The impacts of healthy diets on future greenhouse gas emissions in China

A multi-model comparison

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Contents

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Executive Summary

To achieve the targets of the Paris Agreement, a broad range of socioeconomic sectors must drastically reduce emissions. This includes our food systems, which globally account for a third of global anthropogenic greenhouse gas (GHG) emissions (IPCC, 2019). Food systems are also inextricably linked to other important environmental impacts, such as biodiversity loss, eutrophication, water stress, and land degradation. In addition, a range of health risks are attributed to poor dietary quality, including obesity and noncommunicable diseases. It is widely accepted that diets must shift towards sustainable and healthy consumption levels to address these environmental and health concerns.

China has set ambitious climate targets – it intends to reach peak carbon dioxide (CO_2) emissions before 2030, and to achieve climate neutrality before 2060. Healthy and sustainable food consumption is recognized as a key component and driver of China's transition towards a climate-neutral economy. This assessment evaluates the extent to which healthy and sustainable diets can provide domestic emission reductions and help ensure that China reaches its ambitious climate targets.

Our multi-model comparison shows that GHG emissions from the Chinese agricultural sector could be nearly halved (reduced by 46-51%) by 2050, if healthy and sustainable reference diets (EAT-Lancet or Chinese Dietary Guidelines 2022) are adopted fully and effectively. Furthermore, we find that the shift to healthy diets can help agricultural-source emissions to peak by 2030 at the latest. These mitigation levels would ensure that the Chinese agricultural sector develops in a manner that is compatible with global emissions pathways that limit global warming to 1.5°C as set by the Paris Agreement. However, China's agricultural-source GHG emissions and associated mitigation potentials vary significantly by region. Southwestern and central provinces, such as Sichuan, Yunnan, Hunan, and Henan, have high GHG emissions but also great mitigation potential. In most provinces, and for China as a whole, the reference diets imply a reduced livestock sector and associated decreases in emissions from enteric fermentation and other livestock-related sources.

Achieving the mitigation potentials of healthy and sustainable diets requires rapid action. It will entail effective policies that take into account local contexts, engage stakeholders, and ensure equity and justice by recognizing and addressing potential social barriers. It would be beneficial to conduct more research into consumer dietary choices and behaviours, as well as developing an umbrella policy framework that co-ordinates the agricultural, health, education, and commerce sectors.

1 Introduction

The Paris Agreement sets a long-term objective of limiting the increase in global average temperature to *"well below 2°C above pre-industrial levels and pursuing efforts to limit the increase to 1.5°C"* (UNFCCC, 2015, Article 2.1(a)). On September 22nd, 2020, China announced that it aims to have CO_2 emissions peak before 2030 and to achieve carbon neutrality before 2060. This announcement demonstrates the country's determination to pursue a new model of economic growth and development. To achieve these commitments and long-term goals, all economic sectors and all regions of China must undergo profound and comprehensive transitions (Energy Foundation China, 2020).

The world over, transitioning to a more sustainable food system is becoming imperative and is a crucial component of low carbon transitions (Lucas et al., 2023; Geyik et al., 2022). Currently, the global food system is responsible for emitting 14-22 gigatonnes of CO_2 equivalent ($GtCO_2eq$) per year, which accounts for almost one-third of all anthropogenic GHG emissions (IPCC, 2019; Poore and Nemecek, 2018; Roe et al., 2019; Tubiello et al., 2021). In addition, the food system occupies a substantial area of land, and consumes a large and increasing amount of water, nitrogen and phosphorus (Smil, 2002; Kastner et al., 2012; Metson et al., 2012; Jalava et al., 2014). Decarbonization of the food system requires transitions in both the production and demand sides and will require coherent evidence-based policies that consider multiple factors (UNEP, 2022; Ding et al., 2023). Multiple studies have found dietary change, as a demand-side transition, to be a practical and effective strategy to reduce resource consumption and GHG emissions (e.g., Lucas et al., 2023; Sun et al., 2022).

The optimization of dietary patterns is also one of the most important measures that China can take to facilitate greening and to transform the current food system (AGFEP, 2023; Wang, R. et al., 2022). With 18% of the world's population and only 7% of global arable lands, China's remarkable success in securing its food supply has relied upon continued agricultural intensification. Over the last few decades, China has made tremendous strides in broadly eradicating undernutrition and ensuring food security, and has become a major agricultural producer and trader in the global economy (Attwood et al., 2023). Although these efforts have brought positive results, they have come at the cost of contributing to public health concerns such as overnutrition; an increase in the consumption of meat, refined and processed foods; as well as dietary imbalances leading to micronutrient deficiencies (AGFEP, 2023). Increasing living standards and economic development have also contributed to traditional Chinese food choices being replaced with a more Westernized pattern of eating, including high consumption levels of fat, protein, salt, and sugar (AGFEP, 2021; Huang et al., 2021). In addition, as incomes rise, people tend to consume more expensive products and eat out more often (Zhang et al., 2018; Cheung et al., 2021). Unbalanced diets are one of the leading factors in half of Chinese adults being overweight or obese, and are driving the rise in noncommunicable diseases such as diabetes, heart disease, and cancer (AGFEP, 2023). Unsustainable agricultural practices have also compromised the environment and ecosystem services, such as healthy soil, clean water and pollination, with serious consequences for agricultural productivity and farmers' livelihoods (AGFEP, 2023).

As the world's second largest economy, China can play an important role in shifting to healthy and sustainable diets while fulfilling the large GHG mitigation potential embodied in its food system (Ren et al., 2023). This report emphasizes the mitigation potential of sustainable and healthy diets in China. It examines the extent to which changes in food consumption can have a positive impact on the environment and the climate. The results from the various models allow us to assess the uncertainty ranges of future GHG emissions from the Chinese agricultural sector and potential impacts associated with the widespread adoption of healthy and sustainable diets. We conclude with recommendations for closing knowledge gaps to improve future assessments.

② Diets and food consumption in China

As a country with a very rich food culture, China produces a diverse variety of vegetables and plant-based proteins. Traditional Chinese diets are predominantly plant-based, containing less animal protein than Western diets (Attwood, 2023). However, rising affluence, corporate marketing and Western cultural influences mean that animal-based as well as high- and empty-calorie foods are increasingly sought after. Despite this, Chinese diets still include a significant portion of plant-based foods, such as cereals, legumes, fruit, and vegetables (Wang, X. et al., 2022). According to the FAOSTAT, in 2020 Chinese households consumed an average of 3,294 calories per capita per day (kcal/cap/day) and 2,633 grams of food per capita per day (grams/cap/day), with 82% and 84% of these intakes coming from plant-based foods, respectively (Figure 1).[1] Households obtain the most calories from cereals (1,535 kcal/cap/day), which account for 47% of their total calorie consumption. Pork represents the largest share of animal-based foods (7% of total calorie intake; 224 kcal/cap/day), followed by poultry (64 kcal/cap/day), and eggs (80 kcal/cap/day). Unlike most Western countries, Chinese do not consume a great deal of ruminant products: in 2020 the average calorie intakes from beef, mutton, and dairy were 33 kcal/cap/day, 18 kcal/cap/day, and 65 kcal/cap/day, respectively.

1 It should be noted that both estimates include food waste. There is great disparity between data from FAOSTAT and from National Bureau of Statistics (NBS). According to NBS, in 2020, Chinese households consumed 2,221 kcal/cap/day and 1,114 grams/cap/day, with 85% and 82% of these intakes coming from plant-based foods, respectively. The two data sources differ in methods and statistical caliber. FAOSTAT data is derived from its Food Balance Sheet (FBS) for China, while NBS data is from survey data in urban and rural areas. The former includes food waste, while the latter excludes dining-out data.

2.1 Historic trends

Chinese dietary patterns, including food type, quantity and structure, have undergone a remarkable transformation in recent decades (Meridian Institute, 2023). In 1982, Chinese households' cereal intake reached the recommended level for a calorie-sufficient diet (Yan et al., 2023). This reflects the country's enormous strides in addressing undernutrition and ensuring food security. Since then, the dietary quality and nutritional status of Chinese households have improved significantly. China has evolved into a country that offers its citizens a wide range of food choices, and is a dominant player in global agricultural production and trade.

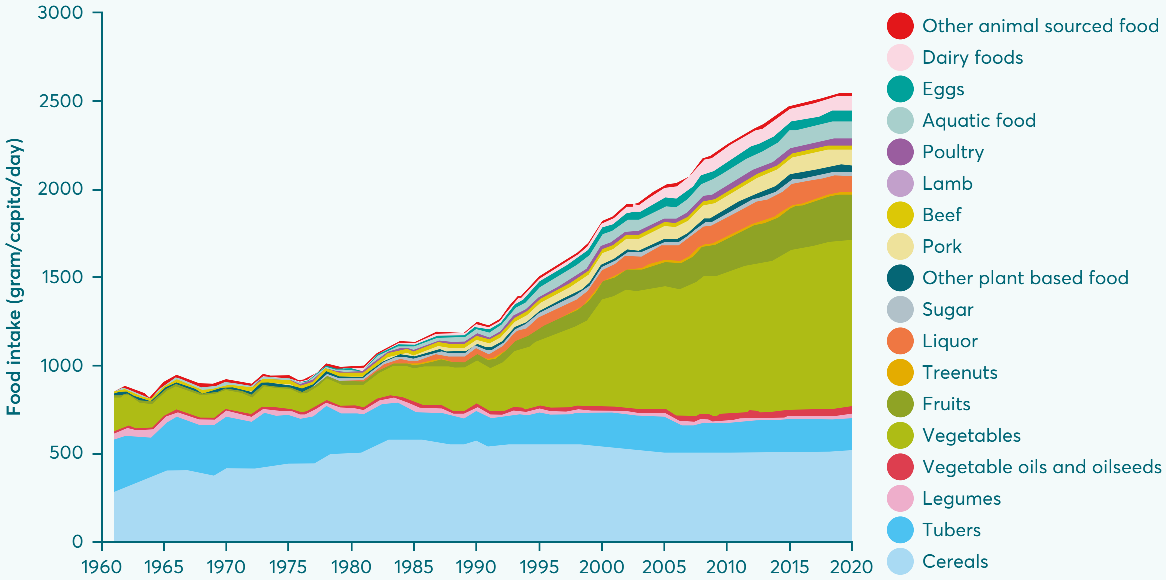
Since 1980, total food consumption and calorie intake have been on the rise, and moving towards a more diversified food choice (Figure 1). Total food consumption has increased from 868 grams/cap/day in 1980 to 2,546 grams/cap/day in 2020, while calorie intake has risen from 2,574 kcal/cap/day to 3,294 kcal/cap/day. Unlike the Western diet, the average Chinese diet is characterized by a high intake of plant-based foods, which in 2020 contributed 84% and 82% to total food consumption and calorie intake, respectively. However, their share in diets has decreased slowly since 1980, when it accounted for 90%.

The most common foods consumed by Chinese households are cereals – accounting for 74% of total calorie intake in 2020 – followed by vegetables (Figure 1b). Consumption of animal-based foods has risen, and they provide on average 585 kcal/cap/day, accounting for 18% of total energy intake. Chinese preferences for animal-based foods are more diverse than in Western countries. Pork remains the largest share of animal-based foods followed by poultry meat and eggs. In 1980, pork constituted 60% of the calorie intake from animal-based foods in China, but its share declined to 28% in 2020. Poultry, aquatic food, eggs, and milk consumption rose rapidly, providing 64 kcal/cap/day, 59 kcal/cap/day, 80 kcal/cap/day, and 65 kcal/cap/day, respectively, in 2020. However, Chinese households have traditionally consumed relatively little ruminant meat. The consumption of ruminant meat (beef and mutton) was merely 51 kcal/cap/day in 2020, respectively, representing less than 2% of total calorie intake. Diet varies significantly by region and province. For example, people in Northeast and East China have lower daily intakes of cereals; in South, Central, and Southwest China people consume a higher proportion of pork; while in Northwest, Southwest, and North China people consume more beef and mutton (AGEFP, 2023).

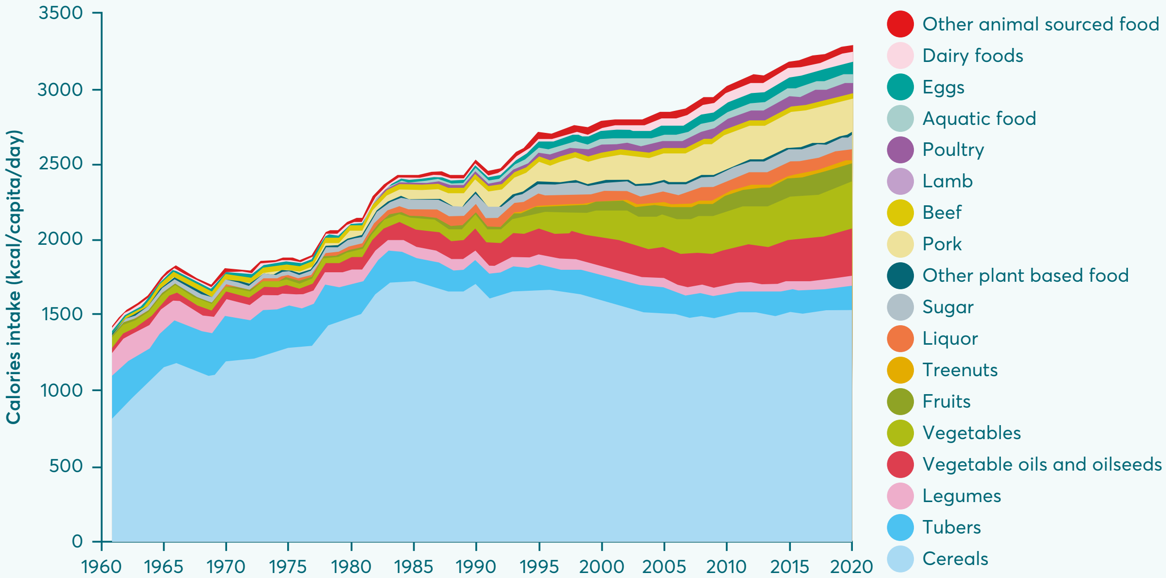
Though both dietary quality and nutritional status have improved substantially over the past few decades, discrepancies between urban and rural residents persist. Compared to rural residents, urban residents consume less grain and vegetables, but more fruit and animal-sourced foods (meat, fish, eggs and milk; Zhai et al., 2005). However, a recent study revealed that the structure of rural residents' food consumption is diversifying, and the gap between urban and rural residents is gradually narrowing (Han et al., 2023).

Figure 1: Dietary patterns of Chinese households, 1960-2020.

A Food intake



B Calorie intake



Source: FAOSTAT, 2023.

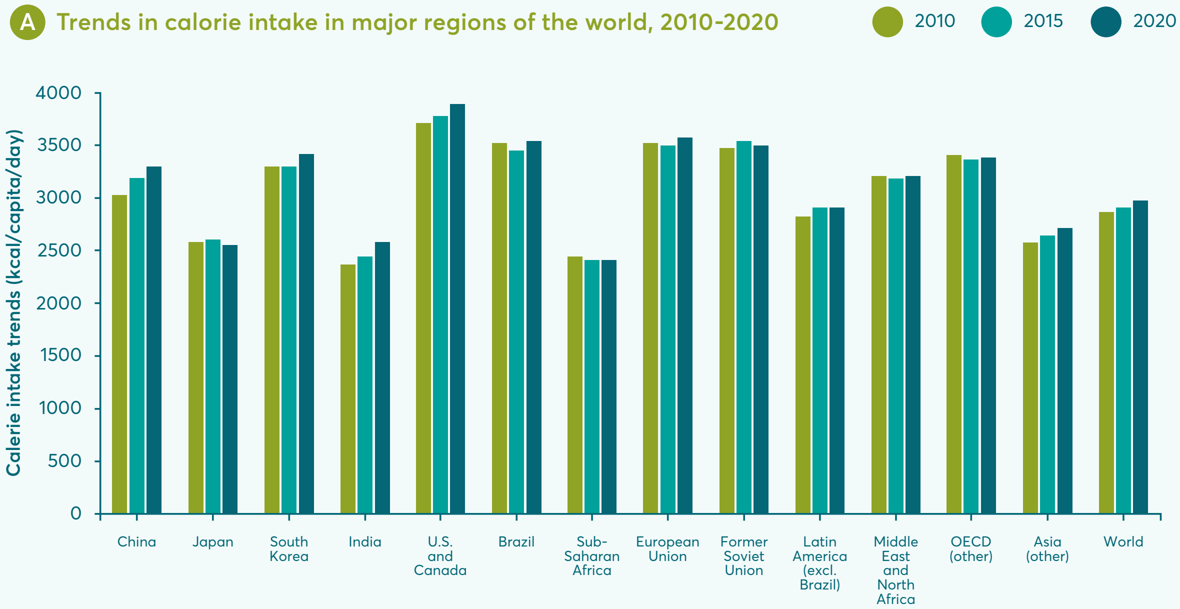
2.2 Comparison between diets in China and the rest of the world

In the 20th century, the average food intake in China (measured as kcal/cap/day) was lower than the global average, but it has exceeded it in the 21st century (Figure 2a). From 2010 to 2020, China's average calorie intake increased from 3,025 kcal/cap/day to 3,294 kcal/cap/day. That decade also saw the total food intake in the United States, India, the post-Soviet states, Latin America, and most Asian countries increase. Today, China's calorie intake is lower than that of the United States and Canada (3,887 kcal/cap/day), Brazil (3,527 kcal/cap/day), European Union (3,556 kcal/cap/day), the post-Soviet states (3,501 kcal/cap/day) and other OECD countries (3,378 kcal/cap/day).

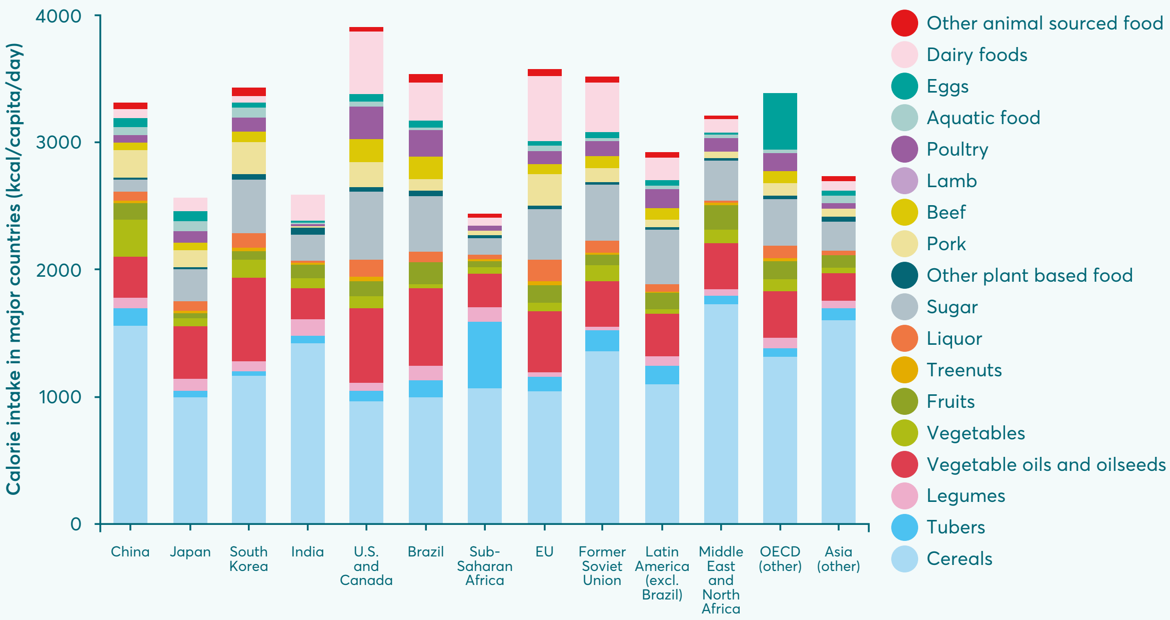
Compared with most other countries and regions, the Chinese diet has a relatively high proportion of plant-based foods, primarily grains, vegetables, and fruit (FAOSTAT 2023). Plant-based foods comprise 82% of the total daily per capita calorie intake in China (Figure 2b), which is similar to most developing countries and regions, such as the Middle East and North Africa (90%), Sub-Saharan Africa (90%), Asia (others) (88%) and Latin America (80%). When it comes to animal-sourced foods, Chinese consumption of ruminant meat, aquatic products, and dairy products is lower than most countries (Figure 2b). The contribution of grains to the total calorie intake is 57%, much higher than in the United States and Canada (36%), the European Union (42%), Brazil (32%), the former Soviet Union region (50%), and other OECD countries (51%). The intake of fruit and vegetables is also high in China, representing 11% of the total calorie intake, which is almost the highest in the world (Figure 2b). However, compared to most countries, the Chinese consume less sugar (2% of total calorie intake), less ruminant meat (2% of total calorie intake), and less dairy (1% of total calorie intake).

Figure 2: Per capita calorie intake in selected countries and regions of the world.

A Trends in calorie intake in major regions of the world, 2010-2020



B Structure of calorie intake in major countries and regions of the world in 2020



Source: FAOSTAT, 2023.

2.3 The health and GHG emission impacts of improving diets

Many health problems can be attributed to unhealthy diets. In addition to obesity and overweight (Popkin et al., 2012; Ng et al., 2014), unhealthy dietary patterns can lead to chronic diseases, including cardiovascular disease, cancer, and type II diabetes (Iriti et al., 2020; Huang et al., 2012), as well as cognitive disorders (Mohamed et al., 2010; Guasch-Ferre and Willett, 2021). An insufficient intake of fruit, vegetables, whole grains, beans, aquatic products, and unsaturated vegetable oils, combined with a higher intake of red meat and processed meat, increases the risk of cardiovascular disease and all-cause mortality (He, P. et al., 2019; Willet et al., 2019). Globally, poor diets risk causing 11 million deaths and 255 million disability-adjusted life years (DALYs)[2] in 2017, with over half caused by a combination of high sodium intake, low whole grain intake, and low fruit intake (Afshin et al., 2019). In China between 1990 and 2016, diet-related deaths and DALYs increased by 19.5% and 9.3%, respectively (He, Y. et al., 2019; He, M. et al., 2019).

While there is no unified definition of a healthy diet, several countries and institutions recommend relatively similar diets (Kim and Rebholz, 2021). The EAT-Lancet reference diet is made up of eight food groups: whole grains, tubers and starchy vegetables, fruits, other vegetables, dairy foods, protein sources, added fats, and added sugars, with a caloric intake limit of 2,500 kcal/cap/day (net intake excluding waste; Willett et al., 2019). The Chinese dietary guidelines (CNS, 2022) advise that plant-based foods should be the primary source of nutrition, with a prominent intake of whole grains, dark leafy vegetables, fruit and legumes, and a diversified intake of animal products. Table 1 compares the EAT-Lancet reference diet and the Chinese dietary guidelines. The health benefits of following these recommended diets have been widely assessed. If humans consumed the same number of calories but substituted plant-based foods for 25% to 100% of animal-based foods in 2030, global premature mortality rates would decrease by 4% to 12% respectively, with the greatest reduction occurring in high-income countries (Springmann et al., 2018). If the entire world adopted the EAT-Lancet diet, approximately 11 million deaths could be prevented each year, accounting for 19% to 24% of all deaths among adults (Willet et al., 2019; Wang et al., 2019). Researchers have also found that replacing 2% of carbohydrates with plant protein or polyunsaturated fatty acids significantly reduces mortality (Wan et al., 2022). Chinese adults could substantially reduce their risk of death by adhering to the Chinese dietary guidelines (Liu et al., 2021). For example, an overall plant-based dietary pattern reduces the risk of all-cause mortality (Chen et al., 2022). Among plant-based foods, fresh fruit, fresh vegetables, legumes, garlic, nuts and tea are the most protective, while preserved vegetables and sugar are associated with higher mortality rates (Baden et al., 2020; Kim et al., 2019; Kim et al., 2018; Martínez-González et al., 2014; Kim et al., 2021; Schwingshackl et al., 2017).

Current dietary patterns in China are also concerning for their impact on GHG emissions. According to several studies, China's agricultural GHG emissions are likely to increase if current dietary trends continue. However, there is wide variation in the GHG footprint of different food products. Ruminant meat, including beef and lamb, has a GHG footprint 10-20 times higher than that of eggs and milk, 20-30 times higher than cereals, and more than 50 times higher than vegetables (Hamerschlag and Venkat, 2011). Consumption-side emissions can therefore be reduced primarily through dietary shifts which reduce the consumption and waste of products with a high GHG footprint (Frank et al., 2018). According to Tilman et al. (2014), a global shift to a Mediterranean, pescetarian, or vegetarian diet could reduce global agricultural GHG emissions in 2050 by 30%, 45%, and 55%, respectively, compared with a typical diet for high-income countries. Westhoek et al. (2014) tested the effects of various alternative diets and found that halving the consumption of meat, dairy products and eggs in the European Union would achieve a 40% reduction in nitrogen emissions, 25-40% reduction in greenhouse gas emissions and 23% per capita less use of cropland for food production. Song et al. (2017) reached similar conclusions for China. According to recent research, following the Chinese dietary guidelines could reduce China's food carbon footprint by 13.6% in urban areas and 14.7% in rural areas, and would reduce GHG emissions from animal husbandry by 47% as of 2050 (Dou and Liu, 2023; Wang, X. et al., 2022). Zhang et al. (2022) find that the EAT-Lancet diet could lower Chinese greenhouse gas emissions by 41%, while replacing 50% of traditional meat with aquatic products could decrease emissions by 22.4%.

2 A DALY (disability-adjusted life year) is a measure of health burden, including both reduction in life expectancy and diminished quality of life. More specifically, the DALY burden for a particular condition is the sum of YLL (years of life lost due to premature mortality) and YLD (years lost to disability). Health interventions seek to avert DALYs, and in doing so, to increase the number of years that a person lives in good health.

Table 1. Comparison of the EAT-Lancet and Chinese dietary guidelines

EAT-Lancet 1.0				Chinese Dietary Guidelines (2022 version)		
Type	**Sub-type**	**Food intake (gram/cap/day)**	**Calorie intake (kcal/cap/day)**	**Type**	**Food intake (gram/cap/day)**	**Calorie intake (kcal/cap/day)**
Cereals	Barley, wheat, maize and others	232 (whole grains, 0~60% of energy)	811	**Cereals**	250 (200~300)	875 (700~1050)
Legumes	Dry beans, lentils and peas	50 (0~100)	172 (0~344)	**Legumes**	100 (50~150)	344 (172~516)
Tubers or starch	Potato and cassava	50 (0~100)	39 (0~78)	**Tubers**	75 (50~100)	58.5 (39~78)
Vegetables	All vegetables	300 (200~600)	78 (52~156)	**Vegetables**	400 (300~500)	104 (78~130)
	Dark green vegetables	100	23			
	Red and orange vegetables	100	30			
	Other vegetables	100	25			
Fruit	All fruit	200 (100~300)	126 (63~189)	**Fruit**	275 (200~350)	173.25 (126~220.5)
Dairy products	Whole milk or equivalent derivatives	250 (0~500)	153 (0~306)	**Dairy products**	400 (300~500)	244.8 (183.6~306)
Meat and seafood	Beef and mutton	7 (0~14)	15 (0~30)	**Meat**	57.5 (40~75)	123 (85.6~160.5)
	Pork	7 (0~14)	15 (0~30)			
	Chicken and other poultry meat	29 (0~58)	62 (0~124)			
	Eggs	13 (0~25)	19 (0~37)	**Eggs**	45 (40~50)	65.8 (58.5~73)
	Fish and seafood	28 (0~100)	40 (0~143)	**Aquaculture and sea food**	57.5 (40~75)	85.8 (64.35~107.25)
Nuts	Peanuts	25 (0~75)	142 (0~426)	**Nuts**	25	149
	Soybean	25 (0~50)	112 (0~224)			
Fats and oils	Palm oil	6.8 (0~6.8)	60 (0~60)	**Fats and oils**	30 (25~35)	265.5 (221.25~309.75)
	Unsaturated oil	40 (20~80)	354 (177~708)			
	Dairy fats	0	0			
	Lard or butter	5 (0~5)	36 (0~36)			
Added sugar	All sweeteners	31 (0~31)	120 (0~120)	**Salt**	<5	

Source: CNS (2022). The Chinese Dietary Guidelines; EAT (2019). The EAT-Lancet Commission Summary Report.

③ Methodology for assessing impact of diets and food consumption

Healthy and sustainable diets play a critical role in Chinese climate mitigation efforts, but tools that incorporate both biophysical production and demand patterns are required for detailed analysis of these aspects. Because of spatial and temporal variability in land carbon stocks and GHG flux processes, developing projections for the food system and the agricultural sector is particularly challenging. Global agricultural commodity markets are dynamic and interconnected, land users vary in their response to market signals, and there is uncertainty regarding the effects of policies that directly or indirectly affect land use and commodity markets (e.g., bioenergy policies). It is important to note that different models are designed to address these challenges in a variety of ways, and at varying levels of complexity, spatial and temporal detail, input data, model structure and specification, sectoral coverage, macroeconomic assumptions, and analytical objectives (Chen et al., 2023).

The multi-model approach used here provides a better understanding of the role that diets play in meeting Chinese climate targets. As different underlying model structures and assumptions may give different results, using multiple models allows for a more robust evaluation of different potential outcomes, reduces the potential bias inherent in single-model projections, and gives us a deeper understanding of how model results are influenced by input data, structural features, and assumptions. Inter-model comparison also allows us to present and compare projections based on different developments in diets and consumption patterns in China. Compared to a single-model approach, this multi-model approach allows for a more transparent representation of uncertainties and a more robust understanding of the directionality and magnitude of mitigation potentials. To build confidence in projections, it is important to identify consistent and robust results across different models and assumptions. Although some key parameters have been harmonized across models, variability is driven by the individual attributes of each model framework.

Four models were selected for this research to assess the effects of dietary shifts on GHG emissions: GLOBIOM-China, MAgPIE-China, FABLE Calculator-China, and AGHG-INV (see Table 2 and Annex 1 for details). All four are independently developed models that are based on observed and modelled economic and biophysical data. Each of these models has been used extensively in assessing the impact of mitigation technologies (practices) and policies on emissions from the agriculture, forestry and other land use (AFOLU) sector. They cover the major pools in the AFOLU sector and are also capable of modelling future developments in agri-food and land-use systems, and assessing the effects of dietary changes

(Chen et al., 2023). The models provide a range of spatial and temporal information and reflect differing underlying structures by integrating varying levels of biophysical and economic detail. The four models therefore possess key characteristics that make them uniquely positioned to provide reliable projections of the impacts of changes in diets on future mitigation quantities. Furthermore, as the models selected here include sectoral models (i.e., AGHG-INV, FABLE Calculator-China) and those that are part of integrated assessment models (i.e., GLOBIOM-China, MAgPIE-China), we can provide a detailed assessment of specific sectoral developments, as well as integrated assessments of the impacts of diet changes in China.

In addition to the multi-model approach, we have used scenario analysis to provide insights into how healthy and sustainable diets can be implemented in China. Three scenarios with alternative future trends in consumption have been harmonized across the models and are used to analyze the consequences of these dietary patterns for both human and planetary health:

Scenario 1: Business-as-usual (BAU).

Scenario 2: EAT-Lancet. Adoption of the sustainable and healthy diets proposed by the EAT Lancet Commission in 2019 (based on the average caloric intake for each food type in Table 1).

Scenario 3: CDG-2022. Adoption of the Chinese Dietary Guidelines (2022 version) (based on the average caloric intake for each food type in Table 1).

The EAT-Lancet scenario follows the sustainable and healthy diets proposed by the EAT Lancet Commission in 2019, advocating for the integration of healthy and sustainable diets into the same framework (EAT, 2019). The CDG-2022 scenario follows the latest version of the Chinese Dietary Guidelines and considers the impact of dietary choices on the broader environment, as indicated by the published CDG methodology explaining how these guidelines were developed (CNS, 2022). See Table 1 for further information concerning the specifications of EAT Lancet and Chinese Dietary Guidelines. Both the EAT-Lancet and CDG-2022 dietary targets were assumed to be achieved by 2050 in the model simulations (Annex 1). The recommended calorie intake for each food category was implemented in the model as the net average food/calorie intake target to be achieved by 2050, while the dietary shift was rolled-out linearly from the 2020 level in all models except the FABLE Calculator-China, where the dietary shift was rolled-out in 2010.[3]

Table 2. Comparison of main model features

Model name	AFOLU sectoral coverage	Methodology	Geographical coverage	Purpose	Reference year	First year of projections	Time horizon and time steps
GLOBIOM-China	Agriculture & LULUCF	Partial equilibrium model	Multi-region	Forecasting	2010	2020	Long-term, every 10 years until 2100
MAgPIE-China	Agriculture & LULUCF	Partial equilibrium model	Multi-region	Forecasting	1995	2020	Long-term, every 5 years until 2100
FABLE Calculator-China	Agriculture & LUC*	Equilibrium model without optimization	National	Forecasting	2000	2010	Medium-term, every 5 years until 2050
AGHG-INV	Agriculture	Inventory	National	Forecasting	2020	2021	Medium-term, every year until 2050

Notes: For further information about each model, and supporting reference material, see Annex 1.

* The FABLE Calculator-China model accounts for land-use change (LUC) but does not account for GHG fluxes related to existing land use or forest management.

3 The calorie intake was implemented as the average across the population without accounting for age structure. In the models, for each simulation step (e.g. 10-year interval for GLOBIOM-China), gross food demand was calculated based on the net calorie intake for that time step, as well as the corresponding food loss and waste fraction for each food category. The model was then run with the calculated gross food demand to simulate the agricultural production, trade, and market balance.

4 The role of healthy and sustainable diets in China's climate neutrality: modelling results

4.1 Impact on calorie consumption

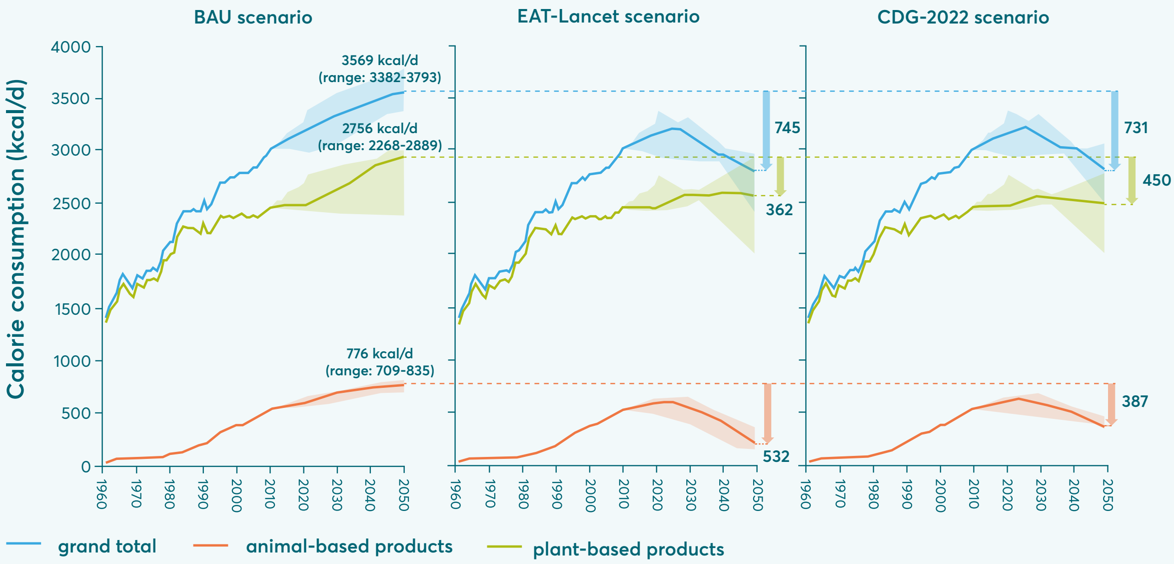
China has seen a significant increase in calorie consumption and contributing animal- and plant-based sources over recent decades (Figure 3). The BAU scenario projects that this increase in overall calorie consumption continues through to 2050. In this scenario, average calorie intake would reach ~3,570 kcal/cap/day by 2050. This corresponds to an increase in daily calorie consumption of approximately 520 kcal/capita/day over the period 2010 to 2050. As seen in Figure 3, this increase is expected to mainly come from plant-based products (e.g., cereals, vegetables, fruits, oilseeds and vegetable oils), but there would also be an increase in consumption of animal-based products such as milk, beef, pork, seafood and eggs. Over the period 2010-2050, plant-based consumption is projected to increase by 400 kcal/cap/day, while animal-based consumption is only projected to increase by approximately 120 kcal/cap/day.

In the healthy and sustainable diets scenarios (EAT-Lancet and CDG-2022), calorie consumption peaks before 2030 and then reduces by 2050 to below 2010 levels. Given that the EAT-Lancet and CDG-2022 dietary targets were assumed to be achieved by 2050 in the model simulations, there is a strong reduction in consumption of animal-based products in both scenarios, and the average consumption level by 2050 is projected to be lower than it was in 2010. The consumption of plant-based foods is projected to increase somewhat in both scenarios over time, but at a slower rate compared with the BAU scenario due to the restrictions in overall calorie consumption.

The EAT-Lancet scenario sees overall calorie consumption decrease slightly more than the CDG-2022 scenario. It projects overall calorie consumption to fall by 745 kcal/cap/day by 2050 compared with the BAU scenario. In contrast, CDG-2022 would result in a reduction of 731 kcal/cap/day. It should also be noted that the EAT-Lancet scenario sees a greater reduction in the consumption of animal products than the CDG-2022 scenario (down by 532 kcal/cap/day compared to 387 kcal/cap/day in CDG-2022) (Figure 3).

Figure 3: Projection of Chinese calorie consumption (by food type) for the Business-as-Usual (BAU), EAT-Lancet, and CDG-2022 scenarios.

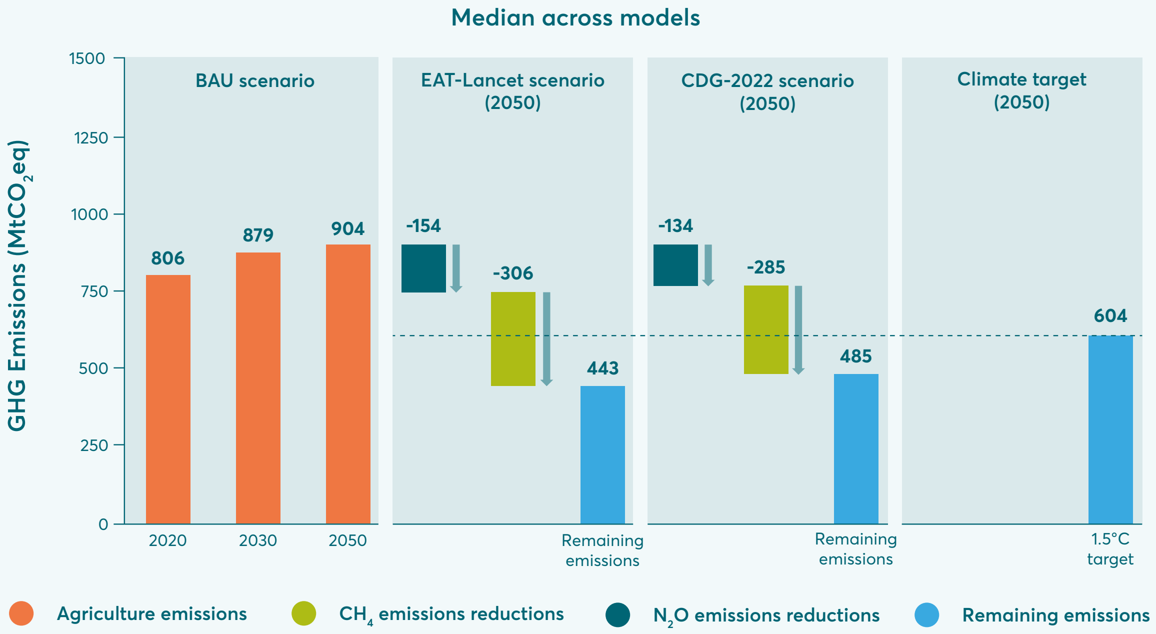
Shaded areas represent the span of model projections. Data for the historical period (1961-2010) came from FAOSTAT while those in the future period (2010-2050) were the ensemble mean of the projections from the four models.



4.2 Mitigation potential and peak year of agricultural emissions

As food production and consumption have increased significantly in China in recent decades, so have the GHG emissions from the agricultural sector. According to the Chinese National GHG Inventory submitted to the United Nations Framework Convention on Climate Change (UNFCCC), the agricultural sector emitted 605 $MtCO_2eq$ in 1994, 788 $MtCO_2eq$ in 2005, and 830 $MtCO_2eq$ in 2014 (Government of China, 2018). Based on these trends, the BAU scenario projects that agricultural emissions would reach 904 $MtCO_2eq$ by 2050 (Figure 4).

Figure 4: Overview of BAU emissions trajectory (2020, 2030, 2050), EAT-Lancet (2050) scenario, CDG-2022 scenario (2050), and emission levels consistent with 1.5°C pathways for the Chinese agriculture sector (2050).



It is evident from both the EAT-Lancet and CDG-2022 scenarios that dietary changes can significantly reduce China's agricultural GHG emissions. The EAT-Lancet scenario projects agricultural GHG emissions in 2050 to be 460 $MtCO_2eq$ lower than in the BAU scenario, while the CDG-2022 scenario projects agricultural GHG emissions to be 419 $MtCO_2eq$ lower. To comply with the 1.5°C pathway, emissions from the agricultural sector would need to peak by 2030 and to fall to 604 (590-617) $MtCO_2eq$ by 2050 (He, J., et al., 2020; EFC 2020). If dietary changes are successfully implemented in China, agricultural GHG emissions by 2050 can be reduced by as much as 51% under the EAT-Lancet or 46% under CDG-2022, both surpassing what is needed to comply with the 1.5°C pathway (Figure 4).

The EAT-Lancet scenario leads to a slightly stronger level of emissions reduction than the CDG-2022 scenario, and this finding is consistent across all four models. The reason for this is twofold. Firstly, the EAT-Lancet scenario leads to a lower level of overall calorie consumption by 2050 than the CDG-2022 scenario. Secondly, the EAT-Lancet scenario places greater emphasis on the reduction of animal-based products than the CDG-2022 scenario, leading to an overall lower level of animal-based products being consumed in 2050. As animal-based products have a relatively high GHG footprint, this reduction in their consumption leads to a lower level of agricultural emissions.

In both scenarios, emission reductions are achieved primarily through the reduction of methane (CH_4) emissions and to a lesser extent through the reduction of nitrous oxide (N2O) emissions. The reduction of CH_4 emissions accounts for 67-68% of the total GHG reduction of emissions in the two scenarios. The composition of the CH_4 emission reduction potential varies significantly between the different models depending on their assumptions and setup. For the GLOBIOM-China, FABLE Calculator and the AGHG-INV models, most of the emission reduction potential relates to the reduced livestock sector (with associated reductions in enteric fermentation and manure accounting for 57% and 12%, respectively, of the total CH_4 emission reduction potential). Reductions in rice production account for 21% of the total CH_4 emission reduction potential. In comparison, the MAgPIE-China model projects that all the reduction of CH_4 emissions relates to the reduced livestock sector (with associated reductions in enteric fermentation and manure accounting for 88% and 12%, respectively, of the total CH_4 emission reduction potential). This finding is consistent for both the EAT-Lancet and CDG-2022 scenarios. The reason for this is that MAgPIE-China projects an increase in rice production in the EAT-Lancet and the CDG-2022 as compared to the BAU scenarios to compensate for the reduction of animal-based products.

The adoption of healthy and sustainable diets could significantly bring forward the peaking of GHG emissions from the agricultural sector. With the adoption of healthy and sustainable diets, agricultural-source emissions can peak by 2030 at the latest. This finding is consistent for both the CDG-2020 and EAT-Lancet scenarios, indicating that regardless of which healthy dietary guidelines are followed, the impact on the year in which China's agricultural GHG emissions peaks will be similar. All of the models, except for the FABLE calculator, project agricultural emissions to peak in the same year for both the EAT-Lancet and CDG-2022 scenarios.

A dietary transformation within the Chinese food system would not only lead to a reduction of agricultural emissions, it could also provide co-benefits by increasing China's land use, land-use change and forestry (LULUCF) sink. The modelled dietary changes will reduce the land-use pressure for food and feed production, potentially freeing up farmland for other purposes, such as rewilding and restoration. These areas would potentially absorb CO_2, thus increasing China's land-based carbon sink. The GLOBIOM-China and MAgPIE-China models estimate that by 2050, dietary changes as simulated under the EAT-Lancet and the CDG-2022 scenarios may increase the LULUCF sink by approximately 20 $MtCO_2eq$.[4] While this increase in the LULUCF sink will be beneficial, it is relatively minor in comparison to the current size of the LULUCF sink. According to the Chinese National GHG Inventory submitted to the UNFCCC, the LULUCF sink was -1,115 $MtCO_2eq$ in 2014 (Government of China, 2018).

4.3 Regional contribution to China's mitigation potential

China's provinces are one of the key policy-making units within the country. As the AGHG-INV model has a spatial scale that includes the provincial level, it can assist in identifying emission trajectories and mitigation potentials for each province in China. As shown in Figure 5, GHG emissions from agriculture in China differ significantly by province, as does the potential for emission reductions. In view of the key role that provinces play in formulating and implementing low-carbon policies in all sectors, we compared the mitigation potential in each province using the provincial data from the AGHG-INV model.

There is significant variation in agricultural GHG emissions across China's provinces, ranging from 0.6 $MtCO_2eq$ to 71.5 $MtCO_2eq$ in 2021. The associated top eight emitting provinces in China are Sichuan, Hunan, Yunnan, Inner Mongolia, Jiangxi, Hubei, Henan, and Heilongjiang, with emissions ranging from 38.4 to 71.5 $MtCO_2eq$. These provinces contribute 46% of the country's total agricultural GHG emissions. In the BAU scenario, the top eight emitting provinces would remain the same, and by 2050 are projected to still account for 46% of the country's agricultural GHG emissions.

The main sources of GHG emissions vary across the top eight provinces. Inner Mongolia, Sichuan, Yunnan, Heilongjiang, and Henan are the provinces with the highest livestock farming levels. Sichuan, Hunan, and Jiangxi are major rice-producing provinces; while Hubei, Hunan, Heilongjiang, and Jiangxi are major aquaculture producers. In addition, N_2O emissions in Hunan, Henan and Sichuan are the highest in the country, due to their large cropped area and widespread livestock farming. The four provinces with the highest projected growth in agricultural GHG emissions between 2020 and 2050 (BAU scenario) are Inner Mongolia, Heilongjiang, Yunnan, and Xinjiang, with increases of 7.3 $MtCO_2eq$, 5.0 $MtCO_2eq$, 4.8 $MtCO_2eq$, and 4.8 $MtCO_2eq$, respectively. The rise in meat and milk consumption is primarily responsible for the increased emissions of CH_4 because of the associated livestock enteric fermentation and manure.

4 The AGHG-INV model only covers the agricultural sector so no estimates from this model are included.

Table 3. Agricultural greenhouse gas emissions by 2050 by province under the Business-as-Usual (BAU), EAT-Lancet, and CDG-2022 diet scenarios, using the AGHG-INV model.

	2020	2030			2050		
Province	(Reference year)	BAU	CDG 2022	EAT Lancet	BAU	CDG 2022	EAT Lancet
Beijing	0.6	0.7	0.8	0.7	0.7	0.9	0.8
Tianjin	2.5	2.9	2.9	2.8	2.9	2.6	2.2
Hebei	24.6	29.3	30.7	29.3	29.3	30.9	26.5
Shanxi	9.5	12.2	11.6	11.2	12.2	9.3	8.1
Inner Mongolia	45.2	54.0	50.9	49.3	54.9	40.2	35.6
Liaoning	24.0	27.0	23.9	23.3	26.7	15.1	13.3
Jilin	22.9	29.0	24.6	24.2	28.9	12.9	11.8
Heilongjiang	38.0	43.4	41.7	40.4	43.4	33.5	30.0
Shanghai	1.5	1.7	1.8	1.7	1.7	1.7	1.4
Jiangsu	32	36.3	32.5	31.7	35.3	21.3	18.7
Zhejiang	12.1	13.3	11.8	11.4	12.9	7.3	6.1
Anhui	35.7	39.3	34.7	33.8	38.3	21.5	18.6
Fujian	13	14.5	12.9	12.6	13.9	8.5	7.5
Jiangxi	41.1	44.7	38.1	36.7	43.4	21.1	16.9
Shandong	29.3	33.0	30.4	29.4	32.8	22.1	19.0
Henan	38.5	44.3	39.3	38.5	43.9	25.1	22.1
Hubei	39.4	45.6	38.6	37.7	44.9	20.4	17.4
Hunan	60.9	67.4	56.9	55.1	65.7	30.2	24.7
Guangdong	34.1	38.4	33.6	32.9	37.1	20.7	18
Guangxi	32.0	36.9	32.2	32.8	35.6	20.3	18.2
Hainan	5.8	6.6	5.6	5.6	6.4	3.1	2.8
Chongqing	20.8	23.1	20.0	19.4	22.3	12.0	10.0
Sichuan	71.4	77.7	67.3	65.2	75.4	40.1	33.4
Guizhou	31.7	34.2	28.3	27.7	33.5	13.8	11.7
Yunnan	54.0	59.1	49.4	48.5	58.5	25	22.1
Tibet	17.5	19.9	16.2	16.0	20.4	7.1	6.6
Shaanxi	12.5	14.2	12.9	12.7	14.2	8.8	8.0
Gansu	21.1	25.2	20.5	20.3	25.6	9.3	8.8
Qinghai	20.9	23	17.9	17.7	23.5	5.9	15.2
Ningxia	8.2	12.5	14.7	13.8	12.8	17.9	15.2
Xinjiang	31.5	38.5	32.8	32.3	39.0	19.0	17.7

Under the CDG-2022 scenario in 2030 (Figure 6), agricultural GHG emission mitigation potentials are expected to range between -2.2 $MtCO_2eq$ and 10.6 $MtCO_2eq$ in each province, and by -5.1 $MtCO_2eq$ and 35.6 $MtCO_2eq$ in 2050.[5] Methane emission reductions are the main source of emission reductions, accounting for 78% of the total emission reduction potential in 2030. Hunan, Sichuan, Yunnan, Hubei, Jiangxi, Xinjiang, Guizhou, and Henan are the top eight provinces with the highest overall agricultural mitigation potential, ranging from 18.8 $MtCO_2eq$ to 35.6 $MtCO_2eq$, and together accounting for 51% of the nation's mitigation potential. Except for Hubei Province, where freshwater aquaculture accounts for 29% of the province's mitigation potential, a reduction in livestock and associated enteric fermentation offers the greatest mitigation potential (26%-84%).

Under the EAT-Lancet scenario in 2030 (Figure 7), agricultural GHG emissions are expected to drop by between -1.3 and +12.6 $MtCO_2eq$ in each province, and by between -2.4 and +42.0 $MtCO_2eq$ by 2050. Sichuan, Hunan, Yunnan, Hubei, Jiangxi, Henan, Guizhou, and Xinjiang are the top eight provinces in terms of mitigation potential, which are the same as those under the CDG-2022 scenario, but ordered differently. In total, the provinces account for 50% of the national agricultural mitigation potential, with a potential that ranges from 21.3 in the EAT-Lance scenario and 42.0 $MtCO_2eq$ in the CDG-2022 scenario.

5 A negative mitigation potential here reflects the case where the projected total agricultural GHG emissions in the province are higher in the CDG-2022 scenario than the BAU scenario.

Table 4. China's agricultural emission reduction potentials by GHG and reference diet scenario in 2030 and 2050.

	2030						2050					
	EAT Lancet			CDG 2022			EAT Lancet			CDG 2022		
Province	CH_4	N_2O	Total	CH_4	N_2O	Total	CH_4	N_2O	Total	CH_4	N_2O	Total
Beijing	-0.1	0.0	-0.1	-0.1	0.0	-0.1	-0.1	0.0	-0.1	-0.2	0.0	-0.2
Tianjin	0.1	0.1	0.2	0.0	0.0	0.0	0.5	0.3	0.8	0.1	0.2	0.3
Hebei	-0.3	0.2	-0.1	-1.5	0.1	-1.4	1.2	1.6	2.8	-2.5	1.0	-1.5
Shanxi	0.7	0.2	0.9	0.4	0.2	0.6	3.1	1.1	4.2	2.1	0.8	2.9
Inner Mongolia	4.1	0.7	4.8	2.6	0.6	3.2	16.2	3.1	19.3	12.1	2.6	14.7
Liaoning	2.9	0.8	3.7	2.3	0.8	3.1	10.4	3.1	13.5	8.8	2.9	11.7
Jilin	3.9	0.8	4.7	3.5	0.9	4.4	13.8	3.3	17.1	12.7	3.3	16
Heilongjiang	2.5	0.5	3.0	1.1	0.6	1.7	10.7	2.7	13.4	7.0	2.8	9.8
Shanghai	0.0	0.1	0.1	-0.1	0.0	-0.1	0.1	0.2	0.3	-0.2	0.2	0.0
Jiangsu	3.7	0.9	4.6	2.7	1.1	3.8	12.6	4.0	16.6	9.9	4.1	14
Zhejiang	1.6	0.4	2.0	1.2	0.4	1.6	5.4	1.4	6.8	4.3	1.3	5.6
Anhui	4.6	0.9	5.5	3.6	1.1	4.7	15.8	3.9	19.7	12.9	3.9	16.8
Fujian	1.4	0.4	1.8	1.1	0.5	1.6	4.7	1.7	6.4	3.7	1.8	5.5
Jiangxi	7.1	0.9	8.0	5.6	0.9	6.5	23.2	3.3	26.5	19.1	3.2	22.3
Shandong	2.6	0.9	3.5	1.8	0.8	2.6	9.8	4.0	13.8	7.4	3.3	10.7
Henan	4.2	1.5	5.7	3.4	1.6	5.0	15.6	6.2	21.8	13.0	5.9	18.9
Hubei	6.3	1.6	7.9	5.3	1.7	7.0	21.5	5.9	27.4	18.6	5.9	24.5
Hunan	10.5	1.8	12.3	8.7	1.9	10.6	34.4	6.6	41.0	29.2	6.3	35.5
Guangdong	4.5	1.1	5.6	3.5	1.3	4.8	14.7	4.4	19.1	11.9	4.5	16.4
Guangxi	4.1	1.0	5.1	3.3	1.3	4.6	13.2	4.2	17.4	10.9	4.4	15.3
Hainan	0.8	0.2	1.0	0.7	0.3	1.0	2.7	0.9	3.6	2.4	0.9	3.3
Chongqing	3.3	0.4	3.7	2.6	0.5	3.1	10.5	1.7	12.2	8.5	1.8	10.3
Sichuan	11.2	1.3	12.5	9.1	1.3	10.4	36.6	5.4	42.0	30.5	4.9	35.4
Guizhou	5.7	0.9	6.6	5.0	0.9	5.9	18.7	3.1	21.8	16.7	3.0	19.7
Yunnan	9.1	1.5	10.6	8.1	1.6	9.7	30.7	5.7	36.4	27.8	5.7	33.5
Tibet	3.8	0.1	3.9	3.6	0.1	3.7	13.3	0.4	13.7	12.9	0.3	13.2
Shaanxi	1.2	0.3	1.5	1.0	0.4	1.4	4.7	1.4	6.1	4.0	1.4	5.4
Gansu	4.3	0.6	4.9	4.2	0.5	4.7	14.7	2.1	16.8	14.4	1.9	16.3
Qinghai	4.8	0.4	5.2	4.7	0.4	5.1	16.2	1.5	17.7	16.2	1.4	17.6
Ningxia	-1.2	0.0	-1.2	-2.1	-0.1	-2.2	-2.5	0.1	-2.4	-5.0	-0.2	-5.2
Xinjiang	5.7	0.4	6.1	5.3	0.4	5.7	19.3	2.0	21.3	18.3	1.7	20

⑤ Conclusions and recommendations

This assessment has highlighted the significant role that healthy and sustainable diets can play in China's transition towards a climate-neutral economy. It shows that the successful adoption of healthy and sustainable reference diets could reduce GHG emissions from China's agricultural sector by 46-51% by 2050. Methane (CH_4) plays a major role therein, accounting for 67-68% of the total GHG emission reductions. Most of the emission reduction potential relates to a reduced livestock sector, with the associated reduction in livestock enteric fermentation and manure emissions. The provinces that are expected to contribute the most to the agricultural sector's emission reduction potential are Sichuan, Hunan, Yunnan, Hubei, Jiangxi, Henan, Guizhou, and Xinjiang.

If China's agricultural sector was to reduce GHG emissions by these amounts, it would ensure that the sector is developing in a manner that is potentially compatible with global emissions pathways that limit global warming to 1.5°C. In other words, the successful implementation of either of the healthy and sustainable reference diets as described in this report would ensure that the emission pathways of China's agriculture sector are consistent with the Paris Agreement. It could also help ensure that agricultural emissions peak by 2030. Healthy and sustainable diets therefore align well with the government's climate goals.

Beyond climate change mitigation, healthy and sustainable diets may also have significant co-benefits for human nutrition and health and the environment. For example, an overall plant-based dietary pattern reduces the risk of all-cause mortality (Chen et al., 2022). However, the models are focused on the domestic GHG emissions associated with dietary change and currently do not account for or quantify health co-benefits. Technological innovations could further enhance mitigation potential and co-benefits (e.g. changing livestock diets and feed additives), but these have not been modelled here either. While all these areas merit further research to better substantiate the implications of healthy and sustainable diet initiatives in China, dietary change should already be prioritized as an enabler of climate change mitigation, with potential co-benefits for food security, human nutrition and health and a reduced environmental footprint.

Transitioning to healthy and sustainable diets will be a particular implementation challenge as it will require changing the behaviour of over a billion individuals. In this assessment, the modelling assumed that reference diets were rolled out in a linear manner across all provinces. China is a country that offers its citizens a wide range of food choices and diets vary significantly by region and province. As such, successful transitioning of diets needs clear policy incentives, and engagement by various stakeholders for the transition to reach all regions and provinces.

Some strategies already exist. The Academy of Global Food Economics and Policy has developed four major strategies to promote the transition to sustainable and healthy diets in China (AGFEP, 2023). These strategies include establishing a healthy dietary pattern that is appropriate for the Chinese population, proposing a sustainable healthy diets optimization programme, adjusting international trade and overseas investment, and taking measures to guide interventions to change the diet of the population toward sustainable health. Attwood et al. (2023) have developed a comprehensive range of behavioural change interventions designed to support the Chinese population in making food choices that align with the Chinese Dietary Guidelines. These include interventions targeting the people who prepare food; the food offering itself; government-led initiatives; the marketing of healthy and sustainable foods, including the way these are described to consumers; and the positioning of healthy and sustainable products so that they are more likely to be selected.

Following China's significant progress in alleviating poverty and undernourishment, the nation now has an opportunity to enable the population's transition to a healthier and more sustainable diet to achieve better outcomes in the areas of human health and nutrition security, climate change mitigation, and environmental sustainability. Achieving the potential of healthy and sustainable diets, however, requires rapid, inclusive, and just action, along with recognizing and addressing potential social barriers. It entails improving, formulating, and implementing effective policies that take into account local contexts, engage stakeholders, and ensure equity and justice. It would be beneficial to conduct more research to address potential implementation challenges, including consumer diet choices and behaviours (such as the factors influencing people's food choices and their health perceptions), and the effectiveness of policy interventions for diet transitions. Such research and knowledge will help develop effective strategies and policies for diet transition. In addition, an umbrella policy will be critical to coordinate key stakeholders, such as agricultural, health, education, and commerce sectors, in the shift towards healthy and sustainable diets.

Annex 1. Model descriptions

GLOBIOM-China (Zhejiang University, Peking University, IIASA)

The Global Biosphere Management Model (GLOBIOM) is a recursive dynamic,[6] spatially explicit, economic partial equilibrium model of the agriculture, forestry, and bioenergy sector with bilateral trade flows and costs (Havlik et al., 2015). The model is built following a bottom-up setting based on detailed grid-cell information, providing the biophysical and technical cost information. The model computes a market equilibrium in 10-year time steps from 2000 to 2100 by maximizing welfare (the sum of consumer and producer surplus) subject to technological, resource, and political constraints. At each step, market prices adjust endogenously to equalize supply and demand for each product and region. GLOBIOM-China was further developed with an enhanced representation of China's agricultural sector and environmental dynamics, a detailed validation, and confined assumptions following existing policies in China (Zhao et al., 2021).

MAgPIE-China (Zhejiang University and Potsdam Institute for Climate Impact Research)

The Model of Agricultural Production and its Impact on the Environment (MAgPIE) (Lotze-Campen, et al., 2008; Popp et al., 2014; Dietrich et al., 2019; Wang, et al., 2020) is a global agro-economic land system model which is connected to the grid-based dynamic vegetation model LPJmL, (Bondeau et al., 2007; Schaphoff et al., 2018) with a spatial resolution of 0.5° x 0.5°. MAgPIE contains 12 world regions, in which countries are grouped together according to their geo-economic conditions (Dietrich et al., 2019). The model is run in a recursive dynamic mode over five-year intervals from 1995 to 2100. Agricultural production is endogenously determined in the optimization, where the total cost of production is minimized for a given amount of regional food and bioenergy demand. The regional food demand is mainly driven by population and income growth. It takes into account regional economic conditions such as demand for agricultural commodities, technological development, and production costs, and spatially explicit data on potential crop yields land and water constraints. Based on these, the model derives spatially explicit land-use patterns, yields, and total agricultural production costs for each grid cell. MAgPIE-China has been further developed to incorporate existing agriculture and environmental-related polices in China to improve the representation of China's AFOLU sector (Wang, et al., in revision).

FABLE Calculator-China (Center for Agricultural Resources Research, Chinese Academy of Sciences (CAS), Sustainable Development Solutions Network (SDSN)

The Food, Agriculture, Biodiversity, Land-use, and Energy (FABLE) Calculator is written in Excel and solved by ensuring equilibrium between the various uses (food, feed, processing) and domestic production minus exports plus imports, under a land availability constraint, for each five-year period over 2000-2050 (Mosnier et al., 2020). It focuses on agriculture as the primary driver of land-use change. It tests the impact of different policies and changes in the drivers of these systems through the combination of many scenarios, including population growth, dietary change, productivity growth, trade, loss and waste, climate change impacts, etc. It includes 76 raw and processed agricultural products from the crop and livestock sectors and relies extensively on the FAOSTAT (2023) database for input data. For every five-year interval over the period 2000-2050, the Calculator computes the level of agricultural activity, land-use change, food consumption, trade, greenhouse gas emissions, water use, and biodiversity conservation. Market balance, agricultural land use and agricultural emissions are calibrated for the years 2000, 2005 and 2010 using FAO statistics. The model is a national model in that it only represents development for China and has been modified to reflect the Chinese context, e.g. China's Cropland Protection Redline, China's target to achieve 26% forest cover rate by 2050, and historical changes in animal feed composition (Jin et al., 2020).

6 The "recursive dynamic" and "forward-looking dynamic" terminology refers to the solution approach of the model but it also implies different representations of the expectations of economic actors. In a recursive model, decisions about production, consumption and investment are made only on the basis of prices in the period of the decision, and this is often referred to as "myopic" expectations. Decisions are thus made as if costs and prices will remain unchanged in the future. In a forward-looking model, decisions today are being optimized over the full horizon, meaning that decisions today about production and consumption are based on expectations that are realized in the model simulation. Thus, economic actors are characterized as having "perfect" foresight — they know exactly what will happen in the future in all periods of time covered by a modeling exercise.

AGHG-INV (Renmin University of China)

The Agriculture-induced non-CO_2 GHG INVentory model (AGHG-INV) is a bottom-up model[7] with technology details (Energy Foundation China, 2020; Chen et al., 2022). It can provide projections of non-CO_2 GHG emissions from agricultural sources at the provincial level and is built on publicly available activity data from the national statistical database and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2008). In AGHG-INV, activity drivers for emission projections enter calculations externally using scenario data from different internationally and nationally recognized sources. Emission factors are consistent with historical levels in a business-as-usual (BAU) scenario, and emissions are a function of the projected activity level of major agricultural activities which reacts to animal feeding and crop farming, changes in national population size, urbanization, economic development, and per capita consumption of major food products.

7 A top-down approach looks at the system under examination as a whole and uses reduced form behavioural relationships with econometrical validation, while bottom-up approaches are developed from an engineering perspective and start from the sector of interest in detail before expanding the focus to the whole system.

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