CLIMATE CHANGE
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Mitigating agricultural greenhouse gas emissions in China

Status, potential and challenges

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Abstract: China country report

This report describes the current state of agriculture in China, focusing on the greenhouse gas (GHG) emissions it produces and the relevant climate and other socioeconomic policies that affect its development. We identify options that could reduce agricultural emissions and review mitigation potential of those options. Finally, we identify barriers to implementing these mitigation options and some possible solutions to overcoming those barriers.

Kurzbeschreibung: China Länderbericht

Dieser Bericht beschreibt den aktuellen Stand der Landwirtschaft in China, mit einem Schwerpunkt auf die von ihr produzierten Treibhausgasemissionen und die relevanten klimapolitischen und sozioökonomischen Rahmenbedingungen, die ihre Entwicklung beeinflussen. Wir identifizieren Optionen, die die landwirtschaftlichen Emissionen reduzieren könnten, und vergleichen ermittelte Minderungspotenziale dieser Optionen. Abschließend werden die Hindernisse für die Umsetzung dieser Minderungsoptionen und einige mögliche Lösungen zur Überwindung dieser Hindernisse aufgezeigt.

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List of abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AGFEP	Academy of Global Food Economics and Policy at China Agricultural University
AWD	Alternate-wetting-and drying
BUR	Biennial Update Report
CCE	Geneva Air Convention of the United Nations Economic Commission for Europe
CPC	Communist Party of China
DNDC	DeNitrification-DeComposition
FAO	Food and Agriculture Organisation of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
IRRI	International Rice Research Institute
IPCC	Intergovernmental Panel on Climate Change
ISSM	Integrated soil-crop system management
LULUCF	Land Use, Land-Use Change and Forestry
Mt	Mega tonne
$MtCO_2e$	Mega tonnes of CO_2 equivalents
N	Nitrogen
N_2O	Nitrous oxide
NBS	National Bureau of Statistics of China
NDC	Nationally Determined Contribution
NDRC	National Development and Reform Commission
P	Phosphorus
SRI	System of rice intensification
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organisation

Summary

The aim of this report is to identify possible emissions mitigation options in the agricultural sector of China, the barriers towards implementing those options and provide some recommendations on how to overcome those barriers. The report begins with a description of the current state of agriculture in China regarding the GHG emissions it produces, and the climate and socioeconomic policies that shape the sector. We then identify three key options that could reduce agricultural emissions and compare available mitigation potential estimates. Other mitigation options are briefly discussed as well. Finally, we identify barriers that act at the farm, national, international and consumer level along with possible steps to overcoming those barriers.

In absolute terms, China has the largest area of agricultural land on the planet (521 million hectares). Agricultural land encompasses land used for crop cultivation and animal husbandry. In relative terms, 56% of the total land area of mainland China were categorised as agricultural land in 2019. Between 1961 and 1994 the share of agricultural land in mainland China increased from 36% to 55.7%. Overall, China has constrained land and water resources. Large parts of arable land are of low quality and water scarcity is a common challenge. The expansion and intensification of agricultural and livestock production has contributed to degradation and pollution of land and water resources in the country as well as to biodiversity loss.

In 2020, agriculture contributed about 8% to the national economy (GDP). Imports and exports of agricultural products have increased since World Trade Organisation accession in 2001.The share of the Chinese workforce employed in agriculture in 2021 is estimated to be 22.9%.

According to FAOSTAT estimates, emissions from agriculture, excluding emissions from land use, land use change and forestry (LULUCF), amounted to 789.6 $MtCO_2e$ in 2019 and made up 6% of national emissions. The largest sources of emissions are emissions from agricultural soils (31%), enteric fermentation (23%), and rice cultivation (19%). According to FAOSTAT, total emissions from agriculture have peaked in 2016 at about 840 $MtCO_2e$ and have since then slightly declined. Compared to 1994, agricultural emissions in 2019 increased by about 10%. The latest available information on GHG emissions from agriculture reported by the Chinese government to the UNFCCC is for 2018.

The central objectives of agricultural policy in China are the so called “three rural issues”, namely 1) improving farmers’ incomes 2) strengthening the economy of rural areas and 3) improving agricultural productivity.

Three mitigation options were identified for detailed analysis based on the contribution of different emission sources, the potential for socio-economic and environmental co-benefits, the country-specific context of the agricultural sector, and the general feasibility for implementation.

For China, we selected the following three mitigation measures:

- Improved rice cultivation
- Improved nitrogen management (focus on synthetic fertiliser use and application)
- Improved manure management (focus on processing, storage, and reutilization).

These three on-farm mitigation measures form part of a broader set of mitigation options that would be available to China, including improved on-farm energy use, improving livestock health, decarbonising the production of synthetic fertiliser, reducing energy consumption of agricultural machinery, and measures to address the trend in increasing meat consumption.

The three selected measures could contribute to reducing the emissions from agricultural production in China. Mitigation potential estimates for rice cultivation range from 14 $MtCO_2e$ to 64 $MtCO_2e$. Mitigation potential estimates from improved nitrogen management are associated with high uncertainty and range from 13 $MtCO_2e$ to 213 $MtCO_2e$. Mitigation potential estimates from improving manure management and utilisation are 119 $MtCO_2e$ and 129 $MtCO_2e$.

There are critical barriers that hinder the implementation of measures to achieve the outlined mitigation potentials and impair other activities to reduce greenhouse gas emissions in the agricultural sector. For the selected mitigation measures, we identified technical, economical, and structural and socio-cultural barriers. More generally, high investment costs, lacking knowledge, and an aging farming population act as barriers at farm level. Additionally, specific targets for reducing agricultural non-CO_2 emissions are still lacking. However, policies that would contribute to reducing these emissions are already partly in place.

To accelerate the uptake and implementation of the measures described in this report, China could 1) enhance the national climate mitigation framework in agriculture with concrete, sector specific targets, 2) align food security objectives with mitigation objectives by better integrating objectives into existing agricultural policies, 3) reforming its agricultural support policies to better incentivise sustainable practices, and 4) expanding the production of green and organic food. In addition, demand-side measures such as tackling food loss and waste and addressing the increasing trend in animal protein consumption can help reduce emissions. These mitigation policies and incentives also foster co-benefits between adaptation and mitigation in the agricultural sector and have co-benefits for achieving food security and rural development targets.

Zusammenfassung

Ziel dieses Berichts ist es, mögliche Optionen zur Emissionsminderung im chinesischen Agrarsektor zu ermitteln, die Hindernisse für die Umsetzung dieser Optionen aufzuzeigen und einige Empfehlungen zur Überwindung dieser Hindernisse zu geben. Der Bericht beginnt mit einer Beschreibung der aktuellen Situation der Landwirtschaft in China im Hinblick auf die von ihr verursachten Treibhausgasemissionen und die klimapolitischen und sozioökonomischen Maßnahmen, die den Sektor beeinflussen. Anschließend werden drei wichtige Optionen zur Reduzierung der landwirtschaftlichen Emissionen aufgezeigt und die verfügbaren Schätzungen des Minderungspotenzials verglichen. Auch andere Minderungsoptionen werden kurz erörtert. Abschließend werden Hindernisse auf Hof-, nationaler, internationaler und Verbraucherebene sowie mögliche Schritte zur Überwindung dieser Hindernisse aufgezeigt.

In absoluten Zahlen hat China die größte landwirtschaftliche Nutzfläche der Welt (521 Millionen Hektar). Landwirtschaftliche Flächen umfassen Flächen, die für den Ackerbau und die Tierhaltung genutzt werden. Relativ gesehen wurden im Jahr 2019 56 % der Gesamtfläche des chinesischen Festlandes als landwirtschaftliche Nutzfläche eingestuft. Zwischen 1961 und 1994 stieg der Anteil der landwirtschaftlichen Flächen in Festlandchina von 36 % auf 55,7 %. Insgesamt sind die Land- und Wasserressourcen in China begrenzt. Große Teile des Ackerlandes sind von geringer Qualität, und Wasserknappheit ist eine häufige Herausforderung. Die Ausweitung und Intensivierung der Land- und Viehwirtschaft zur Verschlechterung und Verschmutzung der Land- und Wasserressourcen im Land sowie zum Verlust der biologischen Vielfalt beigetragen.

Im Jahr 2020 trug die Landwirtschaft etwa 8 % zur Volkswirtschaft (BIP) bei. Die Ein- und Ausfuhren landwirtschaftlicher Erzeugnisse sind seit dem Beitritt zur Welthandelsorganisation im Jahr 2001 gestiegen. 2021 werden schätzungsweise 22,9 % der chinesischen Arbeitskräfte in der Landwirtschaft beschäftigt sein.

Nach Schätzungen von FAOSTAT beliefen sich die Emissionen aus der Landwirtschaft, ohne Emissionen aus Landnutzung, Landnutzungsänderung und Forstwirtschaft, im Jahr 2019 auf 789,6 $MtCO_2e$ und machten 6 % der nationalen Emissionen aus. Die größten Emissionsquellen sind Emissionen aus landwirtschaftlichen Böden (31 %), der enterischen Fermentation (23 %) und dem Reisanbau (19 %). Laut FAOSTAT erreichten die Gesamtemissionen aus der Landwirtschaft im Jahr 2016 mit etwa 840 $MtCO_2e$ ihren Höhepunkt und sind seitdem leicht rückläufig. Im Vergleich zu 1994 sind die landwirtschaftlichen Emissionen im Jahr 2019 um etwa 10 % gestiegen. Die letzten verfügbaren Informationen über THG-Emissionen aus der Landwirtschaft, die von der chinesischen Regierung an das UNFCCC gemeldet wurden, stammen aus dem Jahr 2018.

Die zentralen Ziele der Agrarpolitik in China sind die so genannten "drei ländlichen Themen": 1) die Verbesserung der Einkommen der Landwirte, 2) die Stärkung der Wirtschaft in den ländlichen Gebieten und 3) die Verbesserung der landwirtschaftlichen Produktivität.

Auf der Grundlage des Beitrags der verschiedenen Emissionsquellen, des Potenzials für sozioökonomische und ökologische Nebeneffekte, des länderspezifischen Kontextes des Agrarsektors und der allgemeinen Durchführbarkeit wurden drei Optionen für eine detaillierte Analyse ausgewählt.

Für China wählten wir die folgenden drei Minderungsmaßnahmen aus:

- Verbesserter Reisanbau

- Verbessertes Stickstoffmanagement (Schwerpunkt auf Einsatz und Anwendung synthetischer Düngemittel)
- Verbessertes Düngemittelmanagement (Schwerpunkt auf Verarbeitung, Lagerung und Wiederverwendung).

Diese drei Maßnahmen zur Emissionsminderung in landwirtschaftlichen Betrieben sind Teil eines breiteren Spektrums von Optionen zur Emissionsminderung, die China zur Verfügung stehen. Dazu gehören die Verbesserung der Energienutzung in landwirtschaftlichen Betrieben, die Verbesserung der Tiergesundheit, die Dekarbonisierung der Produktion von Kunstdünger, die Verringerung des Energieverbrauchs von Landmaschinen und Maßnahmen gegen den steigenden Fleischkonsum.

Die drei ausgewählten Maßnahmen könnten zur Reduzierung der Emissionen aus der landwirtschaftlichen Produktion in China beitragen. Die Schätzungen des Minderungspotenzials für den Reisanbau reichen von 14 $MtCO_2e$ bis 64 $MtCO_2e$. Die Schätzungen des Minderungspotenzials durch ein verbessertes Stickstoffmanagement sind mit großer Unsicherheit behaftet und reichen von 13 $MtCO_2e$ bis 213 $MtCO_2e$. Die Schätzungen des Minderungspotenzials durch die Verbesserung des Düngemittelmanagements und der Düngernutzung liegen bei 119 $MtCO_2e$ und 129 $MtCO_2e$.

Es gibt kritische Barrieren, die die Umsetzung von Maßnahmen zur Erreichung der skizzierten Minderungspotenziale behindern. Für die ausgewählten Minderungsmaßnahmen haben wir technische, wirtschaftliche, strukturelle und soziokulturelle Barrieren identifiziert. Generell wirken hohe Investitionskosten, mangelndes Wissen und eine alternde landwirtschaftliche Bevölkerung als Barrieren auf betrieblicher Ebene. Darüber hinaus gibt es immer noch keine konkreten Ziele für die Verringerung der landwirtschaftlichen Nicht-CO_2-Emissionen. Politische Maßnahmen, die zu einer Verringerung dieser Emissionen beitragen würden, sind jedoch teilweise bereits vorhanden.

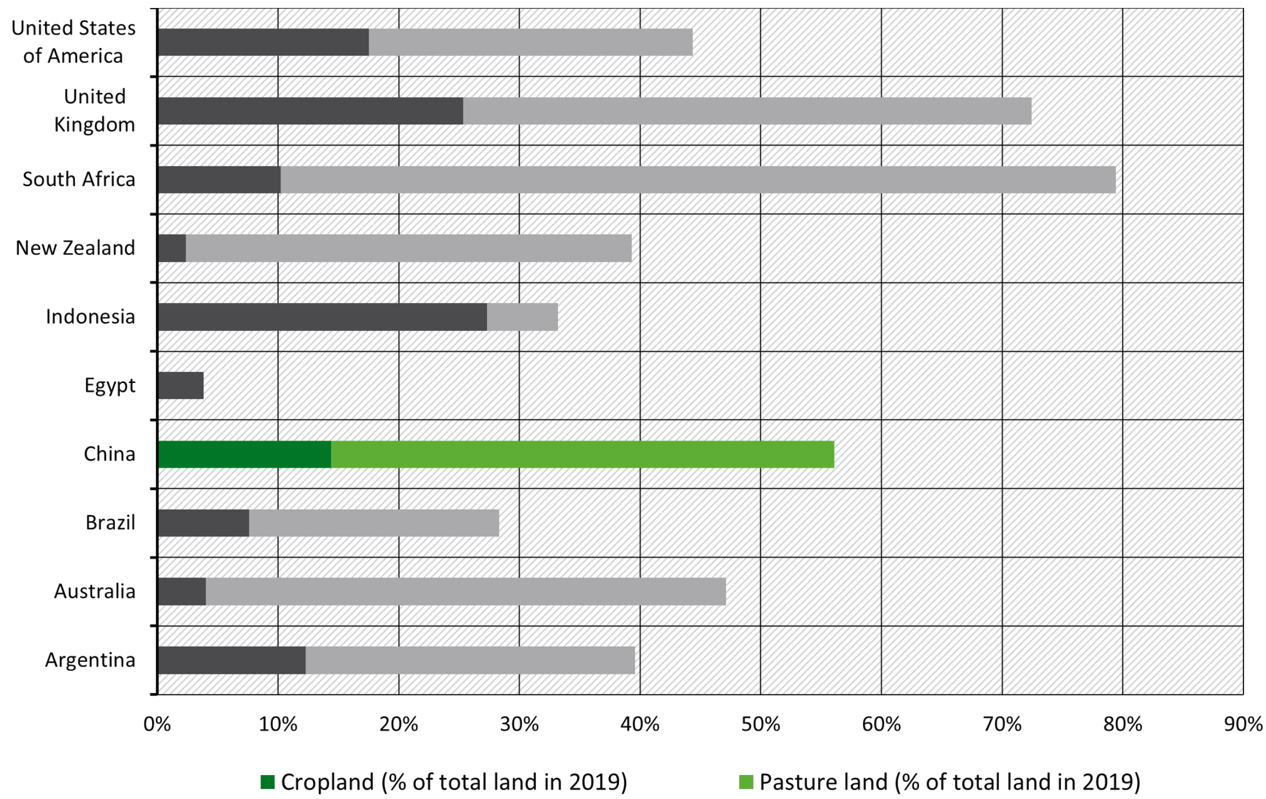
Um die Übernahme und Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, könnte China 1) den nationalen Rahmen für den Klimaschutz in der Landwirtschaft durch konkrete, sektorspezifische Ziele verbessern, 2) die Ziele der Ernährungssicherheit mit den Zielen des Klimaschutzes in Einklang bringen, indem die Ziele besser in die bestehende Agrarpolitik integriert werden, 3) seine Politik zur Unterstützung der Landwirtschaft reformieren, um bessere Anreize für nachhaltige Praktiken zu schaffen, und 4) die Produktion von grünen und ökologischen Lebensmitteln ausweiten. Darüber hinaus können nachfrageseitige Maßnahmen wie die Bekämpfung von Lebensmittelverlusten und -verschwendung und die Eindämmung des zunehmenden Verbrauchs von tierischem Eiweiß zur Emissionsminderung beitragen. Diese Maßnahmen und Anreize zur Emissionsminderung fördern auch den gemeinsamen Nutzen von Anpassung und Emissionsminderung im Agrarsektor und tragen zur Erreichung der Ziele für Ernährungssicherheit und ländliche Entwicklung bei.

1 General characteristics of the agricultural sector and policy landscape

1.1 Characteristics of agriculture sector

China has the largest area of agricultural land on the planet, land used for crop cultivation and animal husbandry covers more than 521 million ha (FAO 2022a). At the same time it has only 0.085 ha of arable land per capita (OECD 2018, The World Bank 2023). Arable land refers to land used for temporary crops, temporary meadows and temporary pastures (FAO 2022b). In comparison, the global average of arable land per capita was 0.18 ha in 2018 (The World Bank 2023). The share of arable land has fluctuated. The size of Chinese farms was in average 0.6 ha in 2012 (OECD 2012), but has been increasing in recent years in response to demand for higher farm income and higher efficiency in agricultural production (OECD 2018). Currently, different types of farms shape agricultural production, including family farms, large-scale state farms and the dominating smallholder farms (Xu et al. 2023).

Figure 1: Agricultural land as a share of total country area (2019)



Source: FAO (2022a) data for all countries. Data includes “Cropland” and “Land under permanent meadows and pastures”.

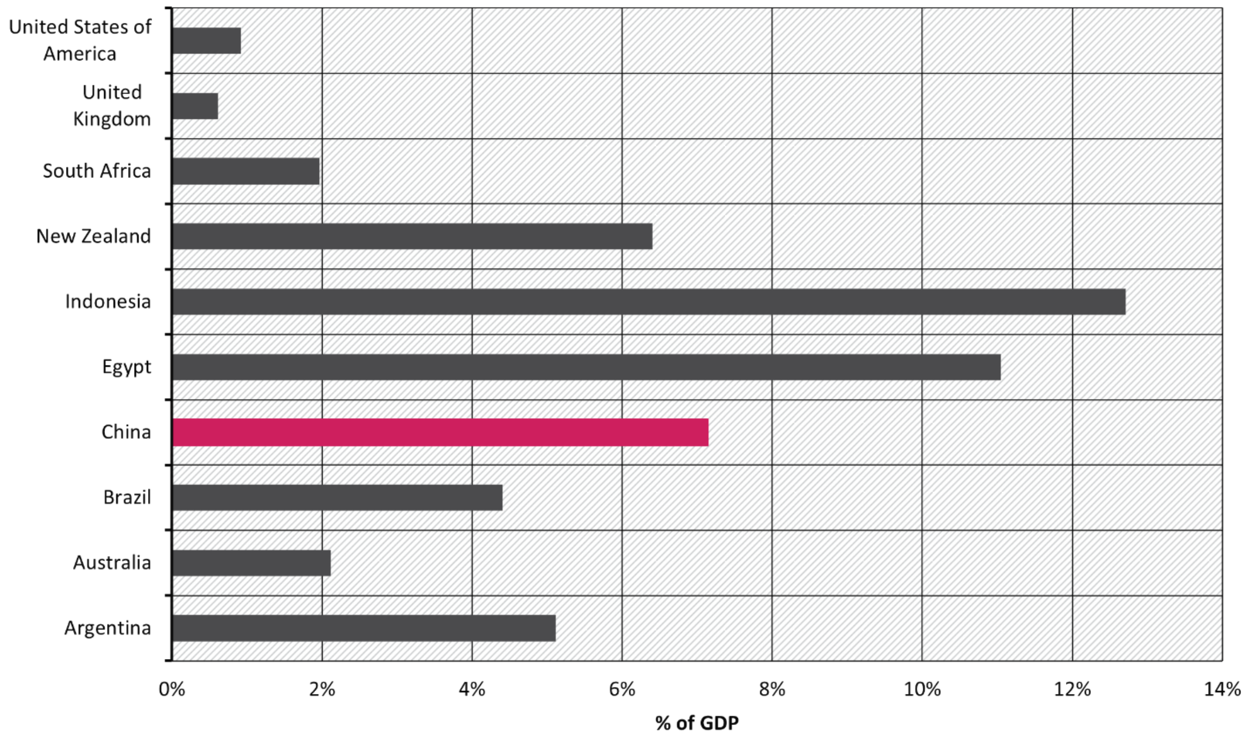
In mainland China, the share of land area categorised as agricultural land amounted to 56% in 2019 (FAO 2022b). The share of arable land has fluctuated. Between 1952 and 1979 China lost around half of its arable land per capita, due to the construction of roads, housing, and factories (Lardy 1983). Between 1961 and 1994 the share of agricultural land in mainland China increased from 36% to 55.7% (FAO 2022b). 26% of agricultural land in 2019 were cropland and 74% were permanent meadows and pastures (ibid). According to the third Chinese national land survey from 2019, 127.9 million ha are classified as cultivated land, 284.1 million ha are forest land, 264.5 million ha are grassland and 23.5 million ha are wetlands (NBS 2022).

Chinese agricultural practices are shaped by the wide range of agro-climatic conditions present in the country and the varied topography. More than 60% of mainland China is composed of mountains, hills and plateaus (China 2018b). Mainland China's plateaus and river basins descend in altitude from west to east in roughly three steps (China 2018a). The Northeast China Plain, the North China plain and the Plain of the Yangtze River at altitudes between 500 and 1000 m are the centres of cereal production in China, including corn, wheat, rice and soybeans (Leipnik et al. 2014). Four main agro-climatic zones are present in China: arid in the west and northwest of the mainland, semi-arid in central China, semi-humid in the north-east and humid in the south and southwest (FAO 2011). The East Asian monsoon shapes the southern part of the mainland and is usually responsible for high precipitation in the summer, roughly from April to August (FAO 2011). Wheat and maize are grown in the arid and semi-humid areas with irrigation. Wheat is also grown in the highlands of the humid zone. Rice is grown in the semi-humid and humid zones (FAO 2011). Drier and more elevated western and north-west mainland China are dominated by pastoral systems and agro-pastoral systems, which face severe overgrazing and grassland degradation (Hua and Squires 2015).

Overall, China has constrained land and water resources (OECD 2018), large parts of arable land are of low quality and water scarcity is a common challenge (CAAS 2012). More than half of Chinse cropland is irrigated (FAO 2011) and the agricultural sector accounted for 62% of total water use in 2020 (NBS 2023). During the last 50 years of the 20th century, agricultural expansion and intensification contributed to severe degradation and destruction of China's croplands, forests and grasslands, and led to associated environmental problems and negative impacts on livelihoods (Yin et al. 2014). The expansion and intensification of agricultural and livestock production has contributed to degradation and pollution of land and water resources in the country as well as to biodiversity loss (OECD 2018). China ranks as a megadiverse country and a significant number of crop species originate from there (Convention on Biological Diversity).

The country's agriculture, fisheries and forestry sector value added in % of gross domestic product (GDP) was 7.7% (World Bank 2020) in 2020 and 8% of the GDP in current prices in the same year (NBS 2021). The share of value added by the sector to China's total GDP has almost steadily declined since 1968, when it was at its highest at 41.6% (World Bank 2020).

Figure 2: Agriculture, fisheries, and forestry's contribution to GDP (2019)



Source: World Bank (2022) data for all countries except New Zealand due to lack of data. Value for New Zealand was taken from OECD (2021).

Agricultural production has continuously increased. China is the main global producer of potatoes, wheat and paddy rice. It has been the main global producer of potatoes over the last 20 years and of what and paddy rice over the last 30 years (FAO 2022d). China has also been the second main producer of maize in the last 30 years (FAO 2022d). Total crop production increased from around 508.3 megatons (Mt) in 1977 (pre reform) to 1827.5 Mt in 2020 as result of economic and land reforms as well as technological development (Garnaut et al. 2018, FAO 2022d). Cereal production more than doubled in this time, while vegetable and fruit production increased more than tenfold, also making China one of the largest vegetable producers in the world. China is also the largest producing and consuming country of pork (You et al. 2021).

Imports and exports of agricultural products have increased since World Trade Organisation (WTO) accession in 2001. In terms of import and export value in USD, China was the third largest food exporter and the largest net importer of food in 2019 (FAO 2021). According to the Chinese National Bureau of Statistics (2023), the value of exported food and live animals in 2020, was over 63.5 billion USD and imports amounted to 122.8 billion USD. The main imported foods are meat, followed by fruits and vegetables (FAO 2021). Despite being among the top producers of grains, China does not export significant amounts of maize, wheat or rice and even is one of the top three importers of rice (FAO 2021).

1.2 Socio-economic dimensions

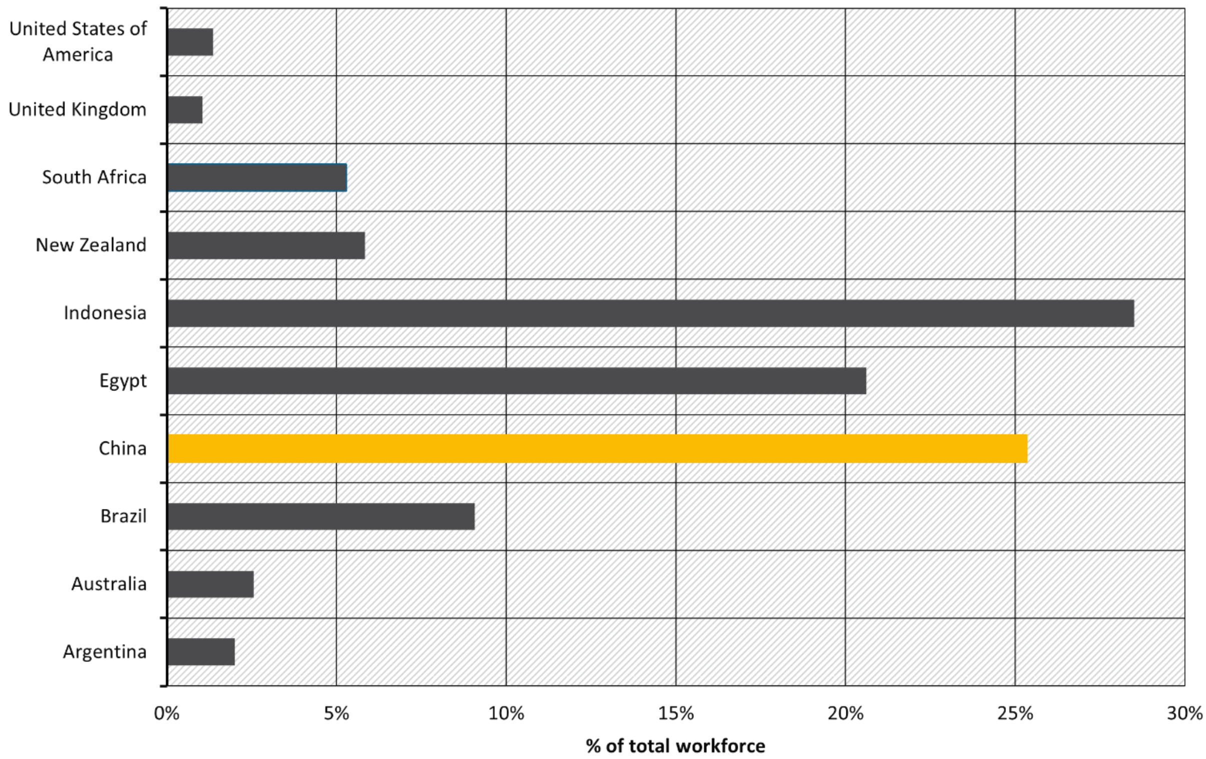
China's population exceeded 1.41 billion people in 2020 (NBS 2023) and is currently undergoing a period of demographic change. The working age population is declining as of 2015 and rural areas have a high share of population over the age of 65 (OECD 2018). China's population is projected to peak before 2030 and to stay below 1.5 billion people (UN 2022). More recent estimates indicate that the population may already have started to decrease (Silver and Huang 2022).

China started an economic reform period in the late 1970s, which led to strong economic growth and structural changes in its agricultural sector (OECD 2018). The liberalisation of the agricultural sector was at the start of the economic reform process and for example included the closure of collective farms (People's Commune system) paired with introduction of the "Household Responsibility System", which included allocation of land to farmer's households and the possibility for them to sell their production surpluses on the market and keep the income (OECD 2012, OECD 2018, Lu 2021b). At the same time the Chinese government focused on promoting industrialisation and urbanisation (Xue et al. 2021b). Part of the agricultural policy reform was to shift away from government issued production plans and targets, and to allow farmers to make their own production decisions on their household farms, which served to develop rural markets and "collective enterprises" (OECD 2002, Sun 2003). The agricultural reform also included the introduction of industrialised farming techniques to enhance productivity (Xue et al. 2021b). Although the Household Responsibility System also contributed to fragmentation of arable land, which limited opportunities for efficient allocation of agricultural inputs and led to environmental degradation from fertiliser and pesticide overuse, it also created opportunities for the creation of rural farm enterprises and over time a market of land leasing (Xue et al. 2021b). Since joining the WTO in 2002, China has committed to adjusting import tariffs on agricultural products, reduce technical barriers to trade and limit subsidies for agricultural production (OECD 2012).

In 2010 the share of rural population was slightly over 50%, in 2020 it had decreased to around 36% (NBS 2023). Since 1958 China has implemented a household registration system (户口), where each Chinese citizen is assigned a residency status (*hukou), w*hich is either rural or urban and passed on through generations (Wong 2019, Wikipedia 2023). Temporary migration was allowed as part of the economic reform around 1990, which drew rural workers into large cities to work in construction and production (Gregory and Meng 2018). This negatively affected rural development but contributed to overall Chinese economic growth (Xue et al. 2021b). The *hukou* system is undergoing reform at the provincial level since rural to urban migration remains high because higher wages can offset some disadvantages of living in an urban area with a rural *hukou* (Jaramillo 2022).

The share of the Chinese workforce employed in agriculture in 2021 is estimated to be 22.9%, down from 34.7% in 2011 (Statista 2023a). In comparison, 3.8% of the EU workforce was employed in agriculture in 2022 (Statista 2023b). The latest official information available from the National Bureau of Statistics is from 2012 and indicates a 35% share of employment in agriculture, forestry and fishery, compared to 44% in 2001 and around 71% in 1978, the start of economic reform after the end of the Maoist period (NBS 2023).

Figure 3: Agricultural employment as a share of total workforce (2019)



Source: World Bank (2021) data for all countries except Argentina due to data discrepancy. Value for Argentina was taken from ILO (2021).

1.3 Greenhouse gas emissions from the Agriculture, Forestry and Other Land Use (AFOLU) sector and drivers

According to FAOSTAT estimates, emissions from agriculture, excluding emissions, amounted to 789.6 $MtCO_2e$ in 2019 and made up 6% of national emissions (Figure 4). Emissions from agricultural soils[1] made up 31%, enteric fermentation 23%, rice cultivation 19%, manure management 7% and, crop residues 4% and burning of residues 1%. On-farm energy use contributed 15% of emissions.

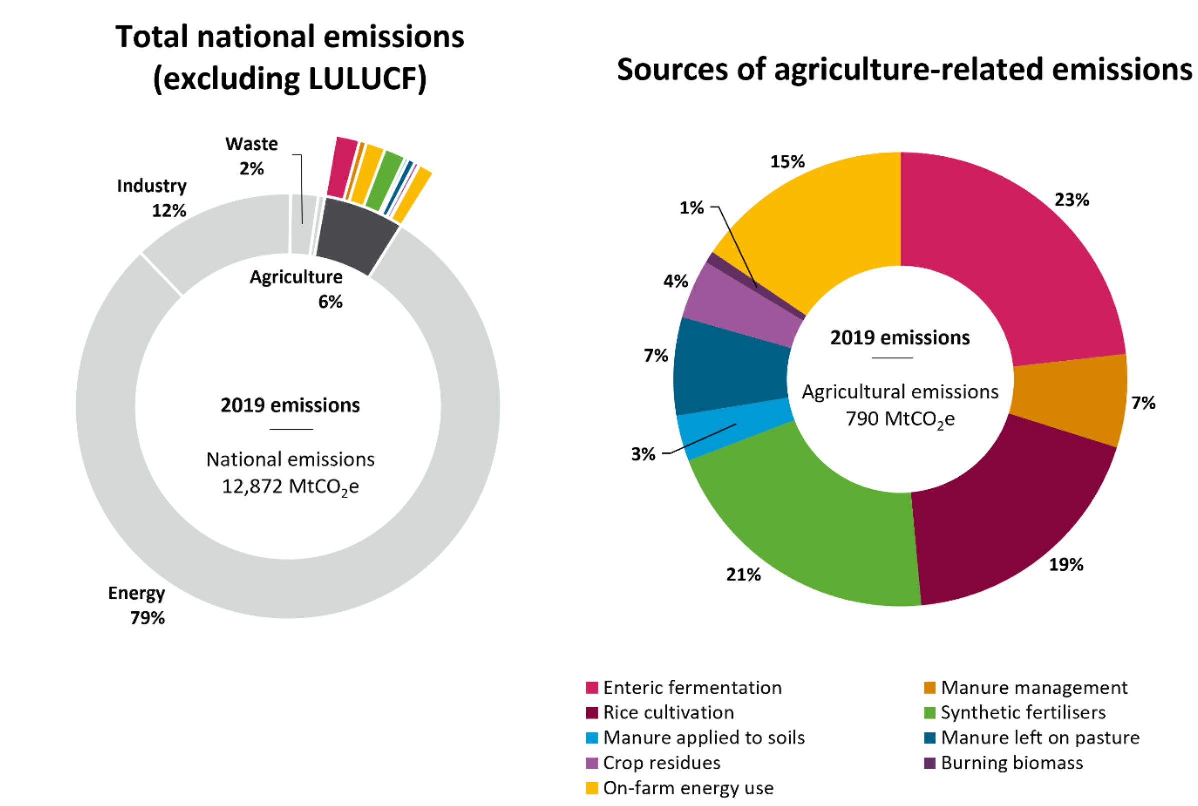
The latest available GHG emissions data provided by the Chinese Government to the United Nations Framework Convention on Climate Change (UNFCCC) is from 2018 and included in its third Biennial Update Report (BUR) (China 2023). According to national data, agricultural emission accounted for 6.1% of Chinese emissions in 2018 (China 2023). The relative importance of the different emission sources is comparable to the FAOSTAT estimates. China reported non-carbon dioxide emissions in five categories of agricultural emissions, namely enteric fermentation, manure management, rice cultivation, agricultural soils and field burning of agricultural residues. According to the BUR agricultural emissions from these categories amounted to 793 $MtCO_2e$ in 2018. The highest share arising from enteric fermentation (28.7%), followed by emissions from agricultural soils (28.1%), rice cultivation (24,7%), manure management (17.7%) and field burning of agricultural residues (0.8%). The inventory uses a combination of tier 1 and 2 methodologies from the 1996 Intergovernmental Panel on Climate Change (IPCC) guidelines. Only CH_4 emissions from rice cultivation are calculated using a tier 3

[1] This number refers to emissions from application of synthetic fertiliser and manure to soils and manure left on pastures.

methodology. The Global Warming Potential (GWP) values are from the second IPCC Assessment Report.

According to the Academy of Global Food Economics and Policy at China Agricultural University (AGFEP), the Chinese agri-food system contributed 8.2% to national GHG emissions in 2018, namely 1.09 Gt CO_2e (AGFEP 2022). This estimate includes emissions from agricultural activities, agricultural land use and energy used for intermediate inputs and food processing.

Figure 4: China's GHG emissions profile (2019)



Source: Gütschow et al. (2021) for energy (excl. on-farm energy use), industry, waste, and other sectors. FAO (2022c) for agriculture and agriculture-related emissions.[23]

According to information reported in the second BUR agricultural emissions declined in 2018, compared to the value reported for 2014 (830 MtCOe) (China 2018a). According to FAOSTAT data agricultural emissions peaked in 2016 at about 840 $MtCO_2e$ and have since then slightly declined (Figure 5). Compared to 1994, agricultural emissions in 2019 increased by about 10%. This increase was mainly driven by emissions from synthetic fertiliser (45%), manure applied to soils and pastures (36%) and on farm energy use 42%. Emissions from manure management, rice cultivation and enteric fermentation decreased by 9%, 8% and 6% respectively.

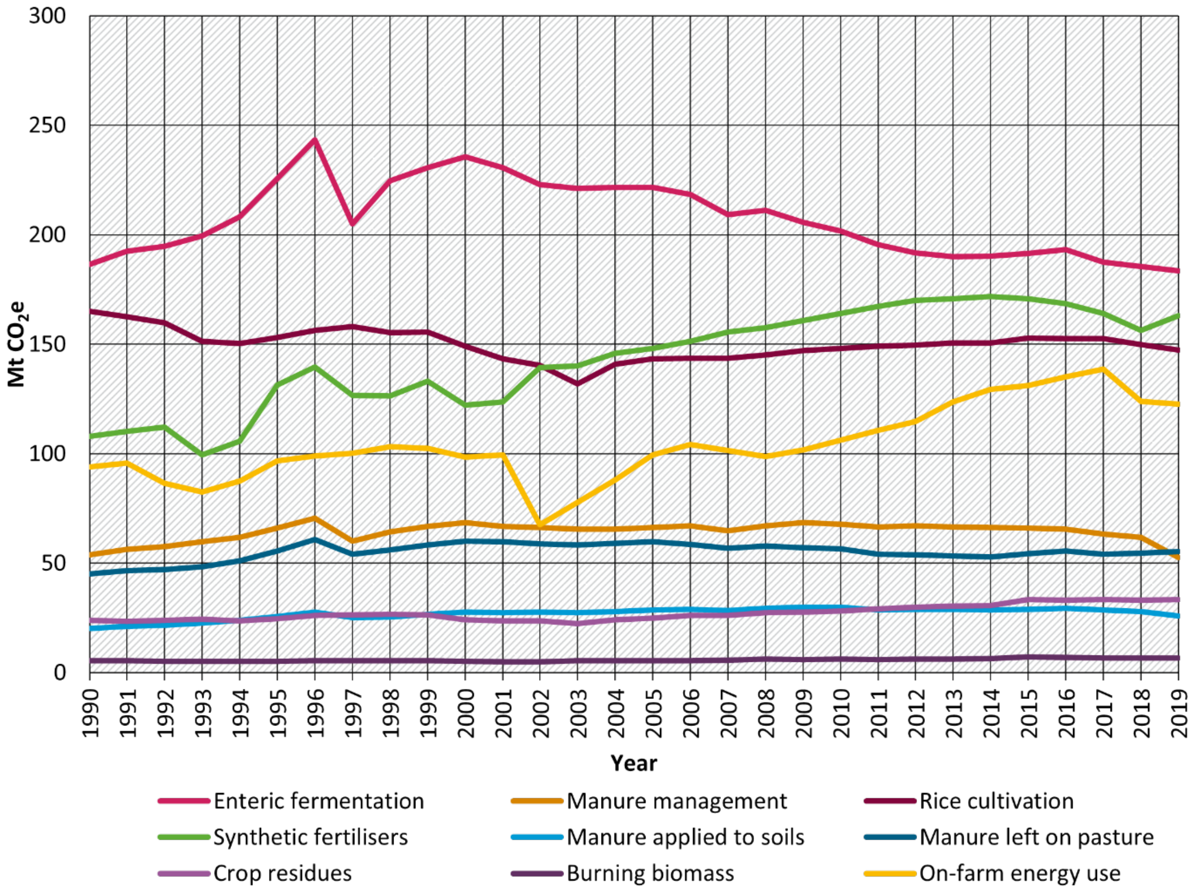
[2] The PRIMAP-hist dataset used for all non-agriculture-related emissions combines multiple datasets but prioritises country-reported data (Gütschow et al. 2021, Gütschow et al. 2016). FAO data may differ from nationally reported agricultural emissions under the UNFCCC, and thus agricultural emissions reported under PRIMAP-hist, as a result of data uncertainties and differing methodological approaches to reporting emissions in this sector. We use FAO for these graphs for non-Annex I countries since it includes a complete time series from 1990 to 2019, has a higher level of detail for non-Annex 1 countries (e.g. enteric fermentation emissions per category of animal), and to maintain consistency across the assessed countries.

[3] While on-farm energy use is generally reported under the energy sector emissions for both PRIMAP-hist (Gütschow et al., 2021) and national data, we include it as an agriculture-related emissions source in this study because it is part of agricultural production (fuel use in harvesters, stable heating, grain drying etc.) and its relevance in several countries in terms of magnitude and mitigation potential. We refer to 2019 instead of 2020 data which was the latest data available at the time of writing, due to COVID-related economic dynamics that affected national emissions in 2020.

According to the second BUR, agricultural emissions in 2014 increased by 37.1% compared to data reported in 1994 (605 $MtCO_2e$, excluding on-farm energy use). This was mainly driven by an increase in emissions from manure management of 11%. Emissions from rice cultivation were reported to have increased by 1.2%. Emissions from agricultural soils decreased by 3.1% and emissions from enteric fermentation decreased by 10.4%. On farm energy use was not reported in the Chinese BUR. The National Bureau of Statistics provides information on the "use of agricultural diesel", the latest available figure for 2019 indicates a use of 19.34 million tons (NBS 2023).

It is not clear what emissions are included under the agricultural soil emissions category by China, hence a comparison with FAOSTAT data is difficult. But assuming it includes manure left on pasture, manure applied to soils and synthetic fertiliser application, and using the same GWP values as the Chinese BUR, FAO estimates for agricultural soil emissions are higher. There are also differences in the trends for each of the emission categories, while FAOSTAT data indicates an increase in emissions from agricultural soils, the BUR indicates a decrease. While the BUR data indicates a slight increase in emissions from manure management, and a larger increase in emissions from enteric fermentation, FAOSTAT data indicates a decrease.

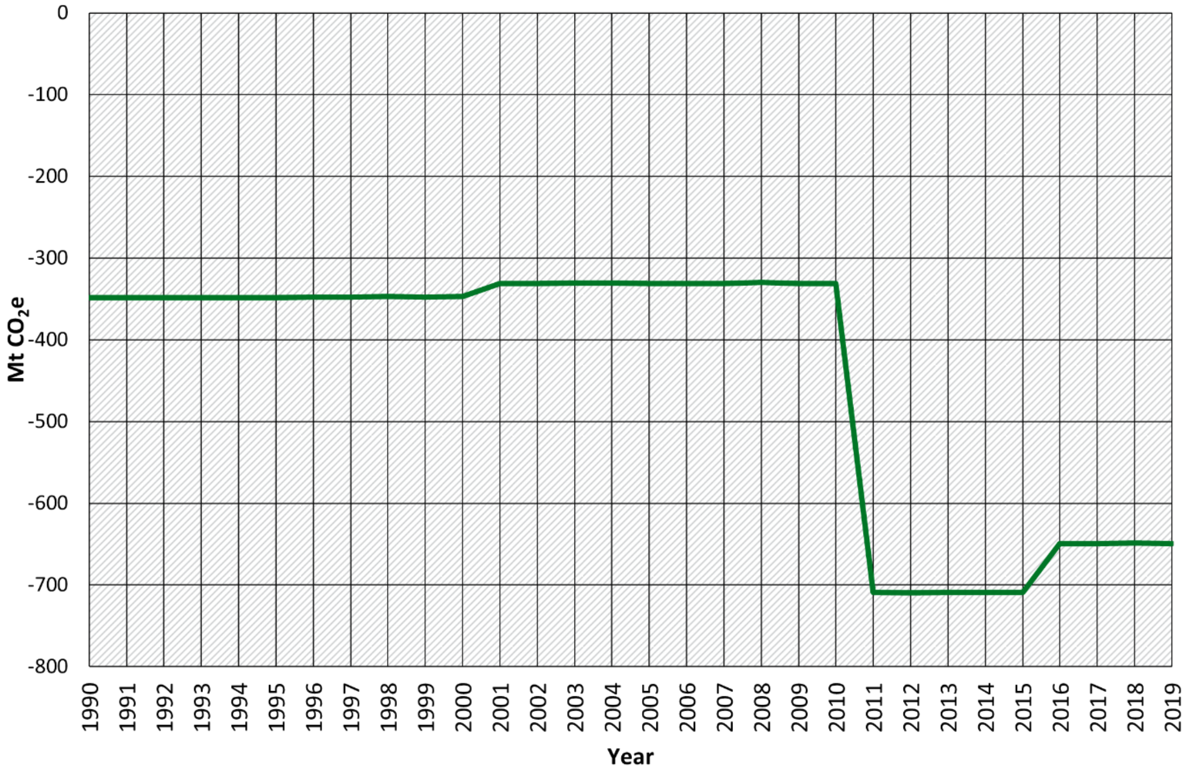
Figure 5: Agriculture-related emissions in China (1990–2019)



Source: FAO (2022c).

According to FAOSTAT, the LULUCF sector was a sink in 2019, removing 649 Mt CO_2e., mainly through forest lands. In the second BUR, the LULUCF sector was also reported as a sink in 2014, with net removals of 1151 Mt CO_2e. The largest share of CO_2 removals came from forest lands (73%), followed by harvested wood products (9.6%), grasslands (9.4%), agricultural soils (4.2%) and wetlands (3.9%.). CH_4 emissions from wetlands were 1.72 Mt. Most LULUCF categories are calculated using tier 2 methodologies, only emissions from croplands were calculated with tier 3 and other land with tier 1. In the third BUR net removals from LULUCF amounted to 1257 $MtCO_2e$.

Figure 6: LULUCF emissions in China (1990–2019)



Source: FAO (2022c). Includes FAO categories "Forestland", "Net forest conversion", "Forest fires", "Fires in humid tropical forests", "Forest fires", "Savanna fires"[4], and "Drained organic soils". Note that FAO data differs from national data and uses forest activity data in 5-year intervals, meaning data is averaged over the 5-year periods and can highly fluctuate between those intervals. This report uses FAO for consistency with the other non-Annex I countries in this report series. The most recent data on emissions from LULUCF reported by China is from 2014, where a sink of 1,115 Mt CO_2e was reported (China 2018a).

1.4 Governance structures and agricultural policy framework

Agricultural policy in China is guided by the "Chinese Communist Party (CPC) Central Committee on work related to agriculture, rural areas and farmers"[4]. Two ministries are relevant for policy formulation and implementation, namely the Ministry of Agriculture and Rural Affairs[5] and the Ministry of Natural Resources[6]. Both ministries are represented in the Chinese State Council through their minister. The State Council is the highest administrative organ of the executive branch[7]. The National Development and Reform Commission (NDRC), a department under the State Council tasked with overall economic and social government planning and strategic

[4] http://english.moa.gov.cn/Institutional/

[5] http://english.moa.gov.cn/

[6] https://www.mnr.gov.cn/jg/sdfa/201809/t20180912_2188298.html

[7] https://english.www.gov.cn/archive/chinaabc/201911/22/content_WS5ed77233c6d0b3f0e9499854.html

development[8], also plays a role in agricultural policy. The Ministry of Agriculture oversees crop farming and animal husbandry policy as well as rural social and economic development. The Ministry of Natural resources is tasked with regulating the use of forests, grasslands, wetlands and water, this includes spatial planning as well as surveying and monitoring natural resources. This ministry delineates and enforces territories destined for ecological protection (ecological conservation red lines) and for permanent agricultural use, as well as establishing urban development boundaries and is responsible for ecological restoration[9]. The establishment of Ecological Conservation Redlines is aimed and complementing the Chinese protected area system and to limit encroachment into vulnerable ecosystems (Gao et al. 2020).

Chinas administrative system is three tiered. The highest level includes administrative units directly under the central government namely the provinces (23), autonomous regions (5), municipalities (4) and special administrative regions (2). The second tier is composed of autonomous prefectures, counties, autonomous counties and cities, which are further composed of townships, ethnic minority townships and towns (China State Council 2014).

The central objectives of agricultural policy in China are the so called “three rural issues” or the “three rural areas”, namely 1) improving farmers’ incomes 2) strengthening the economy of rural areas and 3) improving agricultural productivity. The first two issues relate to the Communist party’s overarching policy goal of poverty eradication and of addressing the rural and urban divide, the third issue is related to the overarching policy goal of food security and self-sufficiency, as well as international competitiveness.

To address the many social and environmental problems arising from the transition from commune system to the Household Responsibility System (see 1.2), as well as the urban-rural divide, the Chinese government implemented a series of policies. A selection of policies, according to their relevance, scale and prominence in literature is mentioned below:

- The **Rural Revitalisation Strategy** a related strategic plan and the **Rural Revitalisation Promotion Law**. This strategy focuses on increasing agricultural production, job creation in rural areas by strengthening agriculture related industries, improvement of infrastructure and governance (Xinhua 22 Feb 2021). The law came into force in 2021 and includes a chapter on ecological protection (Standing Committee of the National People's Congress 2021). The chapter established obligations for the state to strengthen ecological protection, reduce agricultural pollution and promote restoration of fallow land, forests, grasslands, and wetlands. It also aims to improve rural housing and prevent the illegal occupation of arable land by construction.

- The **Sloping Land Conversion Programme** or the Grains for Green Projects. This payment for ecosystem services programme was designed to compensate farmers, with food and subsidies, for retiring marginal and degraded land from crop production (Xue et al. 2021b). Its objective was to combat soil erosion and desertification and promote reforestation.

- **Land consolidation efforts:** The Household Contract Responsibility System led to land fragmentation and associated inefficiencies in the use of agricultural inputs as well as barrier to mechanisation (Lu 2021b). In the late 1990 the Chinese Government started to implement policies to combat land fragmentation. This mainly

[8] https://en.ndrc.gov.cn/aboutndrc/mainfunctions/

[9] https://www.mnr.gov.cn/jg/sdfa/201809/t20180912_2188298.html

included the consolidation of small land plots into larger units and the associated construction of irrigation and transport infrastructure (Jin et al. 2017). More recently land consolidation policy also includes reclamation of degraded agricultural land or urban land for farming and land conversion to arable land (ibid). According to Jian et al. (2022) land consolidation policy in China also relates to land property rights and ecological restoration and rural development. Land consolidation is considered a key policy tool for rural revitalisation (Lu 2021a) and is also expected to reduce labour intensity and may address labour shortages arising from a declining population (Lu 2021b).

At the 2021 UN General Assembly China pledged to reach climate neutrality before 2060 and to peak GHG emissions before 2030 (China 2021). The 2021 submission of its Nationally Determined Contribution (NDC) under the Paris-Agreement mentions “structural adjustments in economy, industry, energy, transportation and consumption” to deliver benefits for both economic development and addressing climate change. Since agriculture is not mentioned in this high-level statement, but does appear later in the NDC submission document, it is presumably included under industry.

The NDC mentions several key institutions for climate policy. These include:

- National Leading Group on Climate Change, Energy Conservation and Emissions Reduction
- Leading Group on Carbon Peak and Carbon Neutrality
- National Development and Reform Commission
- Provinces (autonomous regions, municipalities) have own groups on carbon peak and carbon neutrality
- National Expert Committee on Climate Change plays an advisory role.

As new measures to implement the enhanced NDC, China will “press for emissions reduction and efficiency improvement in agriculture”. The NDC proposes an intensification of efforts to reduce the use of chemical fertilisers and pesticides and indicates that policies to promote efficient fertiliser use and the replacement of chemical fertiliser with organic fertiliser are in place since 2015. The NDC also states the intention to promote soil carbon sequestration and that the treatment of livestock and poultry manure will be refined. As of 2019, 93% of large-scale farms have manure treatment facilities. Additionally, soil testing and “energy-saving and emission-reduction technology” will be promoted. Financial support is provided to farmers to promote “waste-to-resource” utilisation from livestock and poultry manure, replacement of chemical fertiliser with organic fertiliser and use of straw.

While China states in its NDC that it aims to improve the control of non-CO_2 GHG emissions and will take measures to address CH_4 emissions from coal, oil and gas mining and other non-CO_2 industry emissions, it does not mention CH_4 and N_2O emissions from agriculture.

Ensuring food sovereignty and food security is a key policy priority for China[10], stated in high level policy documents such as the current 14th five-year plan (2021-2025) and the 2022

[10] Expressed with statements such as “the Chinese people's rice bowl must be firmly in their own hands at all times” and “the rice bowl is mainly filled with Chinese food”.

"opinions" by the of the Communist Party of China (CPC)[11] and the State Council on promoting rural revitalisation following the Covid-19 Pandemic (Chinese State Council 2022b). Policies related to this priority include the delineation of "food production functional areas" specifically for rice, wheat, and corn and of "protection areas for important agricultural product production" for soybeans, cotton, Chinese cabbage, sugar cane, natural rubber. A number of policies address the protection of agricultural farmland, for example the "red line" of keeping 120 million hectares (1.8 billion mu) of arable land (Chinese State Council 2022a).

The 14th five-year plan (2021-2025) (CSET 2021) includes a binding target to reduce energy consumption per unit of GDP by 13.5% and CO_2 emissions by 18%, which considering the Chinese NDC would need to occur until 2035. It describes plans to promote digital technologies for agricultural production and the management of agricultural services in rural areas (CSET 2021). Concrete applications of "smart agriculture" mentioned in the plan are precision application of agricultural inputs (seeds, fertilisers, pesticides) and the use of digital technology for water conservation and management.

The CPC's and State Council opinions of 2022 further describe plans to increase the expansion of beef, lamb, and diary production, and to strengthen soy and vegetable production, also in cities. The opinions reiterate a priority to save food and reducing food waste along the whole food production chain and state that upgrading of emission standards for newly produced agricultural machinery will be promoted. A whole section is dedicated to "industry for rural development", this includes policies for "green development in agriculture" namely they reiterate goals to promote the reduction in agricultural inputs, improve manure management and straw management, as well as to continue with subsidies for grassland protection and the aim to develop and apply "carbon-reducing and sink-increasing agricultural technologies". The intention to develop mechanisms to pay for agricultural carbon sinks is also stated.

The third national soil census was launched in 2022 and will be completed by the end of 2025 (Chinese State Council 2022c). It will be carried out by the Ministry of Agriculture and includes all lands. The soil census may provide relevant information for improving Chinese reporting on GHG emissions from soils, although no reference to this is made in the official communication.

1.5 Current developments and trends

Following the severe environmental degradation caused by population growth and agricultural expansion, the Chinese government introduced several restoration programmes in the last years of the 20th century and the beginning of the 21st century (see section 1.4). They include, the Natural Forest Protection Programme, the Desertification Combating Programme and the Sloping Land Conversion Programme (Yin et al. 2014).

After the outbreak of African swine fewer in 2018, that led to the culling of animals (You et al. 2021), pig herds are growing again and the sector is switching to modern intensive production facilities, which are expected to increase feed demand (OECD 2022). Likewise, income growth and continued urbanisation will continue to drive the demand for meat and fish in China, which is expected to account for 41% of additional global fish demand and 34% of the additional global meat demand in the next decade (OECD 2022).

The Covid-19 pandemic had only a small effect on the Chinese agricultural and food processing sector and following the termination of the zero-Covid policy, economic growth is expected to recover along with imports of agricultural products (US Foreign Agricultural Service 2023).

[11] The CPC is composed of the communist Party leadership and is the authoritative political body, during the periods between plenary sessions of the National Congress of the Chinese Communist Party.

Agricultural support policies have played an important role in increasing the productivity of Chinese agriculture, they include for example direct grain subsidies, subsidies for agricultural inputs and machinery, minimum purchase prices for rice and wheat as well as storage of maize and soybean (AGFEP 2022) . Reform of these policies is recognised as a key lever to support the transformation of agricultural production and is underway since 2015, as for example subsidies now target efficient agricultural machines and the support for fertiliser production has been phased out (AGFEP 2022).

In the 1990s, China also developed a national approach to organic food certification in form of its "Green Food Logo". The Ministry of Agriculture was responsible for developing the Green Food Programme and promoting the production of green in response to environmental degradation and to boost farmers' incomes. The approach taken by China with its Green Food label, was to introduce a level of certification that would still allow for some use of synthetic fertiliser and pesticides, but still contribute to reducing overuse (Paull 2008). Current grade A certification allows for some use of synthetic fertilisers and pesticides, while grade AA certification prohibits their use and is thus equivalent to organic certification (Paull 2008, Sternfeld 2021). The China Green Food Development Centre is tasked with certifying green food enterprises following strict environmental controls (Lin et al. 2010a, Sun et al. 2021). Green food certification requires that the production area is free of pollutants such as heavy metals (Xu et al. 2020, Lin et al. 2010b). Demand for green foods and its contribution to agricultural value creation have continuously increased reaching 9.7% of agricultural GDP in 2019 with almost 16000 operating green food companies (Xu et al. 2020). The China Organic Food Certification Center introduced an organic food label in 2002, which replaced the grade AA level green food label in 2008 (Sternfeld 2021, Yu et al. 2014).

In line with raising incomes the per capita consumption of animal products has increased and this trend is expected to continue (OECD 2018, Meridian Institute, The Food and Land Use Coalition 2023). The steepest increases are in consumption of pork and poultry meat (OECD 2023). Though pork consumption dropped due to the African swine fever, it is expected to bounce back to around 30 kg per capita per year by 2030.

A recent study by Xue et al. (2021a) showed that 27% of food produced in China in a year is lost and wasted. According to the Chinese Academy of Agricultural Sciences food waste occurring at the storage, transport and processing stages of the supply chain amounted to 35 million tonnes (FAO 2015). The Chinese government has been taking measures to address food waste for in the last decade (Feng et al. 2022). The latest anti-food waste campaign is the 2020 "Clear your plate campaign", which targets food waste by restaurants, caterers, canteens, and individuals (Xinhua 2020). An "Anti-food Waste Law" came into force in 2021 (National People's Congress 2021). The addresses multiple stakeholders of the food value chain, like food producers, food operators and consumer associations, however the main subject of the law is the catering sector which is given a series of complete obligations and can be fined or have its business suspended in case of non-compliance. The law will also help improve information on food waste, since governments starting from the county level upwards are required to showcase their progress in reducing food waste and the food and catering sector is required to carry out food waste monitoring and publish the information.

Energy consumption of agriculture in China has steadily grown, mainly because of increasing mechanization in cropping, livestock rearing and fish production (Fu et al. 2021, Zhen et al. 2023). In crop production increasing fertiliser and pesticide inputs as well as irrigation also led to more energy consumption (Fu et al. 2021). China's agricultural energy use, accounted for more than 20% of global energy consumption in agriculture (Zhen et al. 2023). In 2020 agriculture, forestry, animal husbandry and fishery accounted for 1.9% of total energy consumption in China (9263 Mt standard coal equivalents).

1.6 Vulnerability and adaptation

Adaptation in the agricultural sector stands high on the political agenda since climate change imperils achieving the national food security target. Rising temperatures and changing precipitation patterns are the main climate change impacts affecting China's agricultural productivity (Xie et al. 2020b). China has seen increased river flooding in some areas as well as increasing droughts, especially in the agricultural productive regions of the Northeast and Southwest (OECD 2018). China ranked first, in a 2017 OECD assessment of "water risk hotspots for agriculture" (OECD 2017). In the summer of 2022, the south of mainland China saw a record drought, that affected agricultural outputs and energy supply (Zhu 24 Aug 2022). Crop yields are likely to decrease due to raising temperatures and higher variability in precipitation (Xie et al. 2020a, Saud et al. 2022). Heat, in form of daily average temperatures over 30°C, is also expected to reduce cropland area (Wang et al. 2022b). While heat stress is a risk to livestock in extensive and production systems (Thornton et al. 2022), pastoral systems will likely suffer through increased temperatures but may benefit from increased precipitation (Feng et al. 2021).

Adaptation actions that are being implemented or discussed include the development and use of drought and heat resistant crop varieties (Cui and Xie 2021), shifts in planting dates and growing season, improved agro-climatic zoning at the county level to address risks of meteorological disasters and infrastructure development, e.g. for water conservation and irrigation. The NDC mentions actions such as expanding the area of irrigated farmland, which currently stands at around 68.3 million ha, and improving use efficiency of irrigation water (China 2021).

The Chinese Government first published an adaptation strategy in 2013 with targets until 2020. A new adaptation strategy for 2035 was published in 2022 (Chinese Government 2022). It has a strong focus on improving climate and weather observation capacities as well as prediction and early warning. The section on agriculture and food security includes actions related to improving crop and animal varieties and changing agricultural practices, for example by extending the growing season into winter or planting in higher latitudes. It also states that a system to certify climate friendly and low carbon agricultural products will be developed to strengthen farmer's incomes. Reducing pesticide and chemical fertiliser inputs and increasing their use efficiency are also included as adaptation measures, since these actions contribute to improving the quality of agricultural lands.

2 Key areas with high mitigation potential

2.1 Introduction

In this section, we prioritise three mitigation options for the quantification of their mitigation potential, in the country-specific context. For the prioritisation of measures, we first looked at the emissions contribution of each subsector (See section 1.3). As described in the section, the largest emissions sources are agricultural soils (31%), followed by enteric fermentation (23%) rice cultivation (23%) and manure management (19%) and on farm energy use15%). Manure management, crop residues and burning of residues contribute 7%, 4% and 1% respectively. We further considered measures with a potential to deliver socio-economic benefits, based on the general characteristics of the Chinese agricultural sector as described in Section 1. The feasibility for implementation was also considered in the choice of measures (Siemons et al. 2023).

2.1.1 Selection of priority mitigation actions and mitigation potential estimates

Based on the above-described criteria, we selected the following mitigation measures for China:

- Improved rice cultivation
- Improved nitrogen management (focus on synthetic fertiliser use and application)
- Improved manure management (focus on processing, storage, and re-utilization).

Improved rice cultivation could reduce CH_4 emissions as well as reduce irrigation needs and related energy consumption. Estimated mitigation potentials for improved rice cultivation until 2030 range from 14 $MtCO_2e$ to 26 $MtCO_2e$ per year at the lower end and 51 $MtCO_2e$ to 64 $MtCO_2e$ per year at the higher end (see section 2.2.1).

Improved nitrogen management reduces overapplication of fertiliser and thus decrease N_2O emissions while delivering co-benefits for soil health and water quality. Improving nitrogen management is possible through a wide range of practices and technologies, such as the type of application and the type of fertiliser used. Estimates for mitigation potentials up to 2030 range from 13 $MtCO_2e$ at the lower end and 213 $MtCO_2e$ per year at the high end (see section 2.2.2).

Improving manure storage and processing as well as putting it to use as a source of bioenergy can reduce emissions from excess manure during storage. An estimated mitigation potential is of 129 $MtCO_2e$ (see section 2.2.3).

Targeting the current decoupling of crop and livestock production is a key strategy to address manure excess (Wei et al. 2021). Hence, there is a potential overlap in the measures of improved nitrogen management and improved manure management when it comes to the use of manure as fertiliser. To address this overlap and clearly identify mitigation potentials for the purpose of this report, the replacement of synthetic fertiliser with manure is considered under improved nitrogen management, whereas measures related to processing manure for use as fertiliser are considered under improved manure management. This is carried out under full consideration of the strong link between the measures.

Additional emission reductions can be achieved through improved on-farm energy use, improving livestock health, decarbonising the production of synthetic fertiliser, supporting soil carbon sequestration and measures to address the increasing trend in meat consumption. Some of these measures are already being addressed, for example China is providing support to farmers to replace energy intensive agricultural machinery (China 2022a) and subsidies for the purchase of machinery for straw incorporation into cropland (Chen et al. 2023).

2.2 Prioritised mitigation options

This chapter is based on literature review using mainly Chinese sources that are available in English and limited automatic translations of policy documents only available in Chinese using DeepL. Different estimates for the mitigation potentials of mitigation action are presented, to show the variety in estimates.

2.2.1 Improved rice cultivation

Measure	Reducing CH_4 and N_2O emissions from rice cultivation requires changes in agricultural management practices. The main factors influencing CH_4 and N_2O emissions are the water regime and nutrient input, mainly from synthetic fertiliser or straw residues. Seeding practices and the utilised crop varieties also have an influence on emissions as do temperature and soil properties. The level of mechanisation in rice production also influences the amount of energy used, since machinery increases fuel consumption, but can also lead to a more efficient use of fertiliser and pesticide inputs (Yang et al. 2022). Rice is predominantly grown in puddled or flooded fields, where anaerobic conditions favour the release of CH_4. Cultivation under aerobic conditions (dry rice) with targeted irrigation is also possible. Options to change the water regime in puddled rice are mid-season drainage, where fields are drained in the middle of the growing season and alternate-wetting-and drying (AWD) or furrow flooding[12].
Status	29.45 Mha were sown with rice in 2022 (NBS 2023). The National Bureau of Statistics distinguishes between early rice, mid-season rice and single-cropping late rice, and double cropping rice[13]. 90% of rice in China is cultivated using some form of irrigation (IRRI 2023), providing ample opportunities to optimise irrigation practices. According to Qui (2009), around 80% of Chinese rice farmers have been practicing mid-season drainage on their fields since the 2000s. Reducing methane emissions from rice cultivation features in China's NDC (China 2021). In its communication on progress in implementing the NDC, China describes the implementation of demonstration projects applying "straw mulching" are currently under implementation, this practice is reported to increase yields by around 4% to 9% and nitrogen fertiliser use efficiency by 30% to 36%, as well as reduce methane emissions by 31.5% to 71.7% (China 2022a).
Potential	IRRI (2019) estimates that AWD can lead to a 30-70% reduction in CH_4 emissions without negatively impacting yields. Based on estimates from AGFEP (2022), China could reduce emissions from rice cultivation by 14–37 $MtCO_2e$/year compared to a 2030 baseline, corresponding to 9–25% of emissions from rice cultivation in 2019. The lower end of the range is the mitigation potential from

[12] Furrow flooding refers to a practice where crops are planted on top of little mountains of soil and water flows through adjacent furrows (Chlapecka et al. 2021).

[13] Early rice is planted between March and April and harvesting takes place between June and July. Late rice is planted between June and July and harvested between October and November. The intermediate season has planting between April and June and harvesting between August and October. In many provinces rice cropping is combined with other crops, for example wheat and rapeseed (FAO 2002).

applying a system of rice intensification (SRI)[14]. While SRI usually includes irrigation management, the study only estimated the mitigation potential assuming SRI would lead to a 3% increase in yield and a 20% reduction in fertiliser input. The higher end of the range is the mitigation potential from applying alternative wetting and drying, assuming it leads to a 50% reduction of CH_4 emissions without negatively impacting yields. AGFEP (2022) assumes that AWD and SRI will be implemented on 30% of cultivation area by 2030 and 80% by 2060.

The above range is fairly in line with Roe et al. (2021), who estimate the technical mitigation potential of improved rice cultivation practices to be between 26–51 $MtCO_2e$/year. Wang et al. (2022b) based their calculation on a mitigation potential of 0.65 tCO_2/ha and year, from mid-season drainage and rice straw removal. They assumed these practices would be applied on a total of 30.45 Mha of rice fields. The total technical mitigation potential estimated was about 64 $MtCO_2e$/year, assuming full implementation on the total area by 2030 and of 37 $MtCO_2e$/year, assuming full implementation on the total area by 2060. In their calculation approach faster implementation leads to higher yearly mitigation potentials, because the full potential is realised in a shorter timeframe.

Using the DeNitrification-DeComposition (DNDC) model, the US Environmental Protection Agency estimated a maximum mitigation potential in China of 25 $MtCO_2e$/year in 2030 and 19 $MtCO_2e$/year in 2050 (EPA 2019)[15]. Using linear interpolation for China, Lu et al. (2022) estimated a maximum mitigation potential of 13 $MtCO_2e$/year in 2060.

While the government is promoting straw mulching and reports that this measure contributes to reducing CH_4 emissions, studies also show that straw application can lead to increased CH_4 and N_2O emissions (Wang et al. 2016, Watanabe et al. 1998, Nayak et al. 2015). A more recent study by Jiang et al. (2019) suggests that CH_4 emission estimates from straw addition are over estimated, considering the effects of application during five-year application. Thus, uncertainty around the effectiveness of this measure remains, as long as the supporting data for the government estimates is not available.

Co-benefits

SRI can potentially increase yields and allow for saving in input cost for chemical fertiliser (AGFEP 2022). Water management practices that are alternative to continuous flooding save irrigation water, can also contribute to reducing energy demand for irrigation and reduce farmers' spending for irrigation (He et al. 2020). Under future climate change conditions, where higher variability in precipitation and seasonal drought are expected, improving irrigation management and reducing water use, while at the same time using rice varieties suited for drier conditions, may also contribute to increasing resilience of rice cropping systems in China (Saud et al. 2022, Heredia et al. 2022). A recent study

[14] SRI is an approach that proposes to concurrently adapting plant management (e.g. seeding and planting), nutrient management (e.g. use of organic matter to increase soil fertility instead of chemical fertilisers) and water management (e.g. avoiding continuous flooding).

[15] In calculating the mitigation potential, the EPA study considered combinations of different management techniques with a potential to reduce GHG emissions from rice cultivation. These were: "water management regime (continuous flooding, mid-season drainage, dry seeding, alternate wetting and drying, and switching to dryland rice production system), residue management (partial or total residue incorporation), tillage, and various fertilizer management alternatives (ammonium sulfate in place of urea, urea with nitrification inhibitor, slow release urea, 10% reduced fertilizer, 20% reduced fertilizer, and 30% reduced fertilizer)" (2019).

by Song et al. (2021), also indicates that AWD may have a positive effect on the nutritional value of milled rice.

Barriers

Economical barriers: AWD is labour intensive and can have a negative impact on yields, depending on regional climatic and cropping circumstances (AGFEP 2022). Likewise, alternative fertiliser application and mulching require labour and may need initial investments.

2.2.2 Improved nitrogen management

Measure

Overapplication of nitrogen (N) fertiliser leads to N surpluses in the environment, which contribute to N_2O emissions and N leaching in form of nitrates, soil acidification, eutrophication of water bodies and N depositions that negatively impact biodiversity (Xu et al. 2020). The measure as defined in this report, includes reducing the total input of chemical fertiliser, e.g. by replacing it with organic fertiliser, as well as expanding the use of low emission application technologies, such as injection and rapid incorporation for the spreading of organic fertiliser. To improve the efficiency of fertiliser use, the following technologies are being considered for the three major Chinese grain crops[16]: "slow and controlled-release fertilisers, organic–inorganic compound fertilisers, machine deep placement of fertiliser, and integrated soil-crop system management"[17] (AGFEP 2022). This measure focuses on emissions from fertiliser use, which are influenced by the application method, timing and rate, environmental conditions and the cropping system (Oppenheimer et al. 2022). An approach focusing on maintaining a stable soil N balance has been proposed to facilitate improved N management by smallholder farmers (Yin et al. 2021).

Status

29.4 Mt/year of nitrogen fertiliser on cropland were applied in China in average from 2010 to 2019 according to the China Rural Statistical Yearbooks (Wang et al. 2022a). A policy for zero growth in fertiliser use by 2020 is in place since 2015.[18] Between 2015 and 2019 fertiliser use is reported to have fallen by 10.3%, however fertiliser use per hectare is still 2.9 times the global average (AGFEP 2022). Pilot projects to replace chemical fertilisers with organic fertilisers in fruit, tea and vegetable plantations are underway since 2017 in 100 counties (AGFEP 2022)[19]. China promotes the use of organic fertilisers, the adoption of precision farming practices to improve nutrient use and pesticide use efficiency (Chen et al. 2023). According to relevant documents from the Ministry of Agriculture and Rural Affairs, the area of organic fertiliser application in 2020 exceeded 36.7 Mha, an increase of about 50% over 2015 (Chen et al. 2023). Integrated irrigation and fertilisation (fertigation), to facilitate the precise application of fertilisers is a measure proposed by the Ministry of Agriculture and Rural Affairs since 2015 (Chen et al. 2023).

Potential

Depending on the specific mitigation measure or technology implemented, China can potentially reduce emissions from fertiliser use on cropland by around 13–50 $MtCO_2e$/year compared to a 2030 baseline, corresponding to 8–31% of

[16] These crops are rice wheat and maize

[17] Integrated soil-crop system management combines practices of soil and crop management to improve productivity and resilience. This applies to management decisions on crop rotation, pest control, fertiliser application etc.

[18] "Zero Growth Action Plan for Fertilizer Use by 2020" issued by the Ministry of Agriculture and Rural Affairs.

[19] China has 2851 county level administrative units (Zhang et al. 2022).

emissions from synthetic fertilisers in 2019. The lower end of the range is derived from AGFEP (2022), who estimate the mitigation potential from a reduction in fertiliser usage from applying fertiliser close to the ground. The same study estimates a slightly higher mitigation potential from the use of organic-inorganic compound fertilisers (average of 18 $MtCO_2e$) and integrated soil-crop system management technology (average of 16 $MtCO_2e$). AGFEP (2022) estimate that these technologies can be applied on 20% of crop area by 2030 and 30% by 2060. The higher end of the range is derived from Chen et al. (2022b), who estimate the mitigation potential from knowledge-based nitrogen management and the use of enhanced efficiency fertilisers.

Roe et al. (2021) estimates a significantly greater range of technical mitigation potential of 11–213 $MtCO_2e$. The high maximum potential can be attributed to the study's assumption that improved nutrient management is applied to all cropland, while the lower end of the range is said to be conservative (ibid).

In a study funded by the International Fertiliser Association, Oppenheimer et al. (2022) estimated that applying precision agriculture technology to improve nitrogen use efficiency[20] on half of the sown area of winter wheat could result in emissions reductions of 12 $MtCO_2e$/year compared to a baseline, while improving winter wheat crop rotations with maize and soya bean would result in further reductions between 4–10 $MtCO_2e$/year. The same study estimates that improving nitrogen use efficiency of crops or the use of enhanced efficiency fertilisers (e.g. urease inhibitors) in rice crops can result in collective emissions reductions of ~4 $MtCO_2e$/year.

It is unclear to what extent the management options described above can be combined. Since nutrient and fertiliser management is implemented on a farm level, there is no 'one-size-fits-all' approach, and certain mitigation options may be more successful than others depending on the circumstances. In some cases, technologies to reduce the use of synthetic fertilisers may also be mutually exclusive, as farmers may opt for the application of only one. In general, applying knowledge-based nutrient management could be prioritised and supplemented by technological measures to ensure maximum mitigation potential. Large uncertainties still exist about the actual N_2O emissions arising from the application of 1t of N fertiliser, estimates range from 0.3% to 3% (Wang et al. 2022a).

Co-benefits

Reducing nitrogen surplus has various positive co-benefits for ecosystems and biodiversity.[21] Fertiliser use negatively affects water quality through nutrient enrichment (eutrophication) resulting in excessive growth of macrophytes and algae which can diminish dissolved oxygen levels. Diffuse water pollution from agriculture is a significant problem in China (Smith and Siciliano 2015). Resulting ammonia emissions also contribute to the acidification of soils. Reducing fertiliser use can therefore contribute to soil health and protecting biodiversity by avoiding changes in soil pH, and toxicity of soils (Bobbink et al. 2010).

[20] Nitrogen Use efficiency is a metric for benchmarking N inputs and outputs in cropping systems. Multiple indices exist to express Nitrogen Use Efficiency (Congreves et al. 2021). Sytemiq used the indicator "ratio of the quantity of nitrogen removed from a given area during a harvest and the total amount of nitrogen that enters that area over the season. Nitrogen inputs include mineral and organic fertiliser, biological nitrogen fixation and atmospheric deposition" (Oppenheimer et al. 2022).

[21] According to a recent report under the Geneva Air Convention of the United Nations Economic Commission for Europe (CCE), a number of ecosystem types are more sensitive to nitrogen surplus than suggested by previously assumed values for critical loads for harmful nitrogen inputs (Aazem et al. 2022).

Additionally, negative water effects like freshwater acidification and groundwater contamination can be mitigated if fertiliser use is reduced (Vries et al. 2013). Wang et al. (2023) found that increasing efficient nitrogen management contributes to reducing cropland expansion, as it has a positive effect on land productivity. Moreover, saving costs for fertiliser provides socio-economic benefits to farmers.

Barriers

Technical barriers: Soil and climate conditions imply uncertainty and heterogeneity for required levels of nitrogen and leaching effects (Andersen and Bonnis 2021). Therefore, changes in nutrient management must be targeted and farmers require support to implement the correct improvements.

Economical barriers: The use of manure as fertiliser depends on subsidies because synthetic fertiliser application costs are only about half of costs for manure application (Wei et al. 2021). AGFEP (2022) estimates that subsidies for the use of organic–inorganic compound fertiliser needs to be increased by CNY 500 per ha, assuming that the input cost for compound fertiliser with a share of 60% organic fertilisers costs is CNY 2600/ha and 2100/ha for chemical fertiliser. Alternative N management is also knowledge intensive, and farmers require training for its application. A potential socio-cultural barrier related to smallholder farmers, is that a large N input is considered as insurance against low yields (Yin et al. 2021).

Institutional barriers: As described above, the central government has put in place stringent policies to limit fertiliser overuse, however their success is limited because enforcement and monitoring take are responsibility of local governments (Smith and Siciliano 2015).

Socio-cultural barriers: Under the Household Responsibility System, farmers must fulfil grain quotas and pay taxes, but are allowed to keep any additional income they generate (Smith and Siciliano 2015). This generates an incentive to increase production through fertiliser application. Historically, the reform that replaced collective farms with farms led by individual households under the Household Responsibility System led to significant increases in agricultural production, but also to the overuse of fertilisers and pesticides (Xue et al. 2021b). Although the returns from fertiliser overuse have diminished and environmental problems are acute, farmers still aim to maximise production with fertiliser use.

2.2.3 Improved manure management from livestock and poultry

Measure

The number of large scale and intensive livestock systems has increased over the last 40 years, contributing to a decoupling of livestock and cropping systems (Wei et al. 2021). Large livestock farms operate without having access to cropland for manure application, while crop production is predominantly carried out by small-scale farmers that do not have high capacities for application of manure on their land (Wei et al. 2021). This has created barriers for integrated manure management. In this report, the use of manure to replace synthetic fertiliser is considered under the measure improved nitrogen management. This measure focuses on options to improve management of excess manure from large scale livestock operations. China promotes increasing manure utilisation as a source of bioenergy and fertiliser. Dong et al. (2022) provide a general picture of the manure management practices in China, they mention the following:

"grazing, daily fertilisation, solid storage, open-air drying, liquid storage, oxidation ponds, cesspit storage within confinement sheds, biogas tanks, combustion, beddings, composting, anaerobic treatment". The utilisation of manure to replace synthetic fertiliser is also considered under this measure, since integrated management is required to prepare manure for use. Currently strict limits for manure application per ha are in place as a pollution control measure and before it can be applied on soils, manure from large-scale farms needs to undergo treatment to prevent pollution from heavy metals and antibiotics, which enter the system through the use of feed additives (Wei et al. 2021).

Status

China produces more than 3.8 billion tonnes of livestock and poultry manure per year (Chen et al. 2023). Regulation to address pollution from intensive livestock operations is in place since 2014 (CCAC 2020). The State Council has set a target to increase livestock manure utilisation to 90% by 2035, as of 2017 it was at 70% (Wei et al. 2021). The 2014[22] regulation introduced requirements for establishing and expanding livestock farms, such as carrying out an environmental impact assessment and specifying how manure will be treated and stored (ibid.). Between 2017 and 2020 specific technologies were promoted as part of an action plan for recycling of livestock manure, for example manure collection and land application, specialised biogas plants, composting of solid manure, high-rise fermentation beds and manure treatment before discharge. As of 2020, regulation on manure treatment and release into the environment has been strengthened (Bai et al. 2021). For example, clear requirements are set out for facilities that have land available for manure application and for those that do not. By 2020, 97% of large-scale farms had sewage treatment facilities (AGFEP 2022). Manure excess is distributed unevenly across mainland China as most intensive livestock farms are concentrated in the southern and coastal regions (Bai et al. 2021). Effective manure distribution systems away from regions with excess are currently not in place. The potential for manure distribution is also limited, given associated high costs for storage, transport and application of manure (Wei et al. 2021). 96 counties received support for improving manure recycling and building infrastructure in 2021 (China 2022b).

Potential

Demand for animal products is expected to grow until 2030 leading to an increase in associated GHG emissions. According to Dong et al. (2022), composting of solid manure and anaerobic digestion of liquid manure should be the priority for improving manure management of large-scale farms. Measures to promote this transition are already underway, so that a peaking of CH_4 emissions from manure could be achieved by 2025 at a level of 71 $MtCO_2e$ (ibid.). Bai et al. (2021) argue for manure management approaches that are regionally specific and respond to differences in livestock feed self-sufficiency, soil bearing capacity and ammonia emissions. Generally, feed self-sufficiency is low in counties with excess manure. Improving manure management from pig rearing is especially relevant in China, given the scale at which it takes place. According to Davison et al. (2023), China produces almost 72 Mt of pig manure per year. They estimate a mitigation potential of 1.8 $kgCO_2$/kg pig manure volatile solids and a total mitigation potential of 129 $MtCO_2e$ from anaerobic digestion of pig manure[23],

[22] Regulation on the Prevention and Control of Pollution from Large-scale Livestock and Poultry Operations.

[23] Davison et al. (2023) also include the effect of co-digestion of pig manure with grass, which increases the mitigation potential.

	considering that biogas would contribute to lower the carbon intensity of the electricity grid. Wang et al. (2017) estimated that replacing liquid manure management systems with systems that separate solid from liquid components could reduce CH_4 and N_2O direct and indirect emissions by 65%. Chen et al. (2022a) estimate the mitigation potential from methane production from livestock and poultry manure at 119 $MtCO_2e$ by 2050.
Co-benefits	Reduced pollution of air and water. The measure contributes to pollution control, mainly through reduction of non-GHG emissions, such as ammonia, fine particles and odours and leaching of N and phosphorus (P) into water (Wei et al. 2021). Adequate treatment of manure before application could reduce the risk of heavy metal and antibiotics concentration in soil, preventing negative impacts on human health. Using straw, livestock and poultry manure, and other biomass to produce renewable energies such as biogas, bio-liquid fuels, and combustion power generation can lower the emissions of fossil energy used in agriculture and rural areas, and thus contribute to achieving carbon peaking and carbon neutrality (Chen et al. 2023).
Barriers	**Economic barriers:** Improving manure management on farm can require high up-front costs for infrastructure, including the construction of storage and processing facilities. The lack of economic incentives for farmers to invest in better manure processing and reutilization infrastructure is a key barrier for this option (Chen et al. 2023). **Structural barriers:** Regional differences in the size of farms and available land require that manure management strategies are targeted, especially when it comes to the utilisation of manure as fertiliser. Large animal farms are concentrated in the east where land availability is limited, and manure reutilization not as fertiliser is relevant. While in the northeast and central China smaller farms dominate that require cooperative action to improve manure management. Infrastructure and companies that would allow for manure transport between large livestock farms and small crop farms is still under development.

3 Barriers to implementing mitigation potential

In this section, we look into the main barriers to mitigation of agricultural emissions identified for the country, building on the findings of a report on general barriers prepared under this research project (Siemons et al. 2023) and the country-specific circumstances described in Section 1 of this report. The analysis of barriers below follows the clustering proposed in Siemons et al. (2023), according to the relevant governance level for taking action, while taking into account the classification from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (Smith et al. 2019) within each of the governance levels.

3.1 Farm level

Smallholder farmers dominate Chinese agricultural production as they are responsible for 70% of cultivated land (Xu et al. 2023). Especially smallholders face economic and technical barriers to adopt new technologies or sustainable practices as they lack the investment capacity, resources, and knowledge to adopt new technologies or sustainable practices. The mitigation options discussed in this report require upfront investments in infrastructure, machinery, and equipment, as well as capacity building to transition from current practices to alternative, more sustainable ones (e.g. cost of implementing separation systems for improved manure management or improved nitrogen management). Additionally, farmers may lack the knowledge on potential gains from sustainable practices or new technologies.

Xu et al. (2023) conducted a comparative study of mango farmers in Hainan to understand factors influencing the uptake of organic fertiliser application and soil testing for optimised nutrient management. They found that lower levels of education and larger planting scale and associated costs of labour and transportation were barriers to the adoption of these practices.

As the farming population in China ages, this also poses a barrier for a shift towards sustainable agriculture, since factors associated with higher age limit the adoption of new methods and skills by older farmers (Gu et al. 2022).

3.2 National level

The primary policy objectives in China are ensuring food security and self-sufficiency, as well as addressing the three rural issues (increasing agricultural productivity, increasing farmer's incomes, and enhancing rural development). At the same time, the government has issued national policies to improve environmental quality and address pollution from fertiliser and pesticide overuse and plastic film. Chinese agriculture is naturally constrained by the limited availability of arable land but at the same time, agricultural land is being lost. One cause of loss is degradation driven by farmers, another is urbanisation, especially in the East where most fertile land is located (Smith and Siciliano 2015). However, no overarching policy seems to be in place that would help to address potential conflicts or foster synergies between the policy objectives of increasing agricultural productivity and protecting the natural basis for agricultural production (Yu and Wu 2018).

As Smith and Siciliano (2015) describe, fertiliser overuse is also a result of the imperative of economic growth to maintain high yields, even on marginal lands of low quality. High quality farmland is still lost to urban and industrial development, but since compliance with the target of maintaining the total area of agricultural farmland ("red line", see section 1.4) is still required, farming shifts to marginal lands.

A specific policy and technical barrier for implementing environmental regulation in China is the lack of a clear environmental authority tasked with enforcement and monitoring (Smith and Siciliano 2015). Additionally, local governments, which would play a role in monitoring and enforcement, tend to focus more on the policy objectives related to economic growth and productivity (ibid.).

Agricultural support policies constitute another policy barrier for a shift towards sustainable agriculture, as they are aligned with achieving production targets to ensure food security and only minimally support goals associated with nutrition, health and the environment (AGFEP 2022). According to Chen et al. (2023) the "complex channels and conflicting objectives" of agricultural support policy, are a significant barrier for promoting climate smart agriculture in China.

Implementing mitigation actions in China also faces a structural barrier, arising from the scale at which changes need to take place and the diversity of the Chinese agricultural system. For example, smallholder farmers operate differently than professional large-scale farmers, grain production faces different challenges than fruit and vegetable production and livestock farmers have different land and support structures available to them to improve manure management. Overall, the productivity of agricultural soils and climatic conditions show great variability. Even if high level political guidance proposes targets and measures, implementation at scale in China is still a challenge and requires the collaboration of multiple levels of governance.

Green and organic food production in China (see section 1.5) can contribute significantly to achieving low-carbon and environmental goals. Despite its rapid development since the introduction in the 1990s, analyses show that green food production is highly concentrated in the eastern part of the country and does still not encompass grain or livestock production in a significant manner (Sun et al. 2021). This pattern is driven by beneficial economic and environmental conditions of the green food regions, but environmental quality as per the regulation, also plays a role in limiting the expansion of green and organic food to other areas, since certification is tied to environmental quality and therefor an area with bad air quality, would not qualify for certification (ibid).

The ageing rural population is leading to a decrease in farm sizes, loss of rural income and agricultural productivity. This is especially the case for the more labour intensive fruit and vegetable production (Ren et al. 2023). Additionally, the younger rural generation is seeking work in the cities, where wages are higher (Liu et al. 2023). This socio-cultural barrier limits the possibilities of introducing sustainable farming practices by smallholder farmers. However, it is possible to address this barrier through new farming models such as cooperative farms (Ren et al. 2023).

3.3 International level

As one of the largest food exporters and importers of the world, Chinese agriculture is strongly embedded in international markets. Trade liberalisation can pose an economic barrier to reduce fertiliser input, as observed by Nie et al. (2022), in the case of fruit and vegetable exports from China to countries of the Association of Southeast Asian Nations. The reform of agricultural support policy, for example to support farmer's incomes and the transition towards sustainable agricultural practices, needs to comply with WTO rules, which may complicate this reform (AGFEP 2022). Intellectual property rights may pose a barrier when it comes to adopting better breeding and seeding technologies and agricultural machinery.

International cooperation is an important tool to improve agricultural practices (Chen et al. 2023), Changing perspective and looking into barriers created by China for others, China's food imports, for example of soy and corn, are a driver of land use change for agriculture in exporting countries and creating economic incentives that are a barrier to reduce these emissions.

3.4 Consumer level

The share of animal proteins in Chinese diet has continuously increased along with rising incomes. Although it remains well below the levels seen in Germany or the US (Chen et al. 2022b), this trend may constitute a significant barrier to reduce the emissions caused by excess manure. No other specific consumer level barriers were identified for prioritised mitigation options in section 2. Economic barriers apply with regards to consumption of green and organic foods due to their higher cost, additionally consumer level trust in national food labels is low (Wang et al. 2020). Cultural barriers may exist at the consumer level when it comes to reducing food waste, for example banquet culture and excessive eating.

4 Recommendations

In a world compatible with the Paris Agreement, the agricultural sector will need to meet the growing food demand of people and animals, while contributing to other equally relevant climate and development objectives and adapt to a changing climate. Mitigation action in China, the largest emitter globally, is essential for limiting global temperature increase, including in the agricultural sector. The mitigation of climate change is also essential to Chinese agriculture, where extreme heat, droughts and flooding are already impacting crop production and livestock production. The productivity of the land in China is already threatened by climate change (see section 1.6), and measures to improve soil quality can increase the resilience of the agricultural sector, additionally to reducing GHG emissions. Adaptation in the agricultural sector is key, in light of the limited available land resources and severe degradation of land and water resources due to agriculture. Also, due to its size, productivity and population, China is a cornerstone of global food security.

This study identified and compared potential estimates for three actions to reduce emissions associated with agriculture in China that can be implemented without impacting productivity and provide environmental and economic co-benefits: improving rice cultivation, improving nitrogen management, and improving manure management from livestock and poultry.

Improved rice cultivation could reduce CH_4 emissions as well as reduce irrigation needs and related energy consumption. Estimated mitigation potentials for improved rice cultivation until 2030 range from 14 $MtCO_2e$ to 26 $MtCO_2e$ per year at the lower end and 51 $MtCO_2e$ to 64 $MtCO_2e$ per year at the higher end. Improved nitrogen management reduces overapplication of fertiliser and thus decreases N_2O emissions while delivering co-benefits for soil health and water use and quality. Improving nitrogen management is possible through a wide range of practices and technologies, such as the type of application and the type of fertiliser used. Estimates for mitigation potentials until 2030 range from 13 $MtCO_2e$ at the lower end and 213 $MtCO_2e$ per year at the high end, implying high uncertainties. Improving manure storage and processing as well as putting it to use as a source of bioenergy can reduce emissions from excess manure. Estimates for the mitigation potential of increasing manure use for energy high, considering the carbon intensity of the Chinese energy grid (119 and 129 $MtCO_2e$).

Additional emission reductions related to the agricultural sector could be achieved through improved on-farm energy use, improving livestock health, decarbonising the production of synthetic fertiliser, reducing energy consumption of agricultural machinery, and measures to address the increasing trend in meat consumption.

Many of the suggested measures have co-benefits that are already an integral part of China's national policy goals related to the environment. The suggested measures can play a role in improving and maintaining soil health (increasing use of organic fertiliser) as well as reducing nitrogen pollution (improving fertiliser application). As China has limited land resources, maintaining soil health is a prerequisite of achieving food security. Reducing the water consumption in rice cultivation will support adaptation to potential future water scarcity.

The measures in this report are already included in Chinese high level policy documents. For example, the 14th Five-Year-Plan of 2021 mentions the need to implement actions to reduce fertiliser and pesticide use, promote integrated straw management and enhance the use of livestock and poultry manure (Chen et al. 2023). The plan also states the general aim to promote a "green agricultural transformation and to develop green production and lifestyles by 2035" (ibid).

However, the successful implementation of agricultural mitigation measures is hampered by numerous barriers on the farm-, national-, international-, and consumer-level. These include a lack of investment capacity and knowledge of farmers, the absence of clear institutional mandates to monitor and enforce environmental regulation. Despite the high-level policy recognition of the importance of transforming agricultural practices, progress is slow and faces the challenge to reconcile with the national focus on ensuring food security, coupled with national production targets and economic growth.

A national policy framework that reconciles agricultural development goals and climate mitigation goals would be a significant step towards accelerating the uptake and implementation of the measures described in this report. Some concrete options are outlined in the following paragraphs:

1. *Enhancing the national climate mitigation framework in agriculture*

China has several overarching policy documents and plans that recognise the need to address GHG emissions from agriculture and address environmental degradation caused by unsustainable practices. Given the diversity within the Chinese agricultural systems, mitigation potentials vary according to local economic and agricultural conditions (Nayak et al. 2015). Translating national level policy documents to the local level thus requires improving institutional capacities for identifying mitigation opportunities at the local level, providing related advice and knowledge to farmers as well as for clearly assigned roles and responsibilities for monitoring. A focus on improving advisory service and monitoring capacities at the local level can also be helpful for tracking progress towards achieving national targets.

While China's explicit NDC goals only relate to CO_2 (China 2021), the document communication progress in the implementation of the NDC also refers to success in reducing CH_4 emissions from rice cultivation and non-CO_2 emissions from manure management. This can be considered as a good basis for the Chinese government that could be translated into increased ambition of the NDC by including targets related to non-CO_2 emissions from agriculture.

2. *Strengthen coherence between overall agriculture framework and climate mitigation objectives*

Contradicting policy goals can limit progress towards mitigation objectives. Some options to improve policy coherence include:

- **Strengthening protection of farmland**: Agricultural land is lost to urban and rural development, as this is a driver for local economic growth. At the same time, local governments must comply with the agricultural "red line" and maintain the overall level of agricultural land. As a result, farming shifts to marginal land. This, in addition with unsustainable practices reduces the quality of agricultural land and increases the need for agricultural inputs (Xu et al. 2023). As long as this contradicting development continues, farming will continue to encroach on natural habitats, contribute to environmental degradation and loss of natural carbon sinks. Better consideration of the quality of agricultural land is needed in future urban development.
- **Expanding green and organic food production:** As the production of green and organic food in China is closely linked to environmental quality, they are mutually reinforcing. Increasing the support for expanding green and organic food product development is a key lever to improve environmental quality in China and reduce

key emission sources from agriculture. Additionally, it can improve rural incomes and could help increasing the attractiveness of agriculture to a younger generation.

- **Scaling up financial and technical support and extension for the supply and use of organic fertiliser among smallholder farmers:** Increasing the use of organic fertiliser is a recognised measure by the Chinese government and work in progress (China 2022b), but additional and targeted support could be provided for the older generation of smallholder farmers that may face educational and economic barriers to shift towards organic fertilisers. Additional extension services and easy access to organic fertilisers may incentivise a shift among older farmers.
- **Accelerating the reform of agricultural support policy:** Reduce agricultural support that incentivises unsustainable practices and increase support for alternatives that contribute to reducing GHG emissions and environmental pollution.

3. Selected ideas for how mitigation could be strengthened

The following and non-exhaustive ideas build on existing policies and initiatives from the Chinese government, that can strengthen mitigation in the agricultural sector while providing significant environmental and socioeconomic co-benefits, including climate resilience and adaptation. Chinese researchers recognise the need to take a systemic approach to reducing emission from agriculture. In its 2021 report AGFEP states that the use of better agricultural technology, reducing food loss and waste, and shifting dietary patterns are needed to achieve the necessary contribution towards carbon neutrality (AGFEP 2022). The following recommendations build on this need to follow an integrated approach:

- **Strengthening engagement of local authorities to promote synergies between environmental and food security targets:** Chinese policy documents and scientific works indicate increasing awareness towards the fact that climate change, soil degradation and pollution constitute threats to food security. Yet, additional efforts are required to translate this knowledge into sustainable agricultural practices across the diverse Chinese agricultural landscape. This requires engaging farmers but also a strong focus on engaging and giving guidance to officials at the third administrative level (see section 1.4), who are key stakeholders when it comes to implementing national policies with concrete action on the ground.
- **Coupling efficiency gains with sustainability gains:** China's predominantly smallholder agriculture faces a generational challenge, as ageing and the loss migration of the younger generations to urban areas reduce the availability of agricultural labour. To maintain or improve the level of agricultural production, it is likely that a focus will be placed on land consolidation and agricultural mechanisation. Community farms are an example of how this transition is underway in China. This transformation will only deliver positive environmental results if farmers receive the adequate financial and technical support to apply sustainable agricultural practices.
- **Expanding efforts to reduce food loss and waste to cover the whole value chain:** Addressing food waste has arrived on the political agenda, but the scope of actions is currently limited. There is potential to address food waste not only in the hospitality and consumer sector, but across the agricultural value chain. A first step is to improve knowledge regarding food loss and waste at the processing, distribution and retail sectors (Li et al. 2022).

- **Incentivising non-animal protein intake:** As Chinese household income rises the consumption of animal-based products also increases. As in other countries, this is a barrier for reducing emissions from the agricultural sector and is a challenge to food security. Additionally, overconsumption of animal fats can pose a health risk. As the Chinese government has experience with population wide campaigns and can build on a rich food tradition and variety of crops, there is a good basis to improve awareness among the population of the challenges associated with increased meat consumption. The government can likewise support the development of alternative protein industries.
- **Following an agri-food system approach:** This approach can help to comprehensively address emissions associated with food production and consumption, as it encompasses the whole scope of food related activities that cause GHG emissions. This includes land use change, the proper agricultural production, food processing, packaging and transport, as well as food preparation and waste (Chen et al. 2022b).

While this report focuses on improvements on climate friendly agricultural production, it is essential to highlight that without changes to dietary patterns mainly in developed countries, a sustainable and just 1.5°C pathway is not feasible. Discussing alternative narratives next to the current agricultural expansion plans could help understand the implications of a shift to largely plant-based diets and potentially avoid disruptions in the sector in the medium to long term. International research reports that demand-side measures, such as shifting to less meat intensive diets and reducing food waste, have a high mitigation potential while contributing to other co-benefits at relatively lower costs (Roe et al. 2021).

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