Towards a low-emission agrifood sector in the People's Republic of China

A country profile

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Photo by Patrick Shepherd/CIFOR
Water towers project in Mau Forest

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Summary

Climate change has become a major threat to global development. Agriculture is considered a major contributor through the emission of greenhouse gases (GHG) such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). To feed its large population while reducing its carbon footprint, China's agriculture must be transformed into low-emission agriculture. China is making efforts towards this goal but is facing significant challenges. This report compiles and analyses four groups of literature relating to China's efforts to advance low-emission agriculture: (i) past and projected GHG emissions from China's agricultural sector; (ii) low-emission agriculture practices, plans and governance; (iii) implementation challenges; and (iv) policy recommendations. This report is based on data and information until 2020.

According to FAOSTAT data, net GHG emissions from China's agrifood system reached 1.9 $GtCO_2eq$ in 2020, accounting for 14.2% of nationwide total GHG emissions. Production, intermediate inputs, food processing and energy use were the major contributors to these emissions. Emissions from agricultural activities amounted to 662 $MtCO_2eq$ in 2020, mainly from animal enteric fermentation[1], rice cultivation, manure management and crop residues.

China has made significant progress in the research and implementation of low-emission agriculture nationwide. Three main categories of measures have been identified that contributed to this progress: (i) adopting protective cultivation practices; (ii) enhancing carbon sequestration in forest, grassland and wetland ecosystems; and (iii) using new low-emission technologies.

To reach a CO_2 emission peak before 2030 and achieve carbon neutrality before 2060, China pledged to cut CO_2 emissions by 65% from the 2005 level by 2030. This goal was further split into subgoals including agriculture, with their implementation overseen by four governing bodies:

1. the National Leading Group on Climate Change, Energy Conservation, and Emission
2. the National Carbon Peak and Carbon Neutral Leading Group
3. the provincial, municipal and district level leading groups
4. the governing body on climate change.

Several regulations and plans have been elaborated to support the transition towards low-emission agriculture, including the 14th Five-Year Plan for National Agricultural Green Development, National Agricultural Sustainable Development Plan (2015–2030) and the Implementation Plan for Emission Reduction and Carbon Sequestration in Agriculture and Rural Areas.

However, fast changes in agricultural activities pose challenges for GHG emissions mitigation in agriculture. From a governance perspective, these challenges include insufficient governmental supervision and coordination on policies related to low-emission agriculture transformation, lack of national standards on agricultural GHG emission accounting, limited adoption of low-emission agricultural practices by farmers, and lack of attention to smallholder farmers in the process of low-emission agriculture transformation.

1 A livestock digestive process which releases methane as a by-product.

Seven policy recommendations have been proposed in the report to accelerate the transition towards low-emission agriculture:

1. Strengthen governmental supervision and coordination on low-emission agriculture transformation, e.g., by establishing a cross-ministerial coordination mechanism, and including low-emission agriculture in the performance rating of all government institutions.
2. Establish a national standard for measuring agricultural GHG emissions, in collaboration with national research agencies, international organizations such as the CGIAR, and relevant stakeholders.
3. Enhance agriculture extension services, incorporating them into policies promoting low-emission agriculture, innovating the methods for channelling policies to farmers, and facilitating the adoption of new services.
4. Facilitate the low-emission transformation of smallholder farmers by promoting examples of integrated and locally-adapted agriculture, e.g., environmentally-friendly family farms that combine planting and breeding.
5. Conduct a cost-benefit analysis of low-emission technologies, for the purpose of informing farmers and other stakeholders of best-bet technologies and their returns on investment; facilitate the adoption of these new technologies.
6. Reform fiscal policies on low-emission agriculture, e.g., by increasing financial support for stakeholders through subsidies and ecosystem service payments, and by taxing high-emitting agricultural practices.
7. Use green financing to support low-emission agriculture development to increase the financial volume from both public and private sources; this has the potential to cover the high costs of low-emission agriculture activities and distribute investment risks.

Finally, the report echoes the carbon neutrality targets of China and its challenges and gaps in current climate efforts. It also highlights the need and expectation for research and international collaborations to facilitate the achievement of low-emission agriculture in China.

1 Introduction

Climate change has become a major threat to global development. Climate change imposes great challenges to global agriculture, and in particular China's agriculture in the long-term. According to a recent economic estimation by Ortiz-Bobea et al. (2021), anthropogenic climate change has reduced the total factor productivity of global agriculture (aggregate output per unit of measured aggregate input) by about 21% since 1961, a slowdown equivalent to losing the last 7 years of productivity growth. Climate variability can explain more than 60% of crop yield variability in large breadbasket regions of the world, and accounts for 32–39% of reported yield variability globally (Ray et al. 2015). In China, climate change may reduce the yield of key crops by up to 37% during the late 21st century if no action is undertaken (NLGACCECER 2007). On the other hand, the agrifood system, including production and consumption, is responsible for about one third (31% in 2018, with a range 23–42%) of total net anthropogenic emissions (Babiker et al. 2022). Land-use change, including croplands expanding into carbon-rich forests, was the dominant contributor to land-based emissions throughout the 20th century (Houghton et al. 2012). To feed its growing population, agricultural activities have become increasingly intensive in China, leading to a significant proportion of GHG emissions. It is therefore crucial to transition towards low-emission agriculture to tackle these problems and ensure future food security.

This document provides a profile of China's GHG emissions from the agricultural sector as well as this sector's mitigation potential undertaken in the Mitigate+ initiative (see Box 1). In general, low-emission agriculture aims to "reduce the energy inputs to and GHG emissions from agriculture" (Norse 2012). Besides the obvious advantage of reducing GHG emissions, low-emission agriculture can also bring substantial socioeconomic, as well as environmental and ecosystem benefits.

This country profile is organized as follows: after the introduction (Chapter 1), Chapter 2 presents a brief overview of GHG emissions in China's agriculture sector. This analysis does not cover emissions beyond farmgate (i.e., does not cover emissions generated during pre- and post-production activities) due to the lack of relevant data and research in China. Chapter 3 summarizes the strategies available to implement low-emission agriculture, while Chapter 4 summarizes the challenges that China faces in doing so. Finally, Chapter 5 explores some policy options to address these challenges.

Box 1. The Mitigate+ initiative for low-emission food systems

China has committed to reaching carbon neutrality by 2060, which will require a drastic cut in GHG emissions from all sectors, including agriculture. Considering the urgent need for a low-emission agriculture in China, as well as the existing challenges that stakeholders are facing in their efforts to achieve this identified need, the CGIAR initiative on Low-Emission Food Systems (Mitigate+) provides an avenue for evidence-based research. Mitigate+ focuses on reducing food system emissions and on the predicted consequences of climate change on future generations, sustainable development and social equity. This initiative will ensure that civil society, multilateral, government, academic and private sector actors are equipped with the knowledge, information and tools they need to make robust evidence-based decisions as they confront challenges in food system discourse, policy development and implementation to reduce GHG emissions from agrifood systems. The initiative aims to contribute towards addressing some of the problems and enhancing stakeholders' efforts by collaborating with them and co-developing a transformational theory of change directed towards low-emission agriculture in China (https://www.cgiar.org/initiative/low-emission-food-systems/).

2 GHG emissions in China's agrifood system

GHG emission estimates in this report are based on statistics from the FAO (Food and Agriculture Organization of the United Nations), which were accessed in February 2022. To be comparable with estimates from the Third National Communication on Climate Change (PRC 2018), our estimates include emissions generated within farms, and emissions from pre- and post-production activities. China's GHG emissions from agrifood systems increased from 1.18 billion tons CO_2eq in 1990 to a peak of 1.9 billion tons in 2017 and then declined to 1.86 billion tons in 2020 (Figure 1). The annual growth rate slowed down from 1.55% between 1990 and 2010 to 1.28% between 2010 and 2020. Agrifood systems' share in nationwide total GHG emissions continuously declined from 36% to 14.2%, between 1990 and 2020, mainly caused by a faster increase in the relative share of energy and other sectors.

Farmgate GHG emissions in China amounted to 784 million tons (MtCO_2eq) in 2020, reflecting an increase of 12% compared with 699 MtCO_2eq in 1990 (Figure 2). Farmgate emissions increased at a much slower rate than overall agrifood system emissions, with an annual growth rate of less than 0.4%. As a result, the share of farmgate emissions declined from 21% of national total emissions in 1990 to only 6% in 2020. The main sources of farmgate emission were: enteric fermentation (23.8% of farmgate emissions in 2020), rice cultivation (18.9%), synthetic fertilizers (18.1%),

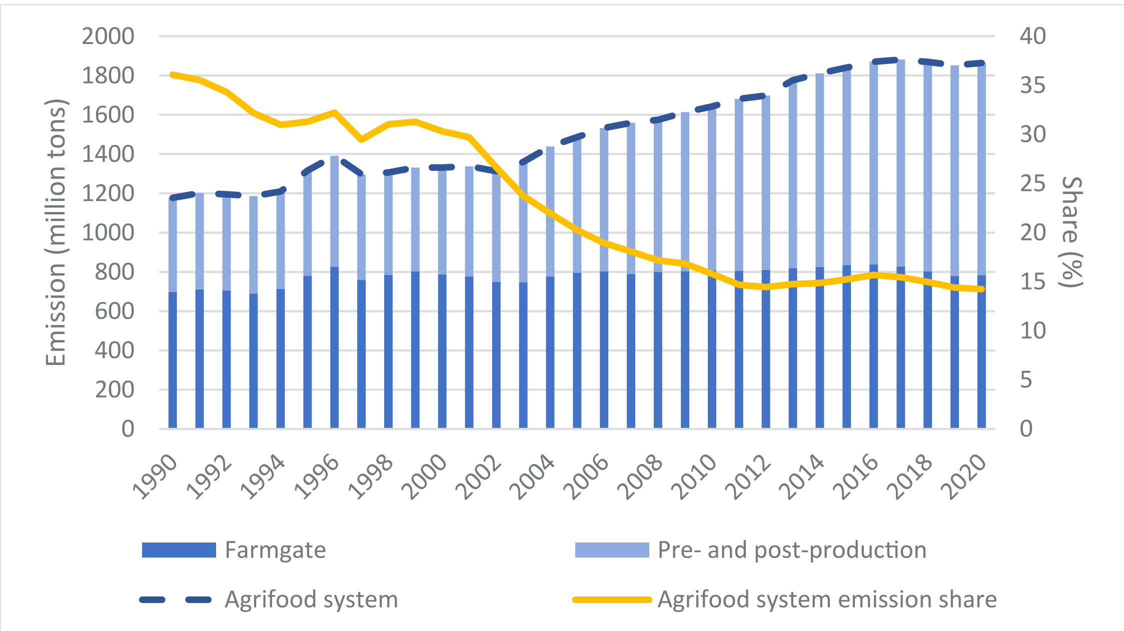

Figure 1. GHG emissions from agrifood systems in China, 1990–2020. Note: The left-hand axis refers to emission data in MtCO_2eq. The right-hand axis refers to the percent share of China's total emissions (yellow line).

Source: FAOSTAT.

on-farm energy use (15.5%), followed by manure management, manure left on pasture and applied to soil, and crop residues (Figure 2). Altogether, enteric fermentation, rice cultivation, synthetic fertilizers and on-farm energy use accounted for more than 76% of farmgate emissions.

GHG emissions from pre- and post-production activities include emissions from food household consumption, food packaging, food processing, food retail, food transport, food system waste disposal, on-farm electricity use, and fertilizer manufacturing. The emissions from pre- and post- production increased quite fast, growing from 478 to 1080 $MtCO_2eq$ between 1990 and 2020, corresponding to an increase of 126%, with an annual growth rate of 2.8% (Figure 3). The share of pre- and post-production in total agrifood system emissions increased from 41.3% in 1990 to 58.5% in 2020, exceeding the relative share of farmgate emissions since 2009. Within this category, food household consumption is the largest source of emissions (43% of total pre- and post-production emissions in 2020), followed by emissions from food system waste disposal (19.2%), the manufacturing of fertilizers (12.2%), food packaging (10.2%) and on-farm electricity use (9.9%). The share of emissions from food transportation increased from 1.5% of pre- and post-production emissions in 1990 to 3.9% in 2020 (Figure 3).

China's agrifood system GHG emissions also have impact beyond China. By importing ruminant products and livestock feed, for example, China transfers large amounts of GHG emissions (which would have happened in China without the import) to exporting countries (Du et al. 2018).

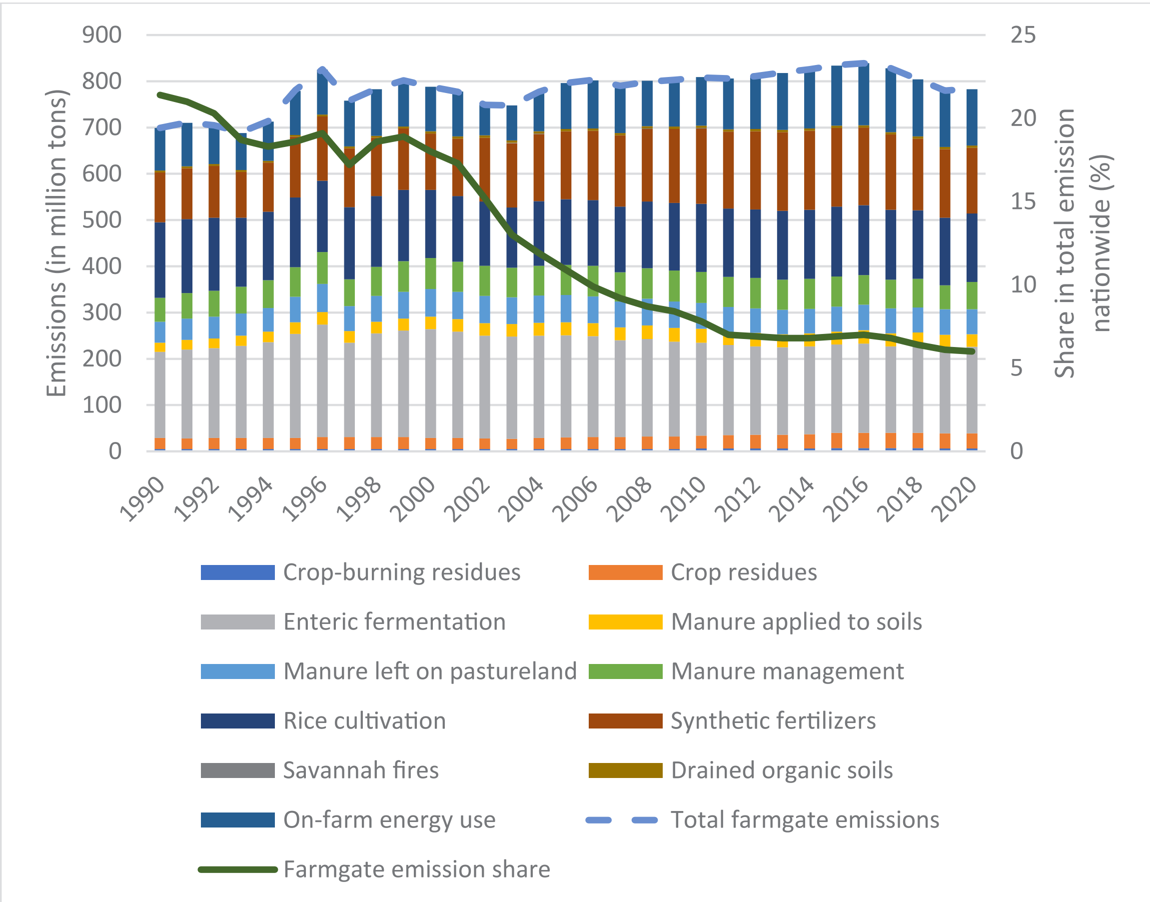

Figure 2. China's farmgate GHG emissions and their share in the country's total emissions, 1990–2020.

Source: FAOSTAT.

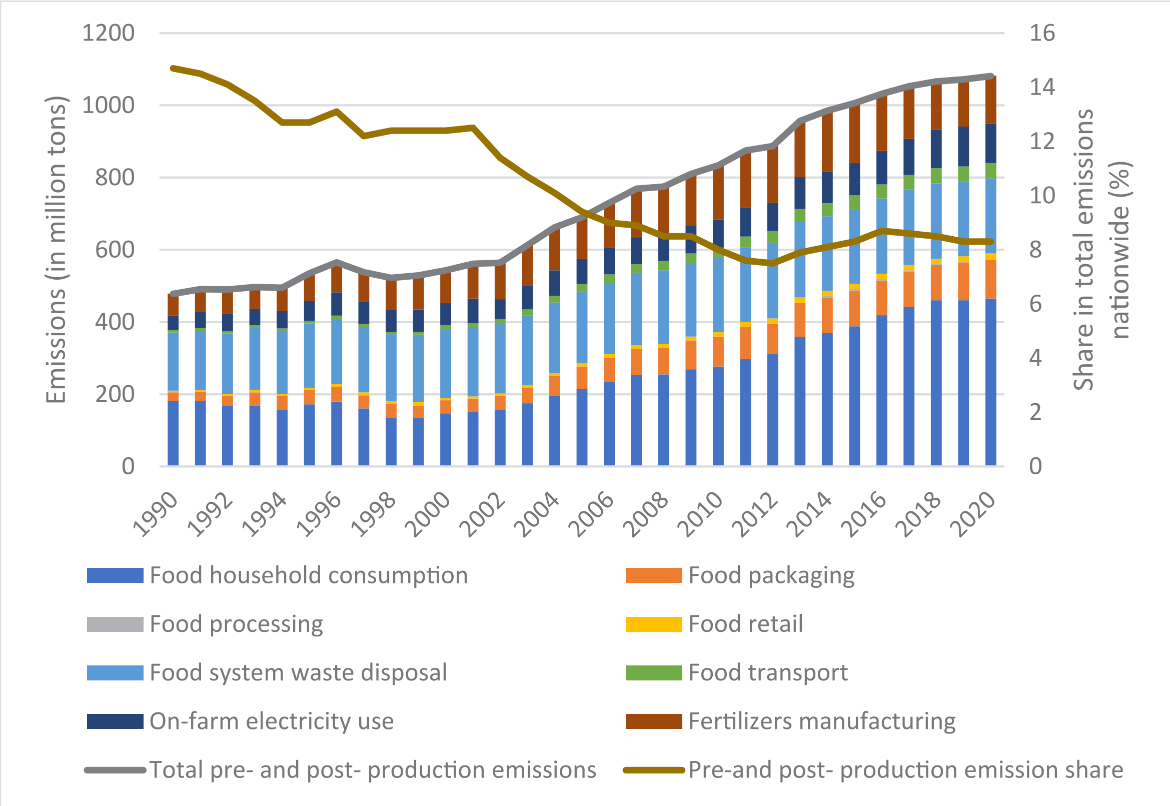

Figure 3. GHG emissions from pre- and post-production in agrifood systems in China, 1990–2020.

Source: FAOSTAT

3 Low-emission agriculture in China

3.1 Low-emission agricultural practices

China has made significant progress in the research and implementation of low-emission agriculture nationwide. Three main categories of measures have been identified to advance low-emission agriculture: (i) adopting protective cultivation practices; (ii) enhancing carbon sequestration in forest, grassland and wetland ecosystems; and (ii) using innovative low-emission technologies (Hou and Hou 2019).

3.1.1 Adopting protective cultivation practices

Strategies of protective cultivation – such as no-tillage, crop residue retention and crop rotation – can significantly improve soil organic carbon content and minimize GHG emissions, in contrast to conventional intensive farming practices which are distinguished by high tillage intensity and frequency, as well as a significant input of chemical goods such as fertilizers, insecticides and plastic films.

No-tillage technology plays an important role in changing farming practices and advancing low-emission agriculture in China. No-tillage technology was introduced in China in the 1950s and, since then, has progressively gained in popularity. Years of studies and technological development of protective cultivation techniques, including no-tillage technologies, in Northeast China's black soil areas have shown visible results (Li and Wang 2019). In 2020, China established the Action Plan for Protective Farming in Northeast China's Black Soil Areas[2], committing to promote the use of protective cultivation technology in appropriate areas (Han et al. 2021).

China has also paid much attention to the use of crop residues. Since 2016, RMB 2.5 billion has been invested in pilot projects for the extensive reuse of crop residues. Meanwhile, a fund of RMB 457 million was established in 2017 for the acquisition of agricultural machinery, to support the process of returning crop residues to the field. As a result of various policies promoting the reuse of crop residues such as the guidance on the utilization of crop residues in the 12th Five-Year Plan (Bai et al. 2023), China's rate of comprehensive crop residue reutilization has surpassed 82%. With government support, including through documents such as *Opinions on Accelerating the Resource Utilization of Livestock and Poultry Breeding Waste*[3], manure management and use has become an effective measure of protective cultivation practice in China. By 2019, China's rate of comprehensive livestock and poultry manure use has reached 70%, with 63% of large-scale farms equipped with manure treatment facilities.

The recycling of wasted agricultural films is also a focal point of the transition towards more sustainable farming practices in China. In 2020, the agricultural film recovery rate in some parts of north-western China reached more than 80% and the pollution caused by wasted agricultural films was effectively managed by policies such as the *Agricultural Film Recycling Action Plan developed by the Ministry of Agriculture*[4].

3.1.2 Enhancing carbon sequestration in forest, grassland and wetland ecosystems

Terrestrial ecosystems such as grasslands, wetlands and forests are essential carbon sinks to offset

2 See http://english.scio.gov.cn/chinavoices/2022-08/02/content_78352594.htm.

3 See https://www.ccacoalition.org/en/news/methane-mitigation-through-manure-management-key-successfully-transforming-china%E2%80%99s-agricultural.

4 See https://www.fao.org/3/cb7856en/cb7856en.pdf

carbon emissions (Pacala et al. 2001; Pan et al. 2011). Lai et al. (2016) showed that, between 1990 and 2010, China experienced a major decline in grasslands, a major increase in urbanization, and smaller increases in farmland and forest areas. Overall, land-use changes and land management failures (e.g., due to forest fires and insect pests) have released 1.45 GtCO_2 to the atmosphere over this period (Lai et al. 2016). Zhang et al. 2021) show that land use, land use change and forestry (LULUCF) play a large role as carbon sink on China, with 1.1 billion t CO_2eq offsetting about half of the agrifoood system emissions, and there is potential for more. According to data from China's Third National Communication on Climate Change (PRC 2018), in 2014 85% of carbon was sequestrated by forest land and forest products, while 10%, 4% and 1% were absorbed by grasslands, croplands and wetland, respectively – sinks that could be grown.

3.1.3 Using innovative low-emission technologies

Innovation in low-emission technologies is the principal driver for low-emission agriculture transformation. Besides the no-tillage technology already described in Section 3.1.1, three areas of technology are important for the low-emission transformation of agriculture.

First, renewable energy and energy saving technologies provide key methods to reduce carbon emissions and increase energy efficiency. Among them, anaerobic digestion – which handles agricultural residues, including crop residues and manure (Nag et al. 2019) – is a crucial technology in rural settings. It "represents an energy positive process that results in the production of biogas and digestate" which can reduce GHG emissions significantly (Chiumenti et al. 2018). Since 2003, the National Development and Reform Commission and the Ministry of Agriculture and Rural Affairs have invested RMB 40.4 billion to support the construction of biogas facilities, and more than 63 million tons of CO_2eq each year have been avoided by 2015 (National Development and Reform Commission 2017).

Second, using innovative technologies and practices, such as substituting manure and organic fertilizers to chemical ones, together with other protective cultivation methods mentioned in Section 3.1.1, can increase soil organic carbon stocks and improve soil carbon sequestration capacity (McLauchlan 2006; Qiu et al. 2009). Organic fertilizer application area surpassed 37 million hectares in 2020, a 50% increase from 2015 statistics (Ministry of Agriculture and Rural Affairs of China 2021). However, statistics reveal that the use of chemical fertilizers by farmers has not reduced in China, despite the wide and increasing use of organic fertilizers (He et al. 2006).

Lastly, climate-smart agriculture is "an integrative approach" established to "sustainably increas[e] agricultural productivity and incomes, adapt and build resilience to climate change, and reduc[e] and/or remov[e] GHG emissions"[5]. Xin and Tao (2020) found that in the North China Plain, the climate-smart winter wheat-summer maize rotation system optimizes irrigation, fertilizer application and appropriate cultivar selection. As a result, this cropping system can obtain the highest yield, water-use efficiency, nitrogen-use efficiency, groundwater recharge and soil organic carbon, as well as the lowest nitrogen loss and carbon footprint.

3.2 Nationally Determined Contribution: governance and policies for low-emission agriculture in China

3.2.1 Nationally Determined Contribution in China

China updated and submitted its Nationally Determined Contribution (NDC) to the United Nations' Framework Convention on Climate Change (UNFCCC) on 28 October 2021.[6] The Chinese Central Government reiterated its goals of reaching a CO_2 emissions peak before 2030 and achieving carbon neutrality before 2060 (UNFCCC 2021). The new primary objective is to cut CO_2 emissions by 65% from the 2005 level by 2030. Other updated goals encompass:

- Increasing the share of non-fossil fuels in primary energy consumption to around 25%.
- Increasing the forest stock volume by 6 billion cubic meters above the 2005 level.

5 See https://www.fao.org/climate-smart-agriculture/en/

6 For an unofficial translation, see on the UNFCCC NDC Registry: https://unfccc.int/sites/default/files/NDC/2022-06/China%E2%80%99s%20Achievements%2C%20New%20Goals%20and%20New%20Measures%20for%20Nationally%20Determined%20Contributions.pdf

- Bringing China's total installed capacity of wind and solar power to over 1.2 billion kilowatts by 2030.

Along with these goals, new policies and measures are also mentioned in the updated NDC, including:
- advancing the work on carbon peak and carbon neutrality in a coordinated and orderly manner
- developing the adaptation strategy for 2035
- making work plans for climate change adaptation for the next 15 years
- making special laws on carbon neutrality, as well as tax policies to support and safeguard low-emission actions
- developing 'green' low-carbon financial products and services
- implementing capacity building around statistical accounting of GHG emissions.

3.2.2 Major policies for low-emission agriculture in China

China is stepping up policy efforts and steadily adjusting its policy focus away from conventional agricultural management practices to support the transition towards low-emission agriculture while securing long-term food security, despite the possible trade-offs between various policy objectives.

At national level, several regulations and plans have been elaborated to support low-emission transformation in the agricultural sector. The *14th Five-Year Plan for National Agricultural Green Development*[7], issued by the Ministry of Agriculture and Rural Affairs and five other ministries and commissions, is China's first special plan for green agricultural development. It clarifies the objectives, key tasks and major measures to further facilitate green agricultural development, and makes systemic arrangements for green agricultural development during 2021–2025. It proposes for the first time to build a green and low-emission food supply chain from production to consumption, and makes comprehensive requirements to promote the development of a green, low-emission and circular agriculture.

The *National Agricultural Sustainable Development Plan (2015–2030)*[8] is a programmatic document to guide the sustainable development of agriculture issued by the Ministry of Agriculture and Rural Affairs and seven other ministries and commissions in 2015. Four key tasks proposed in this Plan can greatly contribute to low-emission agriculture transformation: (i) protecting arable land resources and promoting the sustainable use of farmland; (ii) conserving water and using water efficiently to ensure water security; (iii) controlling environmental pollution and improving the agricultural and rural environment; and (iv) restoring agricultural ecology and enhancing ecological functions. Complementary measures need to be taken, including: reducing agricultural inputs such as fertilizers, reusing crop residues and livestock manure resources, and increasing forest cover and grassland area. These actions can assist the development of low-emission agriculture by enhancing carbon sinks in soils and biomass, and reducing GHG emissions from agriculture. These tasks are also re-emphasized in the *Agricultural Resources and Ecological and Environmental Protection Project Plan (2016–2020)*[9] issued by the Ministry of Agriculture and Rural Affairs in 2017.

Lately, the *Implementation Plan for Emission Reduction and Carbon Sequestration in Agriculture and Rural Areas*[10] was issued in July 2022, by the Ministry of Agriculture and Rural Affairs and the National Development and Reform Commission. This Plan aims to put the carbon peak and carbon neutrality into practice and promote green and low-emission development in agriculture and rural areas. It puts forward six tasks and ten actions. The six tasks focus on: (i) energy saving and emission reduction in crop production; (ii) emission reduction in livestock production; (iii) carbon emission reduction and sink increase in fishery; (iv) farmland carbon sequestration and capacity increase; (v) energy saving and carbon emission reduction of agricultural machinery; and (vi) renewable energy substitution. The ten actions to support these six tasks are: methane

7 See https://www.fas.usda.gov/data/china-plan-for-green-and-sustainable-ag-development

8 See https://www.fao.org/faolex/results/details/en/c/LEX-FAOC207442/

9 See https://english.mee.gov.cn/Resources/Plans/Special_Fiveyear_Plan/201902/t20190222_693384.shtml

10 See https://www.chinawaterrisk.org/regulation/implementation-plan-for-emission-reduction-carbon-sequestration-in-agriculture-rural-areas/

emission reduction in rice fields, reduction of fertilizer application and efficiency increases, low-carbon development and emission reduction in livestock and poultry, carbon emission reduction and sink increase in fishery, energy saving in agricultural machinery, carbon sink increase in farmland, the comprehensive utilization of straw, renewable energy substitution, support of scientific and technological innovation support, and establishment of a monitoring system. This plan provides a solid foundation for the development of low-emission agriculture and enhances synergies between emission reduction, carbon sequestration and food security.

4 Challenges

4.1 Governmental supervision and coordination of policies related to low-emission agriculture transformation

Governmental supervision and coordination ensure that policies designed for low-emission agriculture development can be carried out effectively and efficiently, but supervision and coordination are not always sufficient. For example, the Asian Development Bank partnered with the Ministry of Agriculture and Rural Affairs to provide technical assistance to support sustainable agriculture and waste management in Shandong and Heilongjiang Provinces in China starting from 2019 (Chen 2022). During implementation, it was found that small and medium-size livestock and poultry farmers were not sufficiently included in governmental efforts to encourage the reuse of livestock and poultry waste. It was also discovered that provincial, municipal, county and town-level agricultural resource management and environmental protection institutions and service departments were not systematically set up, and that insufficient coordination between different levels of the government was resulting in insufficient governmental monitoring of low-emission agricultural policies.

4.2 Lack of national standards for agricultural GHG emission accounting

A shared and official GHG emission accounting standard is essential for ensuring the accuracy, verifiability and comparability of measured GHG emissions. It is also the foundation for regulating low-emission agriculture and assessing its effectiveness. However, an applicable and widely accepted national standard for assessing agricultural GHG emissions in China has not been established. The lack of such a national standard causes confusion in the inventory boundary of GHG reporting. Oftentimes, organizations and companies adopt the inventory boundary and report GHG emissions in their favor; inventories can therefore be inaccurate or even falsified. Taking livestock as an example, although all provinces have followed the Intergovernmental Panel on Climate Change (IPCC) Guidelines when preparing GHG inventories, "only Beijing and Shanghai have adopted Tier 2 method, while another 29 provinces are currently using Tier 1 method" (Dong et al. 2020). Lastly, the absence of a national standard leads to inconsistent GHG accounting. In practice, different organizations use different data collection tools to carry out GHG accounting; while specific operational processes, such as the timeframe over which emissions are tracked, also vary.

4.3 Limited adoption of low-emission agricultural practices by farmers

Farmers are the most prominent decision makers when it comes to the adoption of low-emission agricultural practices. It is hard to engage them in the adoption of low-emission agriculture practices in a developing country like China. Despite achievements reached through various government policies (UNFCCC 2021), the overall adoption rate of low-emission agricultural practices by farmers is still low (Liu et al. 2019). For instance, soil testing and fertilizer recommendations can reduce GHG emissions in agricultural production and mitigate agricultural non-point source pollution (Daxinia et al. 2018; Wang et al. 2021), by optimizing fertilizer composition and reducing the intensity of fertilizer application (Rurinda et al. 2013; Chen et al. 2014; Nezomba et al. 2018). However, less than half of Chinese farmers have adopted these practices (Wang et al. 2017; Tong et al. 2018; Liu et al. 2019; Gao et al. 2020).

Multiple factors can affect farmers' decision making on whether or not to adopt low-emission agricultural technologies. Hou and Hou (2019) investigated the relationship between farmers' adoption of low-emission agriculture and individual and household characteristics of 442 rice farmers in four counties of the Jiangsu Province, China. They showed that farmers' intention to adopt low-emission agriculture is significantly and positively correlated with their low-emission agriculture awareness, education, technical or financial capacities, and participation in contract farming. Individual characteristics such as gender and age are significantly correlated with the adoption of low-emission agricultural technologies like soil testing and fertilizer recommendations (Yu and Luo 2022). Farmers' awareness and knowledge of low-emission agricultural technologies also play an essential role in the adoption of low-emission agricultural practices. The adoption of conventional cultivation methods – including high chemical fertilizer use – is mostly attributed to insufficient education among farmers (Huang et al. 2008). In Hubei Province, China, a random sample of 1,115 rice farmers revealed a statistically significant positive association between technical training and rice farmers' adoption of soil testing and formulated fertilization. Nonetheless, the way that extension services are delivered is important for their effectiveness (Huang et al. 2015; Pan et al. 2017). Likewise social networks, which strengthen farmers' learning and innovation capacities, can increase the demand for resource-saving technologies and improve farmers' ability to adapt to climate change (Magnan et al. 2015; Arunrat et al. 2017). Having a better understanding of the factors that can impact farmers' technology adoption is advantageous for future policy making.

4.4 Lack of attention to smallholder farmers in the process of low-emission agriculture transformation

Despite the large-scale off-farm employment of farmers, which has been triggered by agricultural mechanization, rural smallholder farming continues to be a key agricultural production model in China (Rogers et al. 2021). Yet, it is unclear how much smallholder farming affects the development of low-emission agriculture transformation. In one study, farmland operation scale had no significant effect on agricultural GHG emissions (Wang et al. 2022); slightly larger farms may have reduced pollution, however. While a study in Yancheng, eastern China, found that GHG emissions of smallholder pig production (emissions per kg of meat produced) were higher than those of large-scale pig farms in North America and Europe (Li et al. 2022), factors other than size may be behind this. Agriculture is also playing an increasingly marginalized and part-time role for smallholder farmers. It can even purely act as an economic safety net. This is because of the ongoing reduction in comparative returns from agriculture, and the rising proportion of non-farm income in farmers' family income (Rigg et al. 2016). Therefore, it is particularly difficult for smallholder farmers who lack economic capacities to adopt low-emission agriculture practices that require large-scale capital and labour as up-front investments. Policy support and conventional production subsidies cannot alleviate the problem either, since smallholder farmers will become dependent on them and use input-intensive farming methods to grow cash crops (Tilt 2008). Lastly, low-emission technology extension services tend to focus more on large-scale farmers, which makes it difficult for smallholder farmers to learn and access low-emission technologies (Hou and Hou 2019). In summary, more attention should be paid to smallholder farmers in the process of low-emission agriculture transformation.

5 Policy recommendations

5.1 Strengthen governmental supervision and coordination on low-emission agriculture transformation

Insufficient coordination among governmental departments can compromise the development of low-emission agriculture (see Section 4.1). It is therefore imperative to establish a cross-departmental (or ministerial) coordination mechanism, and include low-emission agriculture performance in the performance rating system at all levels of government institutions to improve the monitoring system. The governmental supervision system should ultimately be able to collect precise information on the implementation of policies regarding low-emission agriculture and assist in their revision.

5.2 Establish a national standard for measuring agricultural GHG emissions

The government should first strengthen their cooperation with national research agencies, international organizations like the CGIAR, and relevant stakeholders such as the agricultural industry to define the inventory boundary of GHG reporting, by clearly identifying direct emissions, as well as emissions from purchased electricity, heat, steam and other indirect and supply chain emissions. The methodology for GHG accounting then needs to be created, in line with IPCC guidelines, considering various agricultural conditions across different regions, and testing this methodology through pilot projects to improve its effectiveness. Finally, it is necessary to unify the tools and processes of GHG accounting by applying a management system that collects, tracks and verifies GHG emission data.

5.3 Enhance agriculture extension services

Extension services offer farmers technical assistance and low-cost training programmes on low-emission agricultural practices and innovative technologies, with the aim of increasing their adoption rate (Liu et al. 2019). Technical trainings based on a conventional one-time lecture have a small effect on the adoption of low-emission agricultural practices. Effective technical training requires high intensity and in-field guidance. Consequently, policy makers should incorporate agricultural extension services into the process of making policies on low-emission agriculture, and encourage innovative methods to channel policies to farmers. In addition, smallholder farmers are often neglected when implementing extension services (see Section 4.4). As such, future policy should focus on equity and find new ways to better promote low-emission agriculture among smallholder farmers through enhanced agricultural extension services.

5.4 Facilitate the low-emission transformation of smallholder farms

Smallholder farmers may need support to shift to low-emission production systems as they – and in particular the many part-time farmers among them – may not have sufficient means for investments in technologies and changed farming practices. Subsidy reform and capacity development are therefore important steps to facilitate the low-emission transformation of farms.

5.5 Conduct a cost-benefit analysis of low-emission technologies

Economic capacities can have a great impact on smallholder farmers' attitudes towards the adoption of low-emission technologies. High costs or unclear investment returns hinder farmers' adoption of innovative technologies and cultivation practices. An integrated cost-benefit analysis – covering various low-emission technologies and agricultural practices – is necessary to better inform farmers about the available technologies and practices most adapted to their situation, as well as about their potential benefits and limits, so as to facilitate their adoption.

5.6 Reform fiscal policies to encourage low-emission agriculture

As mentioned in 4.3, one of the reasons for the low adaptation rate of low-emission agricultural practices is the insufficient financial support available for stakeholders. Fiscal policies, such as taxes and government spending, can provide all stakeholders involved in the agricultural value chain with critical incentives and facilitate the adoption of low-emission technologies and practices in agrifood systems. However, conventional agricultural input and production subsidies encourage input-intensive practices. Thus, further reforms to agricultural subsidies are required, along with fair agroecological subsidies and a reduction in conventional agricultural input subsidies (Tian et al. 2020) (see also Section 4.4). The energy expenses of nitrogen fertilizer production account for a sizable proportion of subsidies in China. This compromises the incentive for fertilizer producer to increase energy efficiency, and can result in farmers' potential overuse of chemical fertilizers (Norse 2012). Such input subsidies should be replaced with payments for environmental services, and subsidies for organic fertilizer or other low-emission agricultural technologies and practices. Furthermore, environmental taxes could be imposed on high GHG emission agricultural practices, to correct the failures resulting from missing markets for environmental goods and transfer them to subsidies supporting low-emission agricultural practices.

5.7 Use green financing to support low-emission agriculture development

As mentioned in Section 4.4 and 5.5, the capacity of a project to generate a reasonable return on investment is a major roadblock for low-emission agriculture adoption. Green financing can maintain a promising cash flow and alleviate financial constraints. In general, green financing can minimize carbon footprint, enhance environmental quality, and efficiently support environment-friendly initiatives to increase resource-use efficiency, educate consumers to adopt green consumption habits, promote sustainable social development, and respond to climate change (Khan et al. 2021; Yang et al. 2021). Guo et al. (2022), studying 30 provinces in China from 2000 to 2019, concluded that green financing can significantly reduce chemical fertilizer application and agricultural GHG emissions. However, large challenges still exist in implementing green finance, particularly: limited resources from the private sector (Berensmann and Lindenberg 2016), unclear definition of green financing, and conflicts between investors' short-term return expectations and the long-term targets of green investment projects.

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The global food system is responsible for 23 – 42% of total net anthropogenic emissions. The food systems of all countries need to be transformed to lower their emissions while producing sufficient, nutritious and healthy food. The Low-Emissions Food Systems (Mitigate+) Initiative aims to offer a comprehensive, evidence-based and holistic approach to reducing agrifood systems emissions. It explores possible pathways that reduce greenhouse gas emissions while enhancing food security and nutrition and livelihoods and preserving the environment. In this context, a set of country profiles are being developed opening avenues towards low-emission food systems. The present document focuses on China's agrifood system.

Net greenhouse gas emissions from China's agrifood system reached 1.9 GtCO2eq in 2020, accounting for 14.2% of nationwide total greenhouse gas emissions. China pledged to cut its CO2 emissions by 65% between 2005 and 2030, to reach an emission peak before 2030 and achieve carbon neutrality before 2060. To feed its large population while reducing its carbon footprint, China must transition to a low-emission agricultural model. This report illustrates the progress made by China towards this goal and it discusses the remaining challenges. Three main categories of measures have been identified that are advancing low-emission agriculture in China: (i) adopt protective cultivation practices; (ii) enhance carbon sequestration in forest, rangeland and wetland ecosystems; and (iii) develop innovative low-emission technologies and practices. This document formulates seven specific policy recommendations to address current challenges and accelerate the needed transition towards low-emission agriculture in China.

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