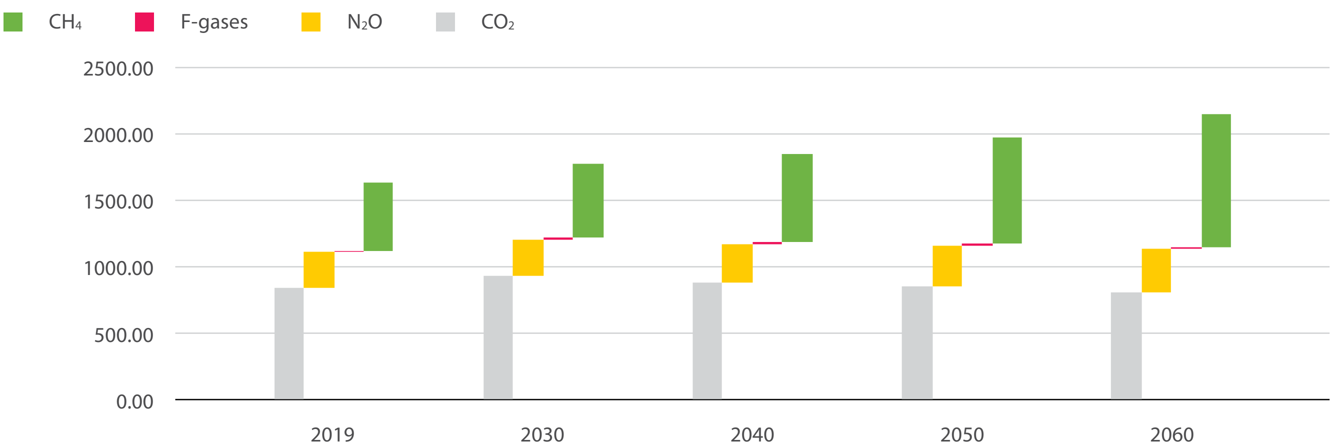


TABLE 8. Projected GHG emissions by gas in China's agri-food system under the reference scenario (Mt CO_2e)



2. Carbon neutrality challenges in China's agri-food system

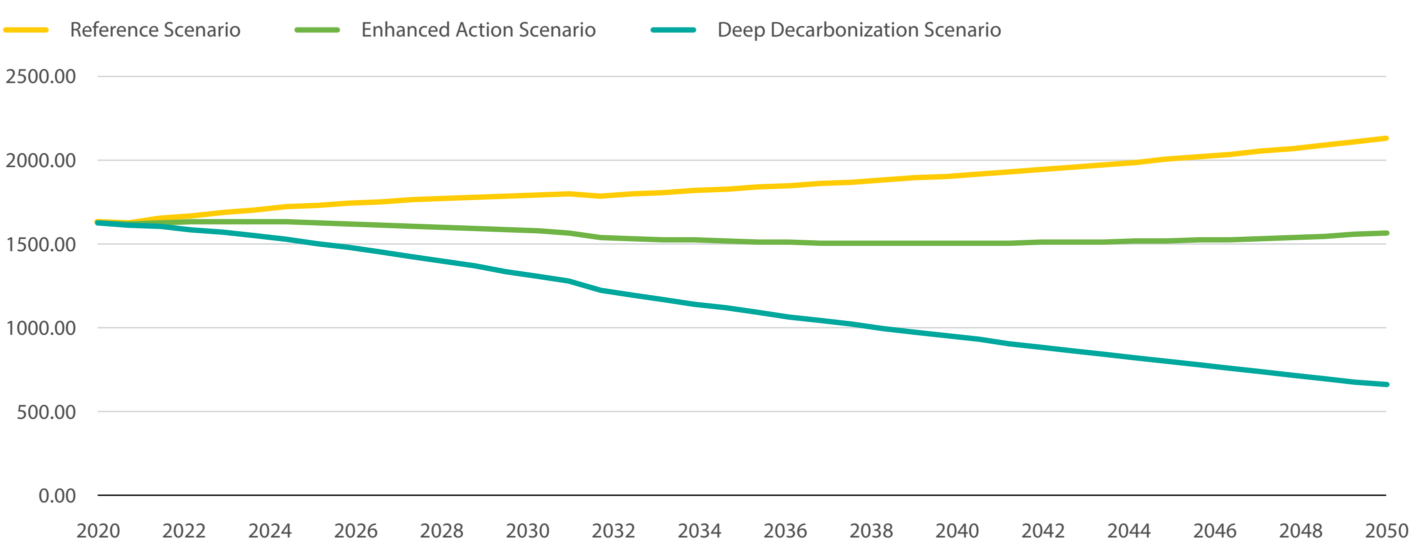
Figure 9 shows GHG emissions pathways for China's agri-food system under different scenarios. Under the reference scenario, GHG emissions are 1.646 billion tons of CO_2e in 2019, increasing to 1.789 billion tons of CO_2e in 2030 and 2.162 billion tons of CO_2e in 2060.

Under the enhanced action scenario, GHG emissions from China's agri-food system start to gently decline from around 2025 to 1.614 billion tons of CO_2e in 2030 and to 1.58 billion tons of CO_2e in 2060, a 36 percent reduction compared to the 2060 level under the reference scenario. GHG emissions under this scenario maintain a small increase up to about 2048, mainly attributed to GHG emissions from livestock management.

Under the deep decarbonization scenario, GHG emissions from China's agri-food system are already on a gradual downward trend from 2020. They decrease to 1.408 billion tons of CO_2e and 651 million tons of CO_2e by 2030 and 2060, respectively, which in 2060 is 70 percent less than under the reference scenario. However, this scenario still fails to achieve near-zero emissions.

The GHG emissions pathways under the three different scenarios are shown below:

TABLE 9. Projected GHG emissions in China's agri-food system under three scenarios (Mt CO_2e)



Mitigation potential by agri-food system component under the three scenarios:

FIGURE 10. Mitigation potential by agri-food system component in the enhanced action and deep decarbonization scenarios (Mt CO_2e)

Mitigation potential by gas under the three scenarios:

FIGURE 11. Mitigation potential by gas in China's agri-food system under the enhanced action scenario and deep decarbonization scenario (Mt CO_2e)

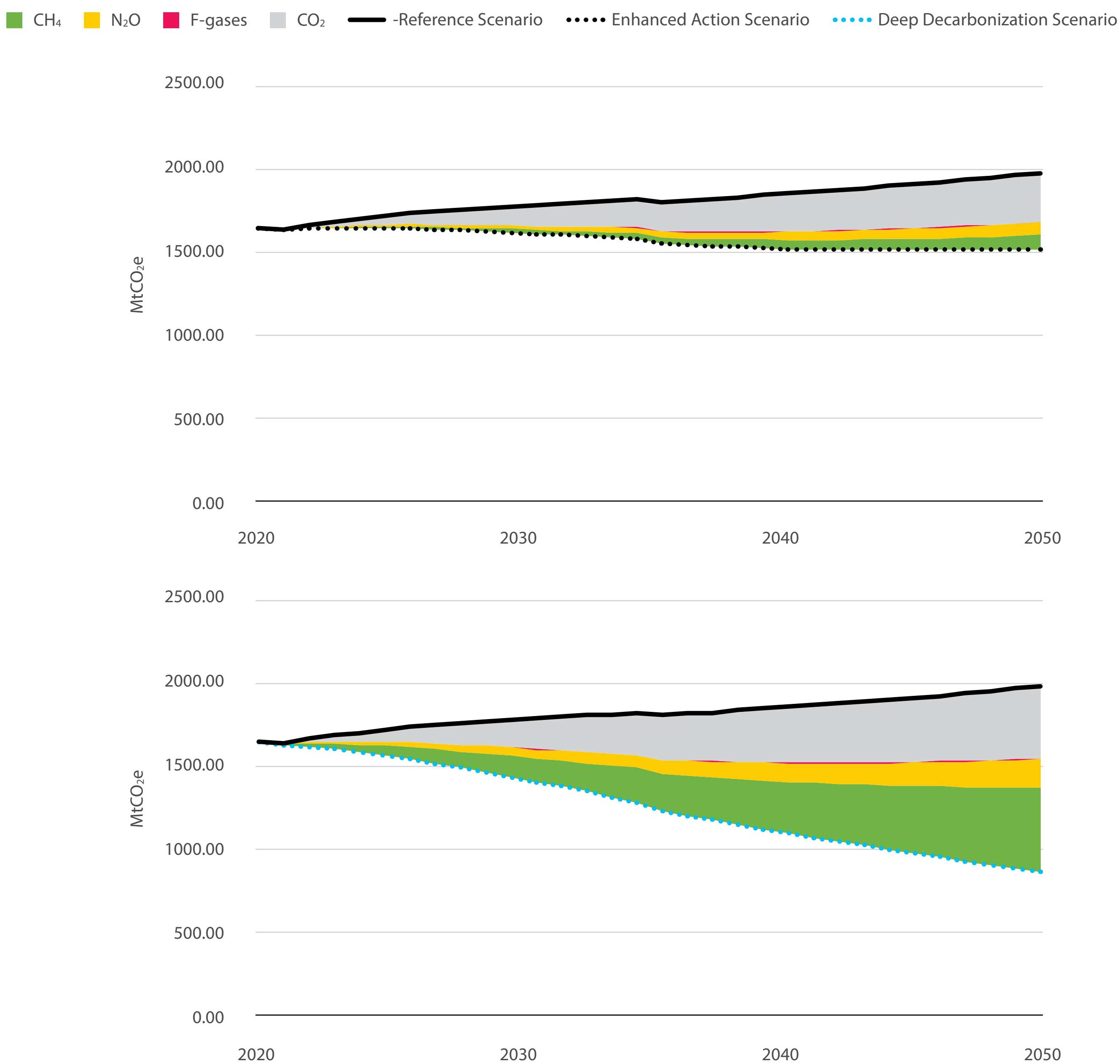


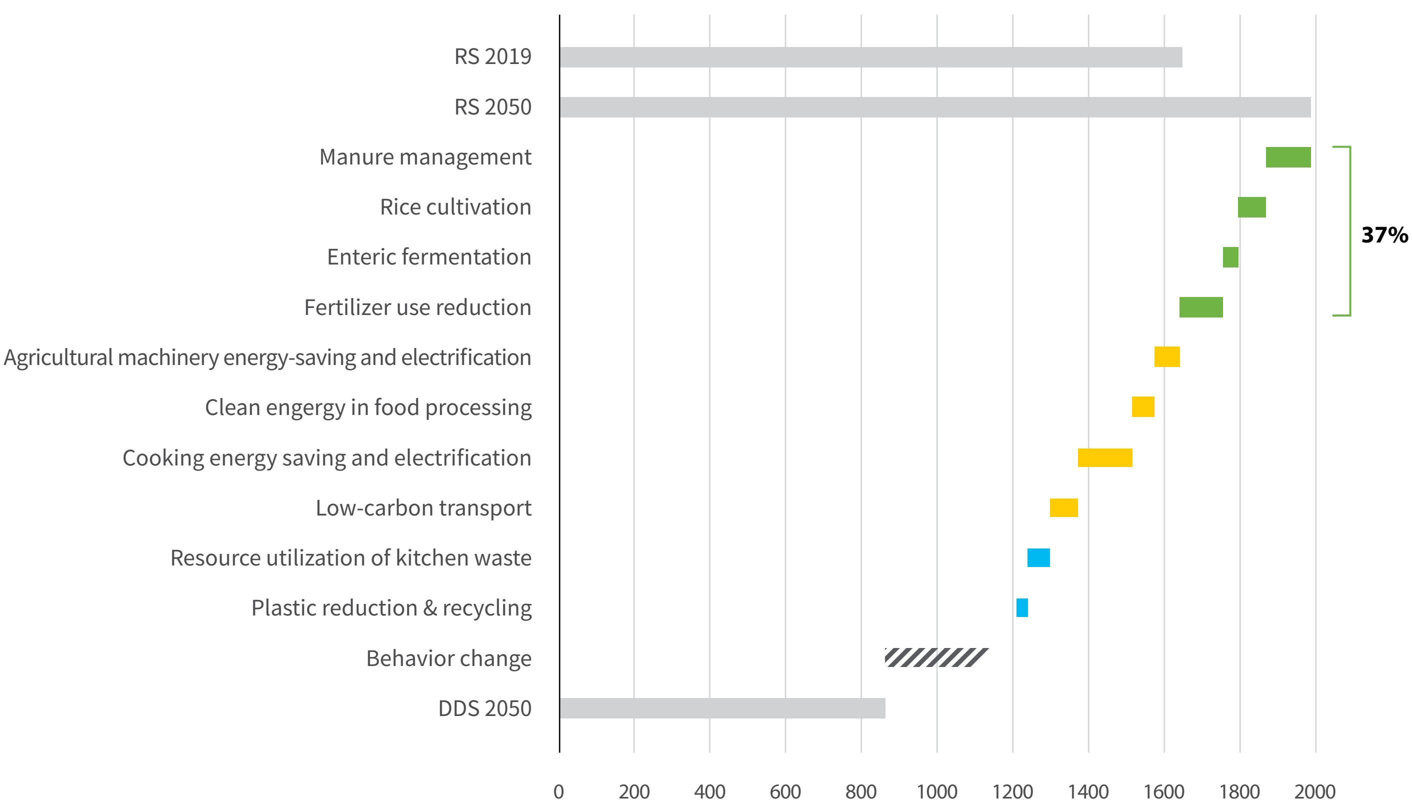
TABLE 5. GHG emissions mitigation by gas under enhanced action and deep decarbonization scenarios

	ENHANCED ACTION SCENARIO 2050 VS. 2019	DEEP DECARBONIZATION SCENARIO 2050 VS. 2019
CH_4	Increase by 40%	Decrease by 43%
N_2O	Decrease by 14%	Decrease by 50%
F-gases	Peak around 2030 and then slowly decrease to 2020 level	Peak around 2030 and then slowly decrease to 2020 level
CO_2	Decrease by 34%	Decrease by 50%

3. GHG emissions reduction for the agri-food system calls for systematic change

As illustrated below, focusing only on reducing emissions from agricultural production will not achieve carbon neutrality in China's agri-food system. In 2050, only 37 percent of the mitigation potential in the agri-food system will come from agricultural production. A great effort will have to be made to unlock the large mitigation potential in other stages of the agri-food system.

FIGURE 12. Mitigation potential of major reduction actions under the deep decarbonization scenario



4. China's existing green development actions could unlock two-thirds of its mitigation potential

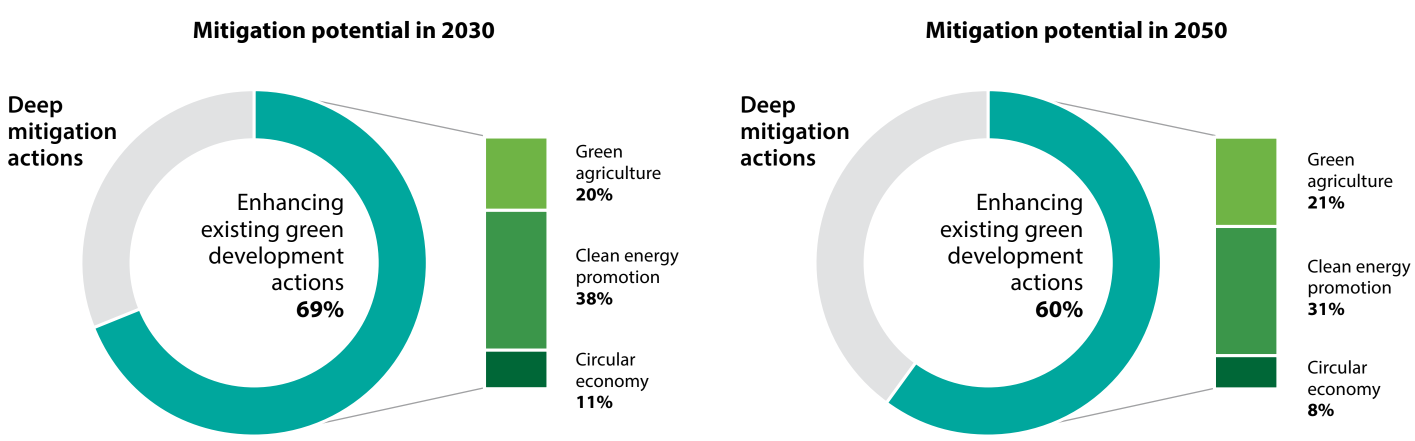
As shown in Figure 13, 69 and 60 percent of mitigation potential in 2030 and 2050, respectively, will come from enhancing existing green development actions, including actions in green agriculture, clean energy promotion and the circular economy designed to address environmental pollution and protect public health. The remaining one-third comes from strengthening low-carbon actions, including low-carbon agricultural actions and behavioral change at the food consumption end.

The green development actions can be categorized as shown in Table 6:

TABLE 6. Categories of green development actions

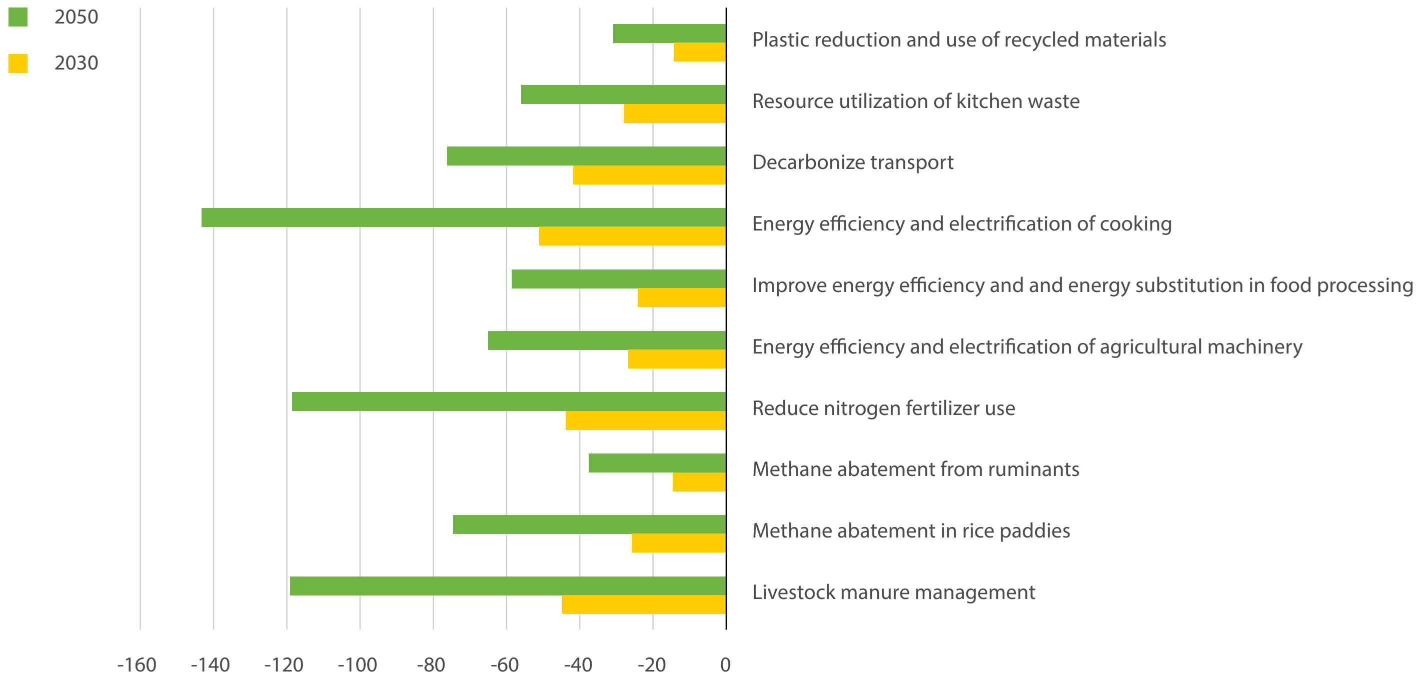
MITIGATION ACTIONS		ENHANCE EXISTING GREEN DEVELOPMENT ACTIONS
Green development actions	Green agriculture	Resource utilization of livestock and poultry manure
		Soil testing and conservation tillage
		Promote the use of environmentally friendly biodegradable films
		Reduce pesticide consumption
	Clean and modern energy systems	Energy efficiency improvement and electrification of agricultural machinery
		Energy efficiency improvement and energy saving in food processing
		Energy efficiency improvement and electrification of light freight transportation in food transport
		Reduce energy consumption and electrification in cooking
	Circular economy	Use of recyclable and biodegradable packaging materials
		Household waste sorting and resource utilization of kitchen waste

FIGURE 13. Mitigation potential of green development actions under the deep decarbonization scenario



5. Mitigation potential of major measures

FIGURE 14. Mitigation potential of major measures under the deep decarbonization scenario (2030 and 2050)



5.3. Major mitigation actions in China's agri-food system

Based on the 2050 GHG reduction potential under the deep decarbonization scenario, we identify the following ten priority actions and the main obstacles they are facing.

TABLE 7. Major mitigation actions in the agri-food system

PRIORITY ACTIONS	MAJOR MEASURES	MITIGATION POTENTIAL IN 2050	MAIN OBSTACLES
AGRICULTURAL PRODUCTION			
Nitrogen fertilizer use reduction	Use of nitrification inhibitor and slow-release fertilizer, conservation tillage, knowledge-based nitrogen management	10%	Lack of strong economic incentives
Manure management	Biogas recovery	11%	Lack of economic incentives
Methane mitigation in rice fields	Irrigation management, dry direct seeding	6.6%	Lack of low-cost technology; Implementation difficulty
Emissions mitigation in enteric fermentation	Animal breeding, feed additives	3%	Lack of low-cost technology
Agricultural machinery energy-saving and electrification	Agricultural machinery energy efficiency improvement and electrification	5.8%	Lack of policy and standards guidance for agricultural machinery electrification

TABLE 7. Major mitigation actions in the agri-food system

PRIORITY ACTIONS	MAJOR MEASURES	MITIGATION POTENTIAL IN 2050	MAIN OBSTACLES
FARM TO TABLE			
Clean energy application in food processing	Energy efficiency improvements	5%	Lack of policy guidance
Low-carbon transportation	Transportation energy efficiency improvements, freight electrification, low-GWP refrigerants	7%	Lack of policy guidance
Plastic reduction and recycling	Recyclable packaging, biodegradable packaging materials	2.8%	Implementation difficulty
FOOD CONSUMPTION			
Cooking energy-saving and electrification	Cooking energy efiiciency improvement and electrification	12.8%	Lack of economic incentives
Kitchen waste resource utilization	Waste sorting and kitchen waste resource utilization	5%	Lack of economic incentives for the scale development of waste recycling
Dietary shift and behavioral change*	Plant-rich diets, eating local	-	Implementation difficulty

Note: * Dietary shift mainly refers to reducing animal-based food consumption and encouraging local food consumption, which can reduce emissions from agricultural production and food transportation. Considering the large uncertainty surrounding behavioral change, quantitative analysis is not performed here. Numerous studies have shown that reducing animal food consumption has large emissions reduction potential, a dynamic that deserves greater attention.

6. POLICY SUGGESTIONS

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- **Develop an integrated carbon neutrality strategy for the agri-food system**

  Since food production and consumption involve multiple sectors – agriculture, transportation, industry and waste – an integrated carbon neutrality strategy for the agri-food system as a whole can provide a comprehensive approach to reduce GHG emissions, help coordinate cross-sector mitigation actions and promote stakeholder participation.

- **Establish a GHG emissions database for the agri-food system to support scientific decision-making and behavioral change**

  The database should include data on GHG emissions from the agri-food system classified by stage and by gas, as well as environmental data on associated activities. Reliable GHG emissions data can provide support for mitigation policies in the agri-food system, and environmental and carbon data labelling can facilitate behavioral change. China's 2021 Updated National Determined Contribution (NDC), which proposes gradually establishing a non-CO_2 GHG emissions inventory system, as well as a policy framework and management system for non-CO_2 GHG emissions, can also provide policy support for agri-food emissions data collection and analysis. China's work on product carbon labeling could also extend to the agri-food system and include carbon information in the existing labelling systems for ecological food and green food.

- **Strengthen existing green and low-carbon actions in the agri-food system to achieve further GHG mitigation, especially methane reduction**

  Numerous policies have been created to promote green agricultural development both in China's NDC and domestic policy documents, such as reduction of chemical fertilizer and pesticide use, collection and biogas recovery, promotion of organic fertilizers, and promotion of knowledge-based N management and green agricultural machinery. Optimizing existing policies and measures, especially by strengthening methane reduction in existing actions, can not only mitigate agricultural pollution, protect agricultural resources, and improve the quality of agricultural products, but also reduce GHG emissions with cost-effective measures.

- **Promote energy efficiency and low-carbon transformation in the agri-food system**

  GHG emissions from energy consumption at different stages of the agri-food system, such as farm machinery, food processing, transportation and cooking, cannot be ignored. It is recommended to enact relevant policies to accelerate the electrification of agricultural machinery, including market-driven adoption of electric tractors, mini-tillers, and lawnmowers. Priority should be given to the use of renewable energy sources, particularly in the replacement of clean cookstoves in rural areas, with government subsidies and incentives to encourage the widespread adoption of high-efficiency household appliances. Transitioning to green and electric transportation in the food cold chain and freight logistics can also effectively reduce carbon emissions from conventional energy consumption.

- **Promote innovative agricultural practices such as community-supported and regenerative agriculture**

  Different types of sustainable agriculture should be explored to improve the resilience of the agri-food system in the face of resource scarcity, environmental pollution and climate change. For example, in addition to industrial agricultural production, given China’s smallholding farmer dominated agriculture, policymakers should promote community-supported agriculture, which can provide healthy food for consumers and financial support for producers. Another example is promotion of regenerative agricultural practices such as conservation tillage and cover crops to improve soil health. In addition, development of mitigation technologies in the food sector requires more private capital to promote technology adoption at scale, while commercialized mitigation technologies and practices require government support to reduce the cost of technology adoption.

  Consumers, as the end users of food, have a decisive influence on the scale and structure of food production and the way food is served, making changes in consumer behavior an important part of the equation. The promotion of initiatives such as food waste reduction and dietary shift, for example, can mitigate emissions in the agri-food system. Importantly, policy design needs to consider the impact on disadvantaged groups, ensure consumer access to affortable, safe and healthy food, and make the transformation of the agri-food system more inclusive.

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