# EFFECT OF DIETARY CHANGES ON AGRICULTURAL CARBON EMISSIONS IN CHINA

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**Abstract.** Global warming caused by carbon emissions is intensifying, and carbon emissions from dietary consumption have also received increasing attention in recent years. The dietary structure and needs of Chinese residents have undergone significant changes with the development of society and economy. This study collected panel data on food production and consumption in China from 2013 to 2020, and quantitatively evaluated the impact of changes in food production and consumption structure on carbon emissions using IPCC and life cycle carbon footprint parameters. The spatial differences in dietary structure among provinces in China were revealed, and the emission reduction potential of future food consumption in China was explored based on nutritional needs. Results show that grain production increased carbon emissions by 10%, while consumption growth drove a 17% rise. The consumption gap between urban and rural areas in China is gradually narrowing. There are still many provinces where the population's dietary consumption fails to meet the nutritional requirements. Therefore, food consumption structure should be adjusted by suitably increasing the consumption of milk and decreasing that of grains and meat. Adjusting consumption structure and reducing waste can reduce carbon emissions by 15%. This study guides residents toward healthy diets and low-carbon consumption synergistically.
**Keywords:** *food consumption, food production, nutrient intake, scenario simulation analysis, healthy diet*

## Introduction

The Paris Agreement aims to limit the temperature increase to 1.5°C or less compared to pre-industrial levels (Clark et al., 2020), and any increase above this threshold would cause irreversible damage to ecosystems, however, by 2021 it has risen to 1.2°C (Zhang, 2019). Growing environmental issues due to greenhouse gas emissions (GHG) are worsening (O'Malley et al., 2023; Gutiérrez et al., 2023), 19%~29% from the agricultural (Goldstein et al., 2017). China is the world's largest emitter of carbon emissions, accounting for 28% of total global emissions in 2019 (Liu et al., 2022; Crippa et al., 2021). To combat the effects of climate change, China has committed to reaching peak carbon emissions by 2030 and achieving carbon neutrality by 2060 ("dual-carbon" goal) (Sun et al., 2019; Song et al., 2023). Reducing carbon emissions from agriculture is therefore important for achieving China's "dual-carbon" goal.

Urbanization in China has driven economic growth leading to significant changes in the structure and quantity of food consumption. The dietary consumption of Chinese residents has significantly shifted from quantity to quality (Yu et al., 2023), leading to a


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change in demand for agricultural products. The change in consumption habits has also altered its carbon emission characteristics. Carbon emissions from diets in meat consumption are much higher than those from vegetarian diets (O'Malley et al., 2023). Carnivorous animals in traditional agriculture typically feed on grains and vegetables, for every kilogram of pork produced, 3 kg of grain are consumed (Zhou et al., 2017), So carbon emissions from red meat are about twice those from poultry and aquatic animals (Han, 2022). The outbreak of COVID-19 in China has heightened residents' *awareness of* healthy diets and nutrition intake, leading to increased consumption of vegetables, fruits and high-quality protein such as aquatic product and vegetable protein. This Change in diet not only poses new challenges to food production, but also puts pressure on carbon emissions. Despite the lower diet emissions in developing countries compared to developed nations (Nabipour Afrouzi et al., 2023), the issue remains significant. Even now, more than half of the world's population still consumes food in wasteful and unhealthy way (Li et al., 2024). It is crucial to change existing consumption patterns in order to fulfil the carbon emission reduction commitments of the Paris Agreement, (Prag and Henriksen, 2020). Most previous research has focused on achieving carbon reductions in agriculture by reducing meat consumption, but dietary habits vary in different regions, and there is currently little research on reducing carbon emissions through rational adjustment of dietary structure and reducing waste. Research has shown that if dietary changes are implemented, it is expected to reduce carbon emissions by approximately 32.4% (Li et al., 2024). And many consumers have also clearly expressed their subjective willingness to change their food consumption behavior to reduce carbon emissions (Nordström and Denver, 2024).

Since 2000, rapid industrialization and urbanization in China have driven accelerated economic growth. The food consumption increased by 0.7% annually from 2000 to 2012, with a slow growth rate. However, since 2013, the growth rate of food consumption has significantly increased. Due to the rapid development of the Chinese economy and the significant improvement of residents' living standards, people's demand and consumption patterns for food have undergone significant changes. The carbon change caused by food consumption poses a significant threat to global warming, and the changing trend of China's food consumption and its future emission reduction potential are still unclear. Therefore, the specific objectives of this study are: (1) Reconstruct the historical time series of food production and consumption in China from 2013 to 2020, and clarify the trends in carbon emissions from food production and consumption; (2) Clarify the consumption differences between urban and rural areas and various regions in China, and explore their future consumption dynamics; (3) Determine the current nutritional status (energy, fat, and protein), changing characteristics, and future development direction of Chinese residents, and (4) construct a synergistic emission reduction model for future consumption structure and production adjustments, and quantify the impact on carbon emissions through scenario analysis, which provides an actionable path for China's "dual carbon" target.

## Methods

### *Carbon emission calculations*

Carbon emissions from food in different years and different provinces were calculated by the carbon footprint coefficient method proposed by Li (2020) (see *Table 1*), which is calculated as follows:


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$$CE_{ij} = Y_{ij} * CF_j \quad \text{(Eq.1)}$$

$$CE_i = \sum_{j=1}^{n} CE_{ij} \quad \text{(Eq.2)}$$

$$CE_{jk} = Y_{jk} * CF_j \quad \text{(Eq.3)}$$

$$CE_k = \sum_{j=1}^{n} CE_{jk} \quad \text{(Eq.4)}$$

$CE_{ij}$ represents carbon emissions of type j in year i (Mt $CO_2e$), $Y_{ij}$ represents type j quantity in year i (Mt), $CF_j$ represents carbon footprint coefficient of type j, $CE_i$ represents carbon emissions of all type j in year i (Mt), $CE_{jk}$ represents carbon emissions of type j in province k (Mt $CO_2e$), $Y_{jk}$ represents type j quantity in province k (Mt), $CE_k$ represents carbon emissions of all type j in province k (Mt).

***Table1.*** *Carbon footprint parameters for various foods (CO2ekg/kg)*

| Index | | Carbon footprint (kg $CO_2e$/kg) |
|---|---|---|
| Grain | Rice | 2.47 |
| | Wheat | 0.97 |
| | Maize | 0.53 |
| | Legumes | 1.29 |
| | Other cereals | 1.14 |
| Vegetable | | 0.87 |
| Fruit | | 0.88 |
| Meat | Beef | 21.3 |
| | Lamb | 13.36 |
| | Prok | 4.22 |
| | Poultry | 3.92 |
| Egg | | 3.26 |
| Aquatic | | 4.84 |
| Milk | | 1.45 |

### *Nutrient calculations*

For the purpose of calculating the nutrient availability of each food category, the paper classified more than 1000 food items according to Institute of Nutrition and Health, Chinese Centre for Disease Control and Prevention (Yang, 2019) into seven major categories: aquatic, fruits, grain, vegetables, meat, milk and eggs. The energy (kcal), fat content (%) and protein (%) provision per kg for each major category was calculated according to the proportion of food produced of each subcategory and the nutrient provision in the subcategories. The outcomes of the computations are displayed in *Table 2*.


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***Table 2.*** *2018 food category nutrient content table*

| Index | Energy supply (kcal/kg) | Amount of fat provided (%) | Amount of protein provided (%) |
|---|---|---|---|
| Grain | 3581 | 2.8 | 10.3 |
| Vegetable | 587 | 0.5 | 4.1 |
| Fruit | 672 | 0.6 | 1.2 |
| Meat | 3255 | 28.9 | 14.9 |
| Egg | 1625 | 12.0 | 12.4 |
| Milk | 540 | 3.2 | 3.0 |
| Aquatic | 2240 | 7.8 | 34.4 |

*Nutrition intake calculations*

Nutrition intake calculations method is as follows:

$$N_{ij} = C_{ij} * SN_j \quad \text{(Eq.5)}$$

$$N_i = \sum_{j=1}^{n} N_{ij} \quad \text{(Eq.6)}$$

$$N_{jk} = C_{jk} * SN_j \quad \text{(Eq.7)}$$

$$N_k = \sum_{j=1}^{n} N_{jk} \quad \text{(Eq.8)}$$

$N_{ij}$ represents nutrition intake of type j in year i (kcal, g, g), $C_{ij}$ represents consumption quantity of type j in year i (kg), $SN_j$ represents the nutrition supply coefficient of type j, $N_i$ represents nutrition intake of all type j in year i; $N_{jk}$ represents nutrition intake of all type j in province k, $C_{jk}$ represents nutrition intake of type j in province k (kcal, g, g), $N_k$ represents nutrition intake of all type j in province k.

*Fat intake proportion of total energy calculations*

Fat intake proportion of total energy calculations method is as follows:

$$FP = \frac{F * 9}{E} * 100\% \quad \text{(Eq.9)}$$

FP represents fat intake proportion of total energy, F represents fat, E represents energy.

***Scenario simulation analysis***

*Food consumption scenario simulation*

In order to better understand the impact of food consumption on GHG emissions, three consumption patterns were evaluated in this study: "Current consumption Patterns (C)", "Outline consumption pattern (O)" and "Adjusted consumption pattern (A)". C:


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Maintaining the current quantity and structure of diet in China's provinces without change. O: Consumption by residents in all regions of China fully adheres to the dietary patterns recommended in the Outline for the Development of Dietary Nutrition for the Chinese Population (2014-2020), in which residents annually consume 135 kg of grain, 140 kg of vegetables, 60 kg of fruit, 29 kg of meat, 16 kg of eggs, 18 kg of aquatic products and 36 kg of milk. A: Based on the (O) pattern, the reality of the inertia of the residents' dietary structure adjustment is fully taken into account, adjustment annually is set to be no more than 20 percent of the difference between (C) and (O).

*Food production scenario simulation*

In order to better understand the carbon emission reduction potential of food production changes, two production models were evaluated in this study: "Reducing waste (R)" and "No Changes (N)."

R: Problem of food waste may result in higher food production requirement and resource waste. Food waste can be reduced properly with the development of food processing industry and transportation and awareness of environmental protection and conservation. The ratio of consumption to production is an important parameter reflecting food waste. Therefore, by appropriately increasing the current consumption to production ratio, excessive food production can be reduced, thereby reducing carbon emissions. Based on the historical peak constraint theory proposed by Xu (2005), the consumption-production ratio in the 1980s was selected as the baseline threshold (the maximum realized value in the natural state was formed in that period due to the constraints of cold-chain technology and transport efficiency), and production was adjusted for various consumption modes, with an adjustment interval of 0%-20% set for compatibility with regional development variability. N: No consideration of waste, the ratio of consumption to production is unchanged, production is simulated.

### *Data resource*

The data of seven major categories: aquatic, fruit, cereal, vegetable, meat, milk, and egg in food production and consumption, and population were derived from China Statistical Yearbook (State Bureau of Statistics, 2013-2020).

## Results

### *Changes in food production*

*Temporal changes in food production*

An analysis was conducted on China's food production from 2013 to 2020 with seven major food commodities as indicators (meat, milk, eggs, vegetables, grains, and aquatic). *Figure 1A* shows that the change in China's food production from 2013 (1693 Mt) to 2020 (1918 Mt) is an increase of 13%, with an average of nearly 2% per year. Changes in the production of various food types between 2013 and 2020 were analyzed comparatively. *Figure 1B* shows that total food increase 225 Mt, the production of vegetables, grains, fruits, and aquatic, eggs and milk increased by 117 (52%), 39 (17%), 59 (26%), 8 (4%), 6 (3%) and 4 (2%) million tons, respectively. Meat production, however, decreased by 9 million tons with 4%.


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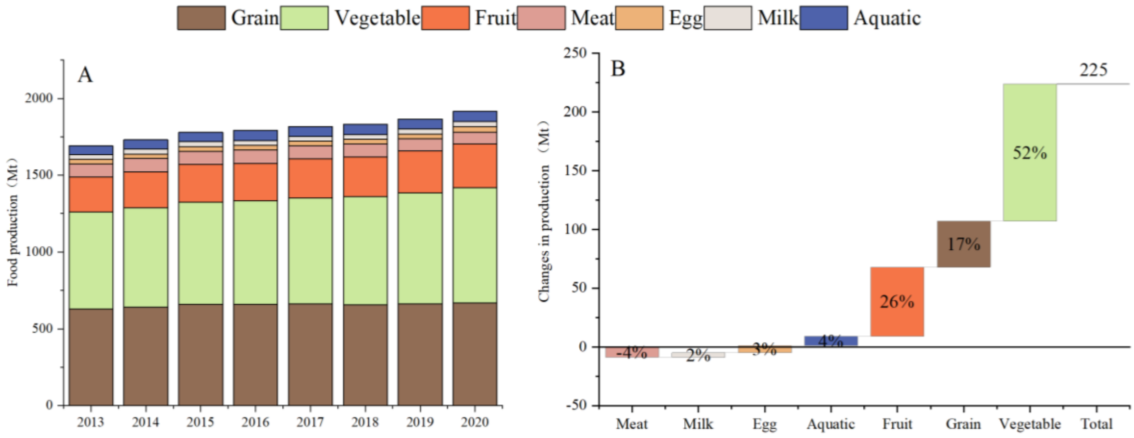


***Figure 1.*** *Changes in food production (A), production by category (B)*

### *Spatial changes in food production*

There are significant differences in the production of food in different province in China. *Figure 2* shows that from the spatial distribution of food production in 2020, it can be seen that Shandong (191 Mt), Henan (183 Mt), Hebei (118 Mt) have higher food production compared to other provinces, accounting for about 26% of the total national production. Food production in eastern China is more remarkable than in western China. Southeast coastal provinces have higher aquatic production, such as Guangdong (9 Mt), Fujian (8 Mt), Shandong (8 Mt), Zhejiang (6 Mt) and Jiangsu (5 Mt), accounting for 55.23% of China's total aquatic production. The highest egg production was in Shandong (5 Mt), Henan (4 Mt) and Hebei (4 Mt) with 38% of total egg production. The provinces with the higher fruit production were Shandong (29 Mt), Guangxi (28 Mt) and Henan (26 Mt), accounting for 28.89% of the total production. The regions with larger milk production compared to others were Inner Mongolia (6 Mt), Heilongjiang (5 Mt), and Hebei (5 Mt), which accounted for 46.37% of the total national production. The areas with higher grain production were Heilongjiang (75 Mt), Henan (68 Mt) and Shandong (54 Mt), accounting for 29.59% of the national total grain production. The higher vegetable production compered to other areas were Shandong (84 Mt), Henan (76 Mt) and Jiangsu (57 Mt), which account for 29.07% of the total national vegetable production. The higher meat production compere to other area were Shandong (7 Mt), Sichuan (6 Mt) and Henan (5 Mt), account for 9.40% of the total national production.

### *Carbon emission changes in food production*

Carbon emissions are calculated based on carbon footprint coefficient. *Figure 3A* shows that carbon emissions from agriculture production are positively correlated with yields, and as agricultural production increases, so do carbon emissions from agriculture. The carbon emissions are increase of 241 Mt from 2013 to 2020. Except for meat, all other six food items increased carbon emissions. Comparing changes in carbon emissions in 2013 and 2020, *Figure 3B* shows carbon emissions from milk, eggs, aquatic, fruit, grain, vegetable increase significantly, increased by 6 Mt (3%), 18 Mt (7%), 39 Mt (16%), 52 Mt (22%), 44 Mt (18%) and 87 Mt (42%) in 2020, respectively. However, that from meat reduced by 21 Mt (9%). The growth rate of carbon emissions


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brought about by meat, eggs, and aquatic products is much higher than the yield increase rate of relative products.

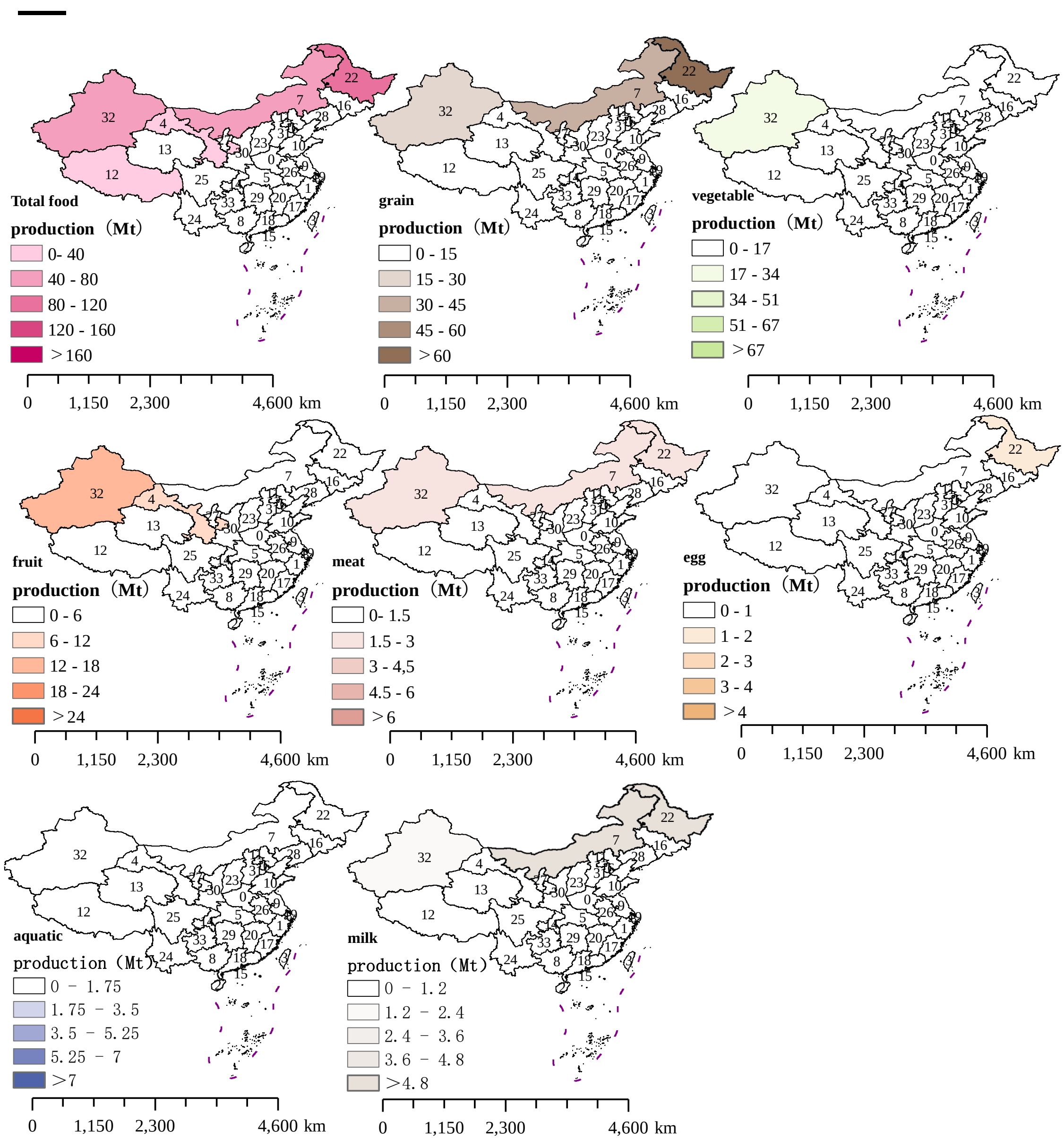


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***Figure 2.*** *Different types food production by provinces in 2020. 0-Henan Province; 1-Zhejiang Province; 2-Hainan Province; 3-Taiwan Province; 4-Gansu Province; 5-Hubei Province; 6-Tianjin Municipality; 7-Inner Mongolia Autonomous Region; 8-Guangxi Zhuang Autonomous Region; 9-Jiangsu Province; 10-Shandong Province; 11-Beijing Municipality; 12-Tibet Autonomous Region; 13-Qinghai Province; 14-Chongqing Municipality; 15-Macao Special Administrative Region; 16-Jilin Province; 17-Fujian Province; 18-Guangdong Province; 19-Shanghai Municipality; 20-Jiangxi Province; 21-Hong Kong Special Administrative Region; 22-Heilongjiang Province; 23-Shanxi Province; 24-Yunnan Province; 25-Sichuan Province; 26-Anhui Province; 27-Ningxia Hui Autonomous Region; 28-Liaoning Province; 29-Hunan Province; 30-Shaanxi Province; 31-Hebei Province; 32-Xinjiang Uygur Autonomous Region; 33-Guizhou Province*


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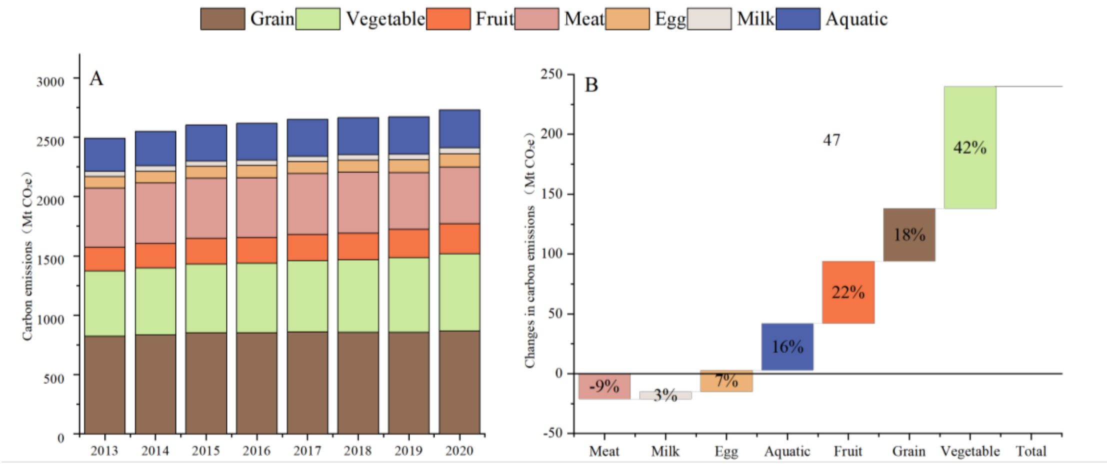


***Figure 3.*** *Carbon emissions from food production (A) and carbon emissions by category (B)*

We calculated the carbon emissions produced by food products in each province. *Figure 4* shows that carbon emission from agriculture in the east is remarkably higher than in other regions of China. In 2020, the regions with relatively high agricultural carbon emissions were Shandong (245 Mt $CO_2$e), Henan (207 Mt $CO_2$e) and Sichuan (167 Mt $CO_2$e). Hebei Province has the third highest food production, but the 7th highest carbon emissions because of the lower ratio of meat, milk and eggs. The production of plant-based products generates less carbon emissions. Thus, the quantity of carbon emissions produced by agriculture depends not only on the quantity of food produced, but also on the type of production.

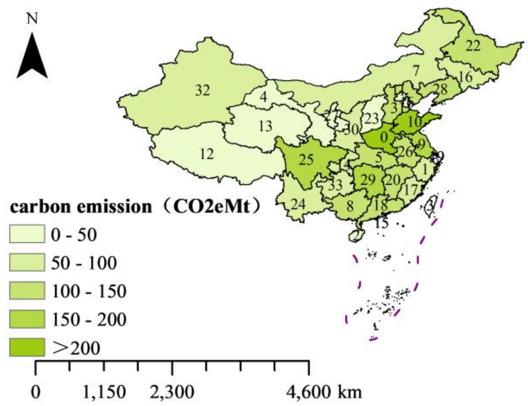


***Figure 4.*** *Carbon emission in food production*

## ***Changes in food consumption in China***

### *Temporal changes in food consumption*

China's food consumption changes from 2013 to 2020 were analyzed. In *Figure 5A, B*, they show that compare to 2013, grain consumption reduced 4 Mt (2%), but Egg, fruit, aquatic, milk, vegetable, meat increased significantly, increasing by 7 Mt (61%), 24 Mt (43%), 5 Mt (38%), 2 Mt (15%), 13 Mt (10%) and 8 Mt (18%), respectively in 2020.


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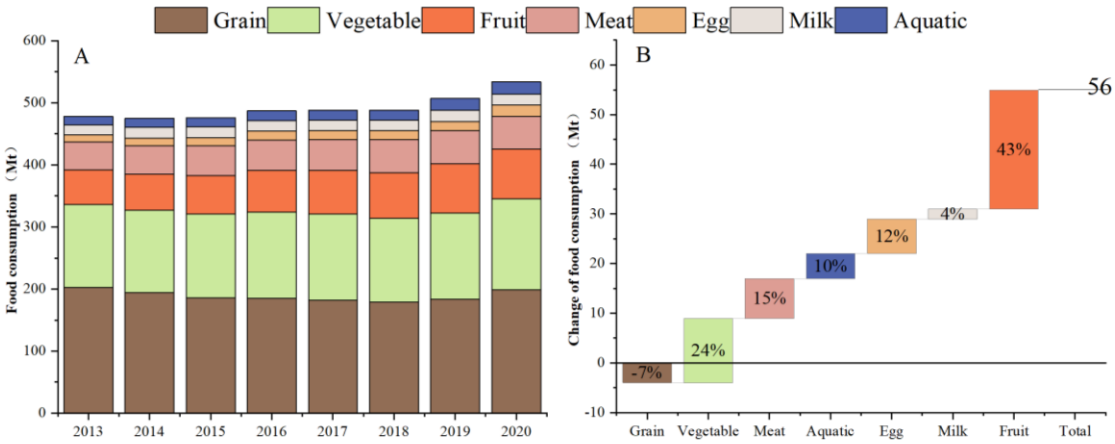


***Figure 5.*** *Changes in food consumption of major foods (A) and changes rates in food consumption by category (B)*

*Temporal changes between urban and rural consumption*

Analysis of annual per capita consumption in urban and rural areas in 2013 and 2020 was indicated. In *Figure 6* it shows total food consumption in urban and rural increased from 353.3 and 346.5 kg per capita in 2013 to 383.7 and 371.3 kg per capita in 2020, respectively, which is significantly higher in urban areas than that in rural areas. Consumption per capita of the plant-based food products in urban areas has increased by 20 Kg, while that of the animal-based food products has increased by 11 Kg, as well as increased by 9 Kg and 15 kg in rural areas. During this period grain consumption in urban and rural areas decreased by 1.1 kg and 10.1 kg per capita, respectively; fruit consumption increased significantly by 14.8 kg and 14.3 kg, respectively. Egg, vegetable, meat, aquatic and milk consumption increased by 4.1 kg, 6 kg, 3.8 kg, 2.6 kg 0.2 kg in urban area and 4.8 kg, 5.2 kg, 5.2 kg, 3.7 kg, 1.7 kg in rural areas respectively. Generally speaking urban and rural change trends are consistent. The consumption of grain in urban areas is lower than in rural areas, the consumption of vegetables, aquatic, meat, milk, fruits, eggs is higher in urban areas than in rural areas. The urban-rural consumption gap still exists in China, but it is gradually narrowing. Grain consumption as a proportion of total consumption decreased by 3% in urban and 7% in rural. Fruit consumption increased by 3% both in urban and rural. Consumption of other foods remained almost unchanged.

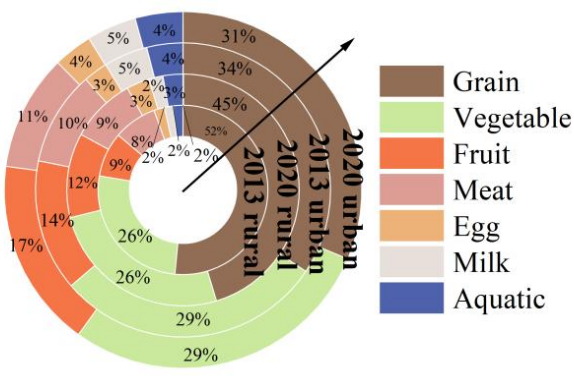


***Figure 6.*** *The gap between rural and urban consumption in 2013 and 2020*


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The food consumption in certain years is affected by some special factors. For example, the rapid decline in vegetable consumption in 2018 was due to hot and rainy weather, which seriously disrupted the harvesting and transportation of vegetables, leading to an increase in vegetable prices. The rapid decline in meat consumption in 2019 was due to African swine fever, which caused a large number of pigs to die and led to a surge in meat prices, resulting in a decrease in meat consumption, but it did not affect the overall trend of various food consumption changes.

*Spatial changes in food consumption*

As *Figure 7* shows the consumption of grain per capita is highest in Tibet Autonomous Region, Inner Mongolia Autonomous Region and Heilongjiang, which are located in the inland and economically underdeveloped regions, with consumption of 193.6, 173.1 and 167.1 kg, respectively. Grain consumption in the Tibet Autonomous Region accounts for 64% of total consumption, but that in Beijing is only 107.2 kg, accounting for 27% of total consumption. The consumption of vegetable is highest in Chongqing, Hubei, and Beijing, with 130.3, 126.8, and 122.7 kg per capita, respectively; the lowest consumption of vegetable in Tibet with only 55.7 kg, accounting for 18% of total consumption. Regions with high consumption of vegetables and low consumption of grains show a significant overlap. The consumption of meat is highest in Guangdong, Guangxi and Hainan, with 64.7, 55.1 and 51.6 kg per capita, respectively. The consumption of egg is highest in Hainan (30.8 kg), Guangdong (30.0 kg), and Shanghai (27.1 kg); aquatic consumption are higher in Hainan, Guangdong and Shanghai; as well as the milk in Beijing (30.1 kg), Inner Mongolia Autonomous Region (24.8 kg), and Shanghai (23.1 kg). The consumption per capita of fruit in Tianjin (85.8 kg), Beijing (81.9 kg) and Shandong (81.1 kg) are higher. Food consumption seems to be related to economically developed level, the proportion of grain consumption is lower in economically developed areas and coastal areas, while the proportion of vegetable consumption is higher in this study. On the contrary, the proportion of meat consumption is high in ethnic minority areas, and the consumption rate of milk is higher in areas with developed animal husbandry and good economic conditions.

***Nutrient intake***

The change of energy intake in daily per capita from 2013 to 2020 was calculated. *Figure 8A* shows the population's average daily energy intake remained relatively stable from 2013 to 2020, with a peak of 2095 kcal and a low of 1930 kcal. It consistently fails to meet the 2200 to 2300 kcal requirement set forth by nutritional health standards. During this period, energy from a plant-based diet decreased by 35 kcal and energy from an animal-based diet increased by 86 kcal. Of these, the energy provided by grains decreased by 74 kcal while all other foods increased. Meat provided the largest increase of 42 kcal of energy.

From 2013 to 2020, fat intake daily per capita increased by 5.86 g, an uptick of 13%. *Figure 8B* shows that a reduction of 51 g by 2020 could meet the 50 g to 60 g required by nutritional health standards. The fat provided by plant-based diet remained almost unchanged, and that by an animal-based diet increased by 6 g. The grain-provided fat decreased 5% by 0.57 g, however, especially, that from eggs, fruit, and aquatic food significantly increased 1.51 g, 0.24 g, and 0.75 g with of 56%, 38%, and 34%, respectively.


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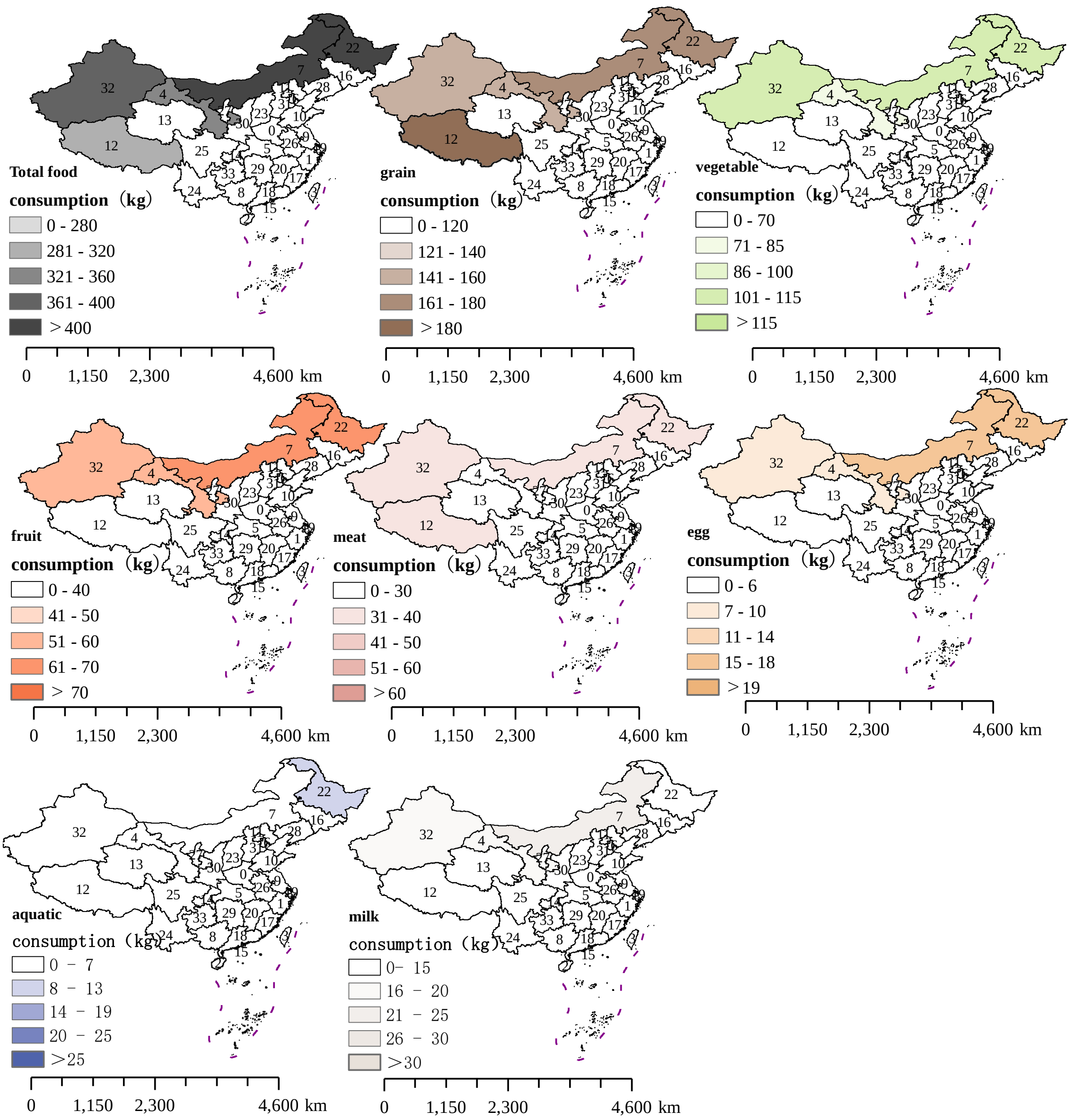


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***Figure 7.*** *Different types food consumption by provinces in 2020*

The ratio of fat to energy is an important parameter, the appropriate range for the proportion of energy provided by fat in the diet is 20-30%. In *Figure 8C* the fat energy ratio shows a trend of first increasing and then decreasing, but all are within the appropriate proportion range.

From 2013 to 2020, protein intake daily per capita increased by 3.44 g, an uptick of 5%. *Figure 8D* shows there was a decrease of 2 g from plant foods and an increase of 5 g from animal foods. Grains provided 5% less protein, the alterations in poultry and aquaculture consumption resulted in a 55% and 34% increase in protein intake, respectively.

The average nutrient intake daily for each province was shown in *Figure 9*. It shows that there are 8 regions energy intake exceeded the Outline requirement (2200–


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2300 Kcal), 5 regions were in the required range and the remaining regions were short of the requirement. *Figure 9B* shows the fat intake in Guangdong, Guangxi and Chongqing exceeded the Outline requirement (between 50 and 60 g/d), while the fat intake in the northern and western regions was inadequate. *Figure 9C* shows that only ten regions will be able to meet the Outline protein targets (78 g/d) in 2020. Shortages of protein intake are found in the Northwest, Southwest, and Central Plains.

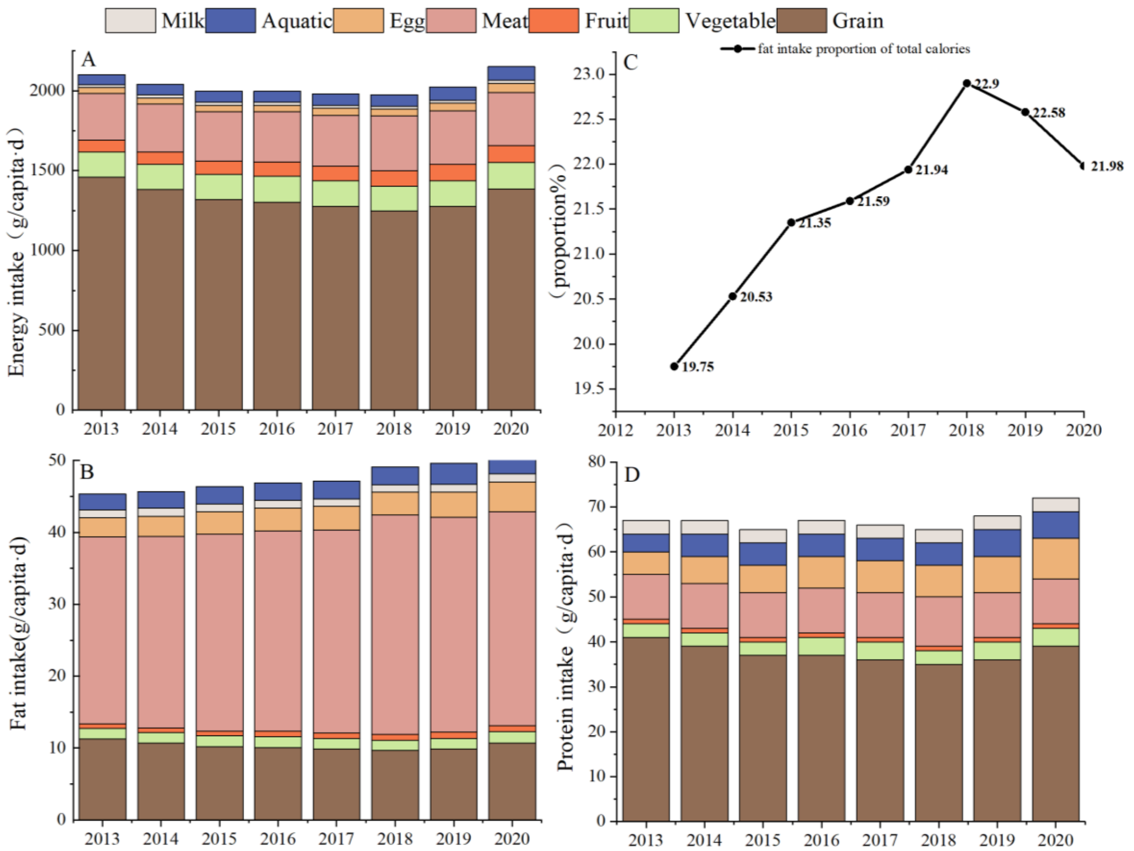


***Figure 8.*** *Daily energy intake (A) and fat intake (B) and changes proportion of fat/energy (C) and protein intake (D) from 2013 to 2020*

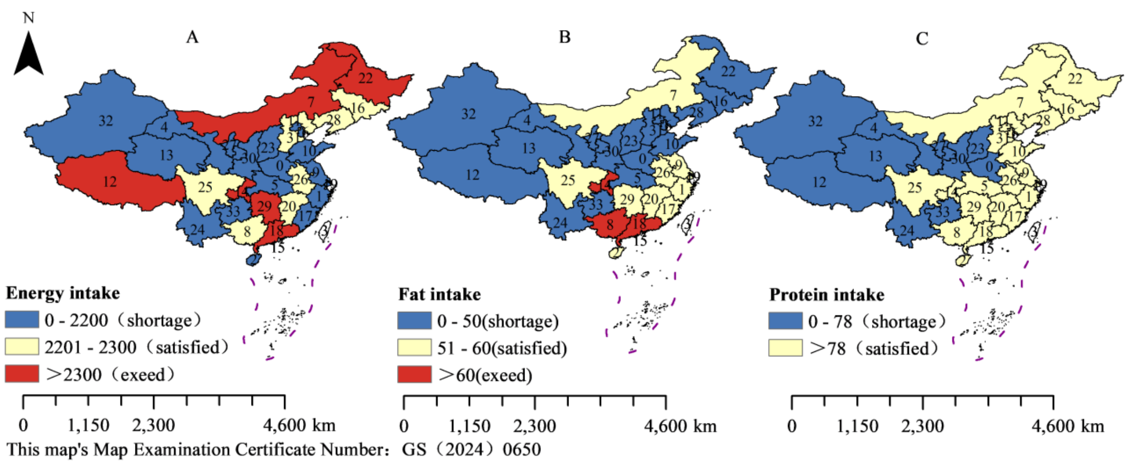


***Figure 9.*** *Nutritional intake in 2020*


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### Nutrient gap

Gap between current nutrient intake and the “Outline for the Development of Dietary Nutrition for the Chinese Population (2014-2020)” (Outline) still existed. The “Outline” recommends that 135 kg grain, 29 kg meat, 16 kg eggs, 16 kg milk, 18 kg aquatic, 140 kg vegetables and 60 kg fruit per capita per year. Therefore, the consumption of meat should be reduced while the consumption of eggs, milk, aquatic, and vegetables should be increased (*Fig. 10*).

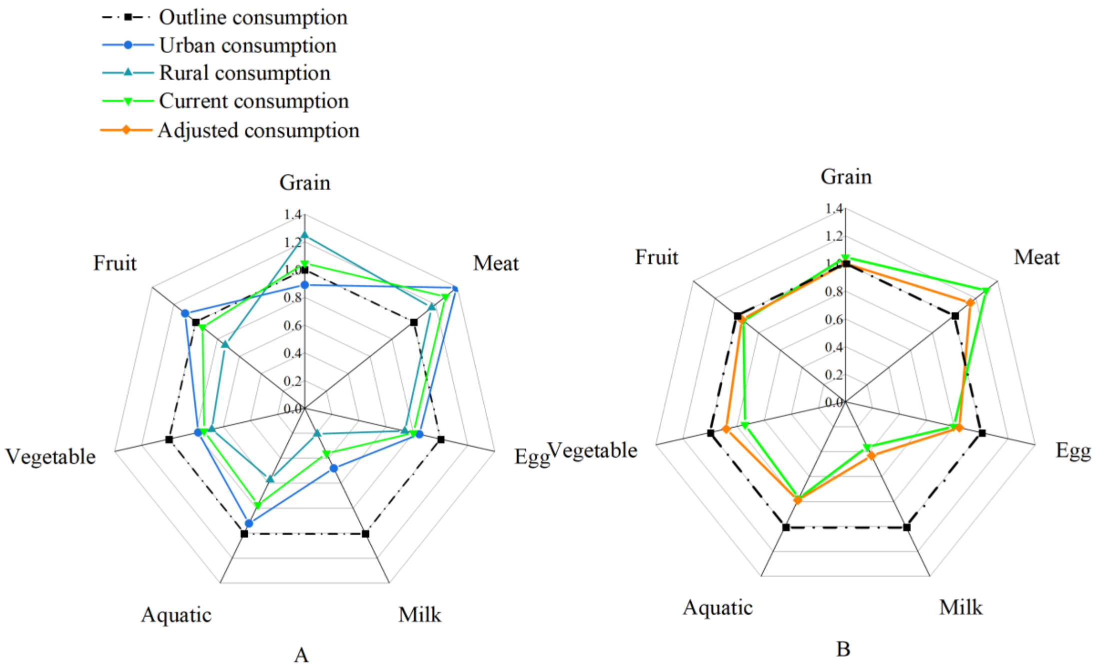


***Figure 10.*** *Differences between urban and rural consumption and outline consumption patterns (A) and between current and adjusted consumption and outline consumption patterns (B)*

### Scenario simulation analysis

With the increasing emphasis on people’s health needs, the reshaping of dietary structure is inevitable, followed by changes in food consumption. At the same time, China’s population trend has also changed significantly due to economic development and reduced fertility willingness. Zhai et al. (2017) proposed that China’s population will reach a peak of 1.45 billion (P) around 2030 on the basis of the current population (S), and 1.35 billion (L) in 2050. Based on this, we evaluated the changes in food production demand and carbon emissions in 2025, 2030, and 2050. *Table 2* shows the scenario of simulating and predicting the carbon emissions corresponding to future food production demand based on three consumption patterns (Current consumption Patterns (C), Outline consumption pattern (O) and Adjusted consumption pattern (A)), two production patterns (Reducing waste (R) and No Changes (N)), and three population bases (S, P, L) through interactive combinations. The results showed that in 2025, 2030 and 2050, the carbon emission will be arrived 2393 Mt and 2268 Mt with A + R methods. By adopting the O and A modes, carbon emissions increase by 11.3% and 2.2%, but if waste reduction is adopted, carbon emissions can be reduced by 14.9% (*Fig. 11*).


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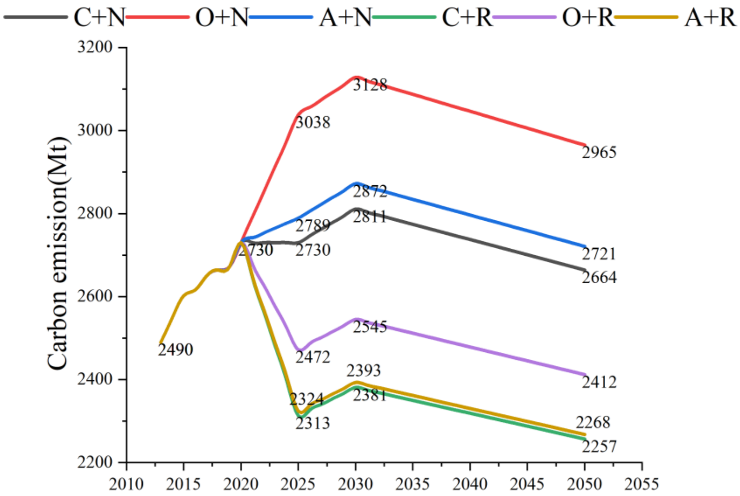


***Figure 11.*** *Carbon emissions under various models*

## Discussion

### *Carbon emission reduction and re-changing layout of agriculture will present opportunities and challenges*

Human activities are the main cause of carbon emissions (Xu, 2018), have increased by 24% over the past 50 years (Hong et al., 2021), with agriculture and food systems contribute more than 30% (Springmann et al., 2018). With steadily expanding global population has triggered greater resource requirements and magnified the crises concerning food and energy (Nabipour Afrouzi et al., 2023; Tilman et al., 2023). Food, as a necessity for human survival, will also produce carbon emissions in the process of production and consumption (Walmsley et al., 2015). However, China’s population is projected to decrease from 1.4 billion to 1.3 billion by 2050, a decrease of about 100 million people (Zhai et al., 2017). Declining populations offer opportunities for restructuring China’s agricultural consumption. The consumption structure of the Chinese population has undergone three stages: the poverty period, the transition period of subsistence, and the structural adjustment period (Li, 2007). With the development of the economy, and the outbreak of the Covid-19 epidemic, there is a greater concern for health, especially in the area of food health. At the same time, optimizing the dietary structure can contribute to reducing carbon emissions while also providing resource and health benefits, based on meeting nutritional requirements (Yu et al., 2023). China is currently undergoing a period of structural adjustment and is in a critical phase of green transformation and high-quality agricultural development. This is also a crucial time for adjusting the layout of agricultural industries to reduce carbon emissions.

### *Production and consumption reveals wastefulness in Chinese food production*

Eight to ten percent of total global greenhouse gas emissions are associated with food loss and waste (You et al., 2022). Food waste occurs at all stages of the food supply chain, such as extraction, production processes, distribution, and food waste generated at home or at retail (Shafiee-Jood et al., 2016; Ten Caat et al., 2022). The issue of waste in food consumption can be identified by comparing the relationship between production and consumption. From 2013 to 2020, the ratio of food production to food


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consumption increased from 3.5 to 3.7, with a maximum potential of 3.8; that increased from 3.1 to 3.4 for grains, from 4.7 to 5.1 for vegetables, decreased from 4.1 to 3.6 for fruits, from 1.9 to 1.5 for meat, from 2.6 to 1.9 for eggs, and remained virtually unchanged at about 3.9 and 1.8 for aquatic production and milk. In contrast to Xu (2005) comparisons of food production and consumption across different eras, we find there is a problem of food waste in China (Virtanen et al., 2011). Reducing food waste can reduce food production and is an important factor in reducing carbon emissions.

### *Changes in population consumption will affect the production of carbon emissions from food consumption*

The Global Burden of Disease study shows that irrational diet is the most significant factor in disease and death in China, with 2.1 million deaths of Chinese residents in 2017 attributable to irrational diet (Chinese Nutrition Society, 2021). Therefore, it is of great significance to understand the current situation of the population's diet and propose nutritional interventions to promote rational diet and prevent chronic diseases (Ruan et al., 2016). Comparing consumption in urban and rural areas, it is clear that the urban population has a healthier diet than the rural population. The dietary diversity index (DDS) was 18% higher in urban than in rural areas ($p < 0.05$), and the gap in animal protein intake was 23% (Institute of Nutrition and Health, 2019). An urbanization progresses, rural population is gradually transformed into urban population. The consumption gap between urban and rural areas is gradually narrowing, both urban and rural areas are transitioning towards a healthier model, but there is still a gap compared to developed countries.

Now the demand for food among residents is no longer solely focused on fulfilling basic needs, but rather, there is a growing emphasis on consuming healthy and nutritious (Virtanen et al., 2011). Surveys show that more than half of consumers will consider sustainability when buying food (Nordström and Denver, 2024), this trend provides a social basis for optimizing consumption structures in the future. In this article, we will focus on the three main nutrients: energy, fat and protein. As a central element in the maintenance of vital signs, the balance of energy metabolism is decisive for the health of the organism. An imbalance in fat intake will lead to a double health risk. Prolonged excessive intake will lead to lipid metabolism disorders, induce obesity and promote the development of atherosclerosis through a cascade of inflammatory factors (National Health Commission of China, 2020); whereas insufficient intake will impair the absorption of fat-soluble vitamins, resulting in abnormal calcium and phosphorus metabolisms (Subcommittee of Pediatrics, 2019). Inadequate protein intake leads to loss of muscle mass and decline in exercise capacity (WHO Expert Panel, 2007). Therefore, it is necessary to adjust and improve the dietary structure in the future according to the recommendations of the Outline.

At present, the nutritional intake in China does not meet the requirements in the dietary guideline, there is still 10% to 40% room for improvement in China. From a spatial perspective, only 5 of the 34 regions meet the required energy intake requirements, 8 regions exceed the energy intake requirements, and the other regions should increase their energy intake. There are three regions need to reduce their fat intake, 12 regions have just the right amount of fat intake, and the remaining regions need to increase their fat intake. A mere ten regions have protein intake levels that satisfy the nutritional intake requirements, with all other regions required to augment their protein intake. In order to meet the nutritional needs of the human body, all


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residents should rationally reduce their consumption of meat, substantially increase their consumption of milk, and reasonably increase their consumption of egg, vegetables, and fish. Dietary consumption will shifted over time from a traditional plant-based pattern to one that emphasizes both plant and animal foods (Virtanen et al., 2011), which means more carbon emission from food consumption. As the world's second most populous country (Yue et al., 2017), China's period of rapid population growth has passed, and it has begun to experience population stagnation or even population decline (Zhai et al., 2017). This also provides a foundation and space for achieving food structure adjustment and reshaping in the future.

### *To meet the nutritional needs of residents and reduce carbon emissions, choose foods with lower carbon emissions*

Strategies for environmental sustainability and global food security must account for dietary change (Peters et al., 2016; Auclair et al., 2021). With rising income levels, the dietary structure of Chinese residents is gradually changing from the eastern dietary pattern to western dietary pattern of high meat, high energy, high fat, high protein and low fiber in the long term (Wang et al., 2022), which will produce more carbon emissions. When we analyzed carbon emissions in different regions, we found that are closely related not only to the amount of food but also to the type of food. Producing the same amount of food, the carbon emissions from animal foods are much higher than those from plant foods. We can reduce our carbon emissions by consuming plant-based foods in place of some of our animal-based foods (O'Malley et al., 2023), which also made our dietary more healthy. However, if it cannot meet the nutritional needs of residents, and we need to consume animal products. Adjusting the consumption and production of different meats can also help reduce carbon emissions. Red meat (such as pork, beef and mutton) produces an extra 150% of greenhouse gas emissions over its life cycle compared to chicken and fish (Weber et al., 2008; Li et al., 2022). Beef has a carbon emission five times higher than pork and 1.6 times higher than mutton. Meanwhile, eggs, milk and aquatic also have lower carbon emissions, they can be used instead of meat, which can effectively reduce carbon emissions while meeting the dietary needs of residents. Therefore, ensuring residents' healthy nutritional intake and reducing carbon emissions from food consumption can be achieved simultaneously.

### *Limitations and perspectives*

This paper has some limitations in terms of research data and research methodology. This study analyses current agricultural production and consumption in China, focusing on carbon emissions and their trends, as well as nutritional intake. This article only mentions seven types of food such as grains, vegetables, fruits, meat, milk, eggs, and seafood, and does not include sugars and oils. More comprehensive data will be collected for further detailed analysis in the future. At the same time, this article is only based on household food consumption statistics released by the government, and does not consider restaurant dining or processed foods. It is worth noting that this article did not take into account the differences in dietary intake among different age groups, but instead used intake per capita as a reference value.

In the future, nutritional intake can also be improved by refining and adjusting the proportion of each food to ensure that consumers consume the same amount of food while obtaining higher levels of nutrition. Structural changes may bring more carbon


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reduction potential. In addition, improving animal feeding conditions and adjusting feed ratios can reduce the carbon emission coefficient of animal products, thereby reducing carbon emissions. Improving food production and efficiency, adjusting food structure layout can achieve more effective carbon reduction in China's agricultural productivity in the new era (Fan, 2020).

## Conclusion

From 2013 to 2020, China's food production, consumption, and carbon emissions were analyzed, and significant regional and urban-rural differences were observed. In many regions, the nutritional intake from food consumption still cannot meet health needs, and the urban-rural consumption gap is gradually narrowing, but it still exists. In the future, the food consumption structure can be improved by reducing the consumption of grains and meat and increasing the consumption of milk. China's food consumption should pay more attention to residents' nutritional intake and dietary balance. At the end of 2024, China proposed a new policy to build a diversified food supply system, proposing to consolidate and enhance the comprehensive production capacity of grain, develop food resources in all aspects and through multiple channels, ensure the effective supply of various types of food, and meet the diversified food consumption and nutritional health needs of the people with higher quality. Simultaneously avoiding waste can significantly reduce carbon emissions. With the increasing awareness of green consumption among the public, we can guide residents to make healthy and sustainable dietary choices, thereby promoting the development of a low-carbon society.

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**Data availability statement.** The data are available upon request.

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