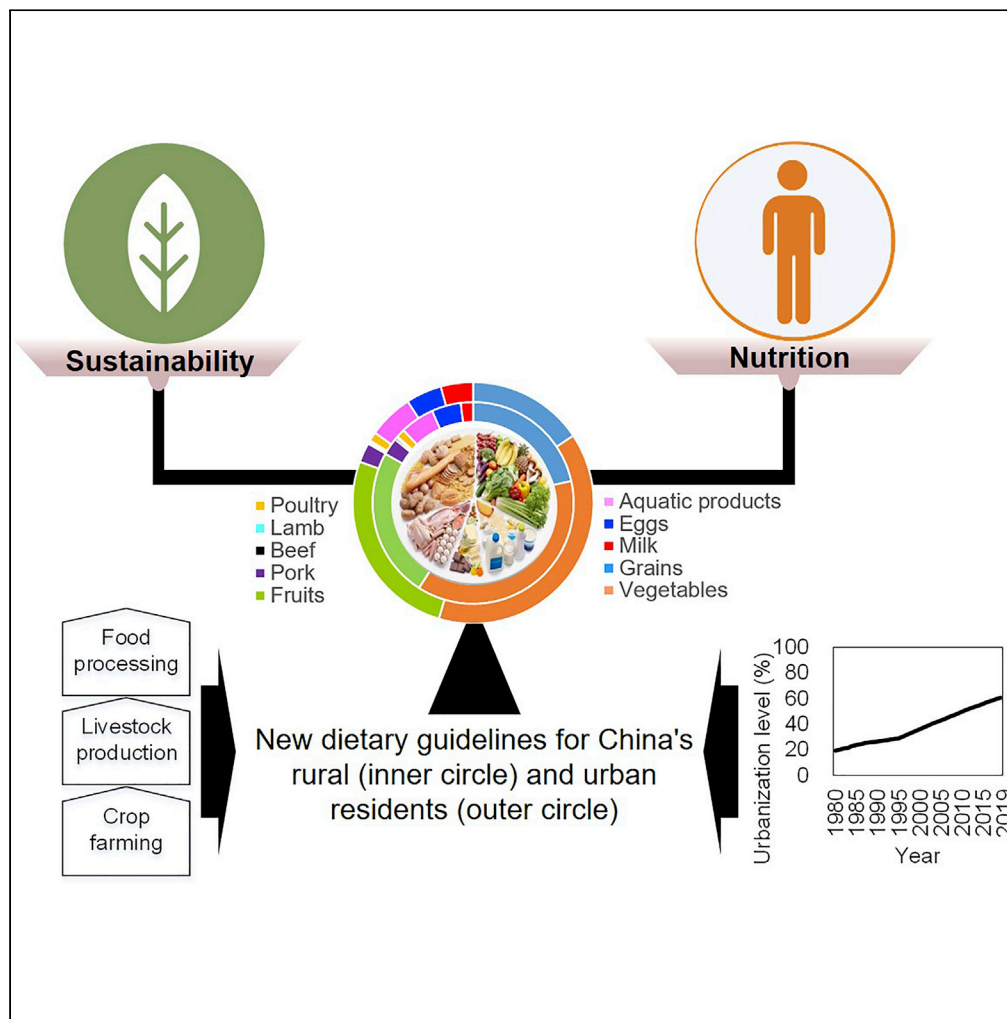


Article

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Highlights

Environmental impacts and nutritional qualities of Chinese diets are evaluated

Environmental and nutritional gaps between rural and urban diets reduced after 2000

Rapid urbanization coincided with broader changes in the sustainability of diets

We propose a new dietary guideline for both rural and urban residents in China

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Article

A new dietary guideline balancing sustainability and nutrition for China's rural and urban residents

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SUMMARY

Diets have important but often complex implications for both environmental quality and nutrition. We establish a production-oriented life cycle model to quantify and compare the farm-to-gate environmental impacts and food nutritional qualities underlying rural and urban diets in China from 1980 to 2019, a period of rapid urbanization and socioeconomic changes. The environmental impacts of rural diets were generally higher than those of urban diets, but this gap reduced after 2000. Environmental and nutritional values varied considerably across the 31 Chinese provinces due to their different food intakes and dietary structures. Dietary changes coinciding with urbanization increased greenhouse gas emissions, eutrophication potential, and nutritional quality, but decreased energy consumption and acidification potential. Based on our results, we propose a new dietary guideline to mitigate environmental impacts and improve nutritional quality.

INTRODUCTION

Population growth, urbanization, and growing affluence have led to changes in food demand and diets globally (Tilman and Clark, 2014; Willett et al., 2019). With continued urbanization, people are increasingly disconnected from food production, reflecting broader changes in food systems (Seto and Ramankutty, 2016). Consumers have in turn begun to pay more attention to food quality, nutrition, and health. Nutritional recommendations or dietary guidelines released by national governments (HCPH, 2017; Kromhout et al., 2016; United States Department of Agriculture, 2010) and international organizations (World Health Organization, 1998; Willett et al., 2019) can help support this. However, consumers often lack the knowledge or access to make decisions to address sustainability dimensions of their food (Leach et al., 2016) aside from food labels, such as organics (Hansmann et al., 2020) or nutritional characteristics (Mozaffarian, 2020).

Chinese diets have changed dramatically in recent years, particularly with a quadrupling of per capita meat consumption between 1970 and 2015, a period when the urban population rate increased from 17% to 56% of the total population (Seto and Ramankutty, 2016). With rapid economic development, Chinese consumers have become more concerned with their health. In response, the Chinese government issued the Chinese Food and Nutrition Development Program (2014–2020) (NP) (General Office of the State Council of the People's Republic of China, 2014), Chinese Dietary Guidelines (DG) (Chinese Nutrition Society, 2016), "Healthy China 2030" Planning Outline (General Office of the State Council of the People's Republic of China, 2016), and the Chinese National Nutrition Plan (2017–2030) (General Office of the State Council of the People's Republic of China, 2017). However, healthier diets do not necessarily lead to lower environmental impacts (Poore and Nemecek, 2018). Since food labels, governmental programs, and guidelines mainly focus on health or nutrition dimensions, tools to link health/nutrition with environmental impacts of food could be beneficial to consumers.

Food systems can lead to not only health disparities among people but also environmental degradation (Crippa et al., 2021; Springmann et al., 2018; Willett et al., 2019). As the largest developing country in the world, China is facing rapid industrialization and urbanization, which has greatly affected agricultural production. Crop production had increased by 43% and livestock production had increased by 40% during

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2000–2017 (National Bureau of Statistics China, 1981–2020). However, such rapid agricultural development has resulted in considerable environmental impacts. For example, China's agricultural sector consumes nearly one-quarter of the world's total agricultural energy use and is responsible for approximately 17% of the total domestic carbon emission (Cui et al., 2020). China's aquatic pollution loads of total nitrogen and total phosphorus increased by 196% and 244% during 1978–2017, respectively, over 80% of which were contributed by non-point sources (Zou et al., 2020).

It is well known that diets contribute to a broad range of environmental impacts (Springmann et al., 2018; Willett et al., 2019). Nutritional compositions of diets play a vital role in human health (Green et al., 2020). Several studies have analyzed nutritional quality and environmental impacts of diets on the global scale (Friel et al., 2020; Poore and Nemecek, 2018; Springmann et al., 2018; Willett et al., 2019) and national scales using country-specific diets (Chapa et al., 2020; Guinée, 2002; Perignon et al., 2019). However, past studies have often focused on specific nutritional characteristics or dietary outcomes (e.g., calories, protein, or disease burden), and specific environmental indicators, such as greenhouse gas emissions. Linking different nutritional and environmental indicators simultaneously can help to evaluate the overall impact of dietary change over time, which can be combined with additional nutritional characteristics (e.g., protein, fiber, vitamins, calcium, and saturated fat) from existing databases (such as the U.S. Department of Agriculture Food Composition Database and the World Health Organization Database). Diet impacts on nutrition and environment have also been investigated in China. However, these studies mainly focus on the environmental impacts of diets (Sun et al., 2021; Xiong et al., 2020). Only two studies analyzed both dimensions, but did not propose new dietary recommendations (He et al., 2018; Yin et al., 2020).

Consumers' socioeconomic characteristics, including whether they reside in rural or urban areas, can also affect food consumption habits (Seto and Ramankutty, 2016), which in turn affect both nutritional quality and environmental burden related with their diets. Rural residents and urban residents have different dietary patterns and therefore face different challenges. China's rapid urbanization has profound implications for food production (Zuo et al., 2018), as well as for diets changes (He et al., 2018). Comparing the environmental impacts and nutritional quality of different diets with those under the existing dietary recommendations can help develop new dietary guidelines that mitigate environmental impacts and improve consumers' health, which are vital for achieving more sustainable food systems.

Previous studies have used the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Springmann et al., 2018, 2020), environmental footprint approaches (Sun et al., 2021; Willett et al., 2019; Xiong et al., 2020), or the data envelopment analysis method (Lucas et al., 2020) to assess environmental impacts of diets from a consumption perspective. In contrast, life cycle assessment (LCA) is a comprehensive method to assess multiple environmental impacts associated with one product, process, or activity by quantifying the total resource consumption as well as emissions and wastes released into the environment along the supply chain (Guinée, 2002). LCA has been applied to assess various impacts of agriculture (Cucurachi et al., 2019), including nutrient flows from food production and consumption (Liu et al., 2016; Ruffi-Salis et al., 2020), health, and environmental dimensions of food (Chapa et al., 2020; Semba et al., 2020). Nutrients such as carbon (C), nitrogen (N), and phosphorus (P) play a critical role in agricultural production (Janes-Bassett et al., 2020; Leach et al., 2016; Wang et al., 2018). Excess nutrient losses have resulted in many environmental problems, such as climate change, eutrophication, and acidification (Springmann et al., 2018; Wu et al., 2018). It is therefore necessary to measure such environmental impacts. In this regard, LCA is one mature method and can provide valuable insights from a production perspective.

Consequently, we analyze the implications of dietary changes that coincided with urbanization and socioeconomic changes over the past four decades in China. The corresponding domestic environmental impacts are measured by four environmental indicators, while the nutritional characteristics are measured by food nutrition densities. Both urban and rural diets are investigated so that the role of urbanization can be identified. First, we develop the EINQA (*Environmental Impact and Nutritional Quality Assessment*) model based on partial life cycle analysis that focuses on farm-to-gate environmental impacts of crop farming and livestock production, as well as food processing. Second, we compare the changes of five indicators measuring environmental impacts and nutritional quality of diets from 1980 to 2019 for both urban and rural residents and uncover regional disparities across the 31 Chinese provinces. Third, we design six different diet scenarios by applying several national/international dietary guidelines/programs and compare the potential impacts and nutrition qualities between these scenarios and current Chinese diets.

Table 1. Environmental impacts from food production and primary processing (EN, GWP, AP, and EU) and food nutrition densities (NUTR)

Food	EN (MJ/kg)	GWP (kg CO ₂ -eq/kg)	AP (kg SO ₂ -eq/kg)	EU (kg PO ₄ ³⁻ -eq/kg)	NUTR (per 100g)
Fruit	0.74	0.08	0.00	0.02	75.57
Aquatic products ^a	4.10	0.36	0.36	0.36	53.81
Poultry ^a	4.44	4.84	0.27	0.69	47.10
Beef ^a	4.74	8.08	0.06	0.22	35.79
Grains	18.89	1.05	0.13	0.08	33.69
Eggs ^a	1.12	0.21	0.00	0.00	22.87
Vegetables	2.12	0.21	0.00	0.05	14.97
Pork ^a	4.78	4.19	0.08	0.13	12.60
Milk ^a	8.16	1.56	0.00	0.00	9.44
Lamb ^a	10.77	8.96	0.09	0.32	2.18

All the indicators are on a per weight (kg or 100g) basis. EN: Energy consumption, GWP: Global warming potential, AP: Acidification potential, EU: Eutrophication potential, NUTR: Nutritional quality index factoring beneficial dietary nutrients, vitamins, and micronutrients as well as limiting sugar and fats in diets. A lower value of NUTR indicates lower nutritional quality, after subtracting the total limiting nutrients from the total recommended (beneficial) nutrients.

^aOur partial LCA method does not include environmental impacts embodied in feed production for livestock products, meaning that impacts are conservative.

Finally, we propose a new dietary guideline to balance environmental impacts and nutritional quality for both rural and urban residents.

RESULTS AND DISCUSSION

Nutrient-related environmental impacts

Table 1 lists the farm-to-gate environmental impacts and food nutrition densities of ten different food items. Similar to several previous studies (Poore and Nemecek, 2018; Springmann et al., 2018, 2020; Willett et al., 2019), meat and grain consumptions resulted in relatively higher environmental impacts than other food items on a per kg basis in China. The environmental impacts between animal products and vegetal products measured in our study are different from those in previous studies, mainly due to different system boundaries. Our study focuses on farm production and primary processing, without considering upstream processes (e.g., fertilizer manufacturing and imported fodders).

We compare these four environmental impacts derived from China's food production (crop farming and livestock production) and processing (agri-product primary processing) to those based upon the Chinese Dietary Guidelines (DG), including minimum diet (DG_min) and maximum diet (DG_max) (Figure 1). Due to dietary changes, the overall environmental impacts for both rural and urban diets gradually decreased during the study period, but with slight increases in the past decade. Environmental impacts from rural diets were relatively higher than those from urban diets although the gap between them reduced considerably after 2000. Such rural and urban diets differences are mainly due to the larger share of grains in rural diets, roughly twice that of urban residents (see Figure 2A). Although both rural and urban grain consumption began to decrease in the 1990s due to increased consumption of fruit, meat, aquatic products, eggs, and milk, the share of rural grain consumption to the overall rural food consumption was still high. Grain cultivation resulted in relatively high fertilizer application at the global level, especially for rice, wheat, and maize (West et al., 2014). Also, food production (crop farming, livestock, and poultry production) generated considerably higher environmental impacts than food processing. For example, average energy used for cultivating grains (9.66 MJ/kg) was much higher than processing grains (0.23 MJ/kg) during the study period (Table S2).

Although the four environmental impacts from rural and urban diets were quite different in the early stage of this study period, these values have become relatively close after entering this century. The main reason is that rural and urban diets have become similar in recent years (Figure 1). Another key finding is that energy consumption changed slightly over time mainly due to grain consumption (Figure 1A). Grain consumption contributed over 80% of the total energy use. Although grain consumption decreased gradually, the energy intensity of grain cultivation fluctuated mainly due to the application of N fertilizers. For instance, Wu et al. (2018) found that energy consumption related with N fertilizers used for the three main grains (rice, wheat, and maize) decreased from 50% to 20% of the total energy used for producing

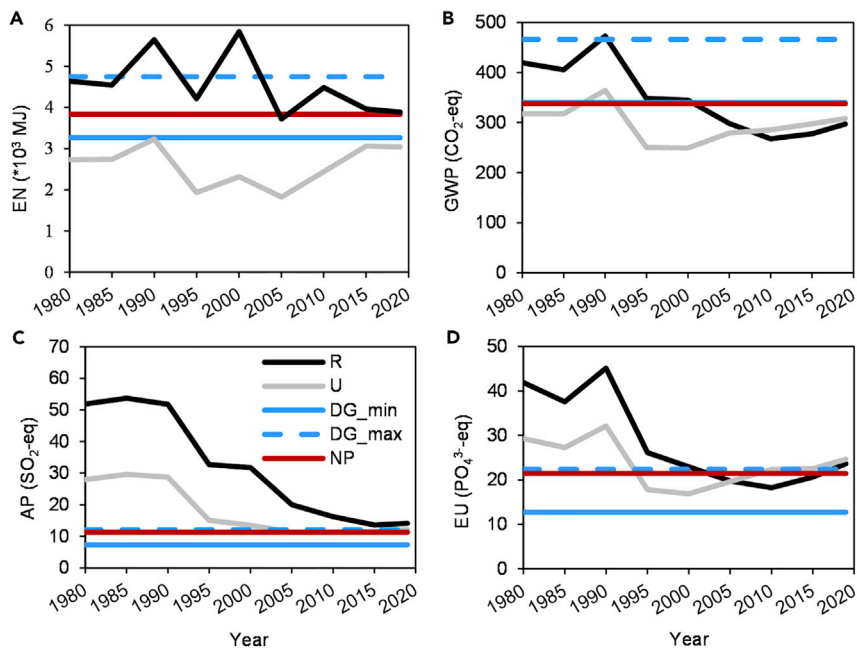


Figure 1. Four nutrient-related environmental impacts derived from rural and urban consumption in China during 1980–2019

(A) Energy Consumption, EN; (B) Global Warming Potential, GWP; (C) Acidification Potential, AP; (D) Eutrophication Potential, EU. Note: These impacts are also compared to those related to the Chinese Dietary Guidelines (DG) and the Chinese Food and Nutrition Development Program, “National Nutrition Plan” (2014–2020) (NP), including the minimum diet (DG_min) and maximum diet (DG_max).

N fertilizers applied to all the crops during 1978–2015. Zuo et al. (2018) found that excess N and P intensity for crops, especially grains, increased from 1987 to 2000, then decreased from 2000 to 2010. Also, Guo et al. (2010) found a 3-fold increase in China’s N fertilizer application since 1980. These findings induced growing concerns around the environmental impacts of fertilizer overuse and helped initiate efforts to reduce fertilizers application.

Global warming potential (GWP) closely couples with energy consumption (Li et al., 2016), which is illustrated in Figure 1B. However, differences between the GWPs for rural and urban diets are negligible. While rural grain consumption resulted in a higher GWP than urban grain consumption before 2005, urban meat consumption (especially pork) increased the GWP in the final stage of the study period. With rapid economic growth and dietary transition, the demand for meat products has increased, leading to rapid expansion of livestock and poultry populations. Therefore, pork and poultry consumption increased rapidly after 1990, with pigs contributing the most environmental impacts, especially N₂O and CH₄ emissions from corresponding manure management (Zhou et al., 2007).

Acidification potential (AP) was the highest in the 1980s (Figure 1C), mainly from NH₃ and NO_x. The value of AP was mainly determined by the farming practices in the production stage, including N fertilizers in crops (Zhu et al., 2019) and manure from livestock and poultry production (Wu et al., 2018). The value of AP decreased considerably after 1990, particularly for rural diets, coinciding with the initial reduction of N use in China.

Eutrophication potential (EU) resulting from NH₃, NO_x, NO₃, and P losses was mainly from the use of mineral and organic fertilizers, especially livestock and poultry manure. The production of grains, vegetables, pork, and poultry contributed 90% of the total EU. This finding echoes with Zou et al. (2020), who illustrated that mineral fertilizers and livestock and poultry breeding contributed the largest total N and P discharges. In comparison, N and P losses from food processing were much lower than those from food production (farming and breeding) (Figure 1D), in part due to growing concerns on environmental quality and stricter environmental regulations.

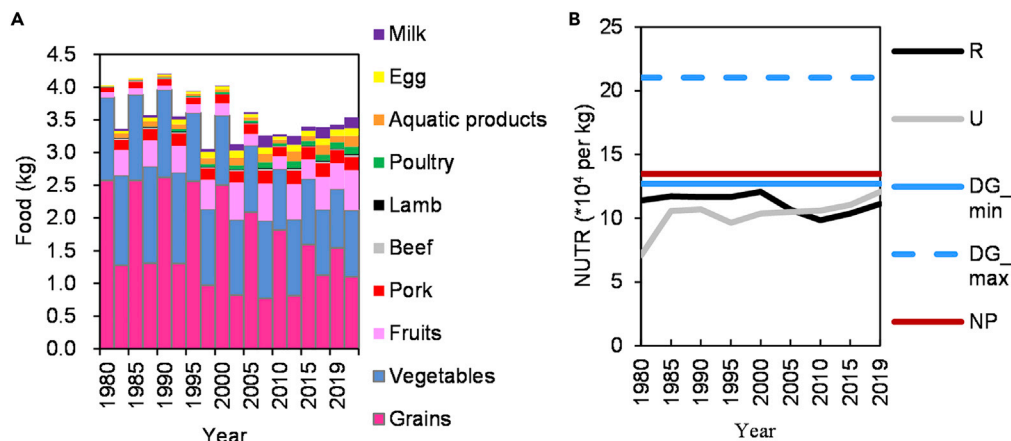


Figure 2. Changes in (A) and the corresponding nutritional quality (B) of rural and urban residents' food consumption in China during 1980–2019

Note: In [Figure 2A](#), there are two bars for each year, representing rural food consumption (left side) and urban food consumption (right side), respectively. DG represents NUTR values from Chinese Dietary Guidelines, ranging between DG_min and DG_max, while NP represents NUTR values from Chinese National Nutrition Plan (2017–2030).

Nutritional quality

We use the Nutrient Rich Food (NRF9-3) Index to assess nutritional quality. [Table 1](#) lists the NUTR scores. Fruits are rich in fiber, vitamins, and calcium, while aquatic products are rich in protein, calcium, magnesium, and potassium. Both food items have the highest NUTR scores (see [Table S5](#) for details). In terms of meat products, poultry and beef contain rich protein and minerals (calcium, iron, magnesium, and potassium), with low sugar contents. As the largest food item consumed by both rural and urban residents, the nutritional quality of grain ranked fifth among the 10 food items, containing a mix of protein, fiber, and minerals. Other food items (e.g., lamb, milk, and pork) have relatively lower nutritional quality.

We calculated the overall nutritional quality of diets by combining the NUTR index values with the intake of each food item at each timestep for both rural and urban diets ([Figure 2](#)). The values for both rural and urban diets were lower than those from the three Chinese dietary guidelines. The nutritional quality of the rural diet was higher than that of the urban diet (2–3 times that consumed by urban residents) before 2000, leading to a greater overall food intake (kg per year) and enhanced nutritional quality. However, fruit and aquatic products (with the two highest nutrition scores) have been increasingly consumed by urban residents, especially after 2010. Moreover, with increasing incomes and meat demand, the fraction of grains in rural diets also decreased. In summary, although rural and urban diets were still slightly different in terms of composition in 2019 ([Figure 2A](#)), they had similar overall nutritional quality ([Figure 2B](#)).

Environmental impacts based upon national dietary guidelines

We use values recommended in China's national dietary guidelines (DG and NP) to evaluate potential environmental impacts under these guidelines and found that the two diets recommended by DG_min and NP result in similar AP and EU potentials due to their similar dietary structures and total food intakes ([Figure 1](#)). However, the greater food intake under DG_max results in much higher energy consumption and GWP. Both DG and NP recommend moderate grains consumption and lower meat consumption. They also recommend residents to consume more vegetables, fruits, aquatic products, eggs, and milk. Since both rural and urban residents' food intakes were larger than the proposed total food intakes under DG and NP before 2000, the corresponding environmental impacts from both urban and rural diets were generally higher than those from DG_min and NP. But such impacts had become less in recent years due to their decreased food consumption and changed food consumption structure.

Regional disparities and urbanization effects

We measure environmental impacts and nutritional quality of food consumption across the 31 Chinese provinces for year 2019 ([Figure 3](#)). Among these 31 provinces, Tibet and Inner Mongolia had the highest energy consumption intensities and GWPs because their residents consume more grains than those in

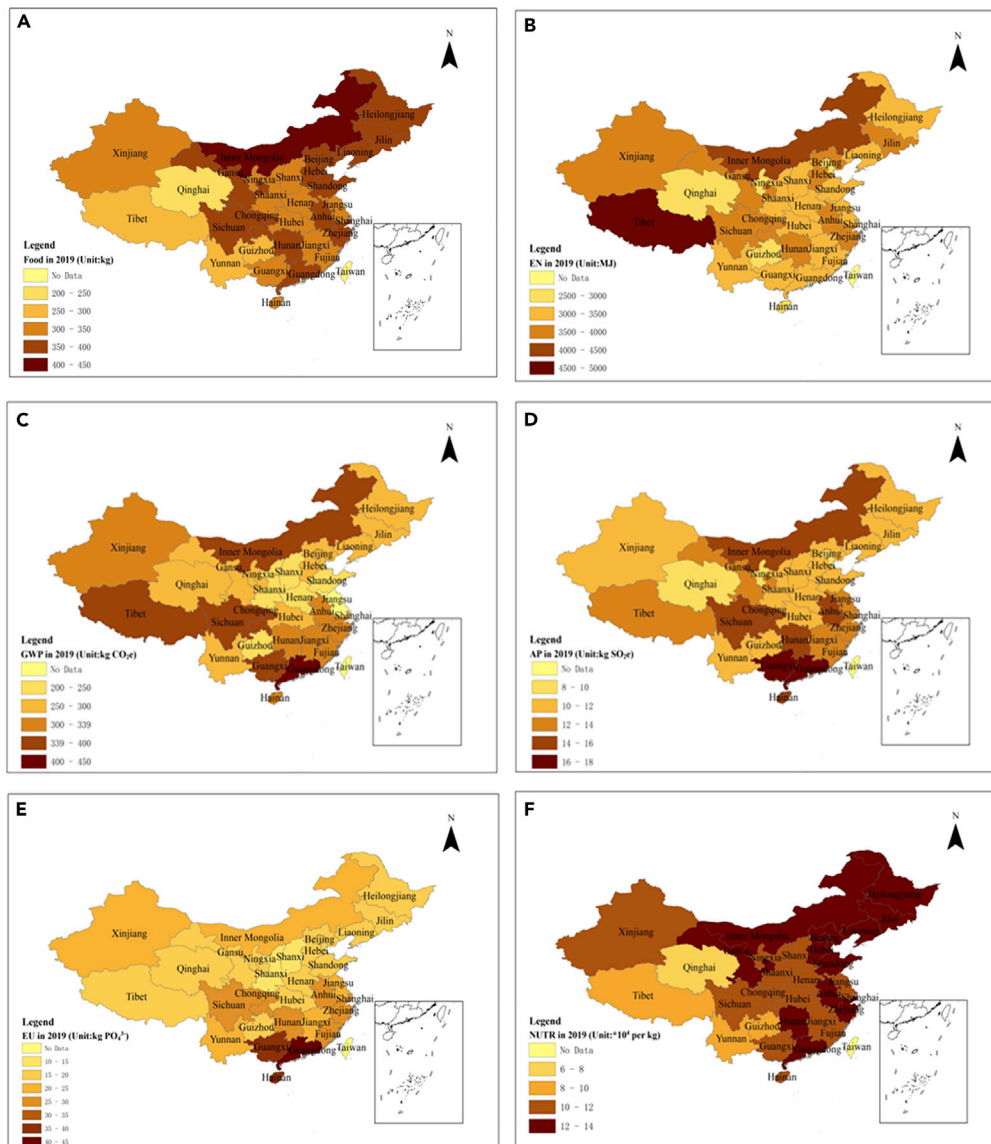


Figure 3. Regional disparities in environmental impacts and nutritional qualities of Chinese residents' food consumption among 31 Chinese provinces in 2019

(A) Food Consumption, Food; (B) Energy Consumption, EN; (C) Global Warming Potential, GWP; (D) Acidification Potential, AP; (E) Eutrophication Potential, EU; (F) Nutritional Quality, NUTR.

other regions. Also, higher meat consumption (especially pork and poultry) in Guangdong, Guangxi, and Sichuan resulted in their higher GWPs, APs, and EUs. In addition, residents in Tianjin, Inner Mongolia, and Anhui generally consumed more food (especially fruit) and therefore had the highest nutrient quality. By comparison, residents in Qinghai, Guizhou, and Tibet had the lowest nutritional quality.

Nationally, the percentage of urban population in the total population increased from 19% in 1980 to 61% in 2019. While urbanization occurred across all 31 Chinese provinces, some provinces experienced much higher urbanization rates during the study period. Such imbalanced urbanization led to different environmental impacts and nutritional qualities from food consumption among the 31 Chinese provinces. In fact, total food consumption decreased slightly with increasing urbanization during the study period (Figure 4A), while the NUTR index increased (Figure 4F), mainly from the increased consumption of fruit, aquatic products, and poultry. Also, because of decreased grain consumption, total energy consumption and AP decreased during the study period (Figures 4B and 4D). Such findings echo the results of Song et al.

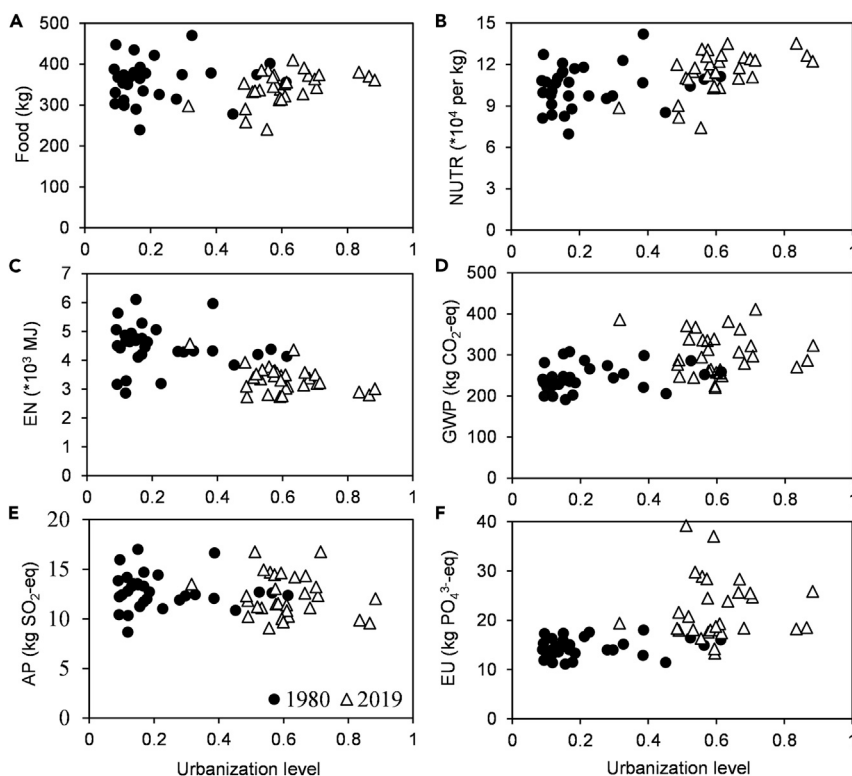


Figure 4. Relationships between environmental impacts/nutritional densities and urbanization levels among the 31 Chinese provinces in 1980 (black dots) and 2019 (hollow triangles)

(A) Food consumption (Food) and urbanization; (B) Nutritional qualities (NUTR) and urbanization; (C) Energy consumption (EN) and urbanization; (D) Global warming potential (GWP) and urbanization; (E) Acidification potential (AP) and urbanization; (F) Eutrophication potential (EU) and urbanization.

(2019), who also found that urbanization led to less total energy use from food consumption. But urbanization led to substantial GWP and EU increases (Figures 4C and 4E), mainly associated with increased meat consumption.

China's rising wealth and social infrastructure changes have accelerated urbanization processes, leading to ripple effects on food systems (Wang et al., 2021). For example, with increased income and changing demographic structure, Chinese dietary patterns have shifted from basic food necessities (i.e. grains, vegetables, and starchy staples) to more luxury food products (i.e. beef, poultry, lamb, and aquatic products) (Sheng and Song, 2019). It is estimated that China's urbanization level will reach 80% by 2050, with an annual growth rate of 1.0% (United Nations, 2018). With continued urbanization in the next decade, the overall demand for various food products will continue to increase although grain consumption may remain stable and even decrease. According to MARA (2018), the consumption of dairy products, beef, lamb, and sugar will grow with an average annual growth rate of over 2.0%, while the average annual growth rate of vegetables, fruit, poultry, and soybeans consumption will be 1.0%–2.0%.

Proposed new dietary recommendations

Under most national and international recommendations, China's rural and urban diets in 2019 would feature considerable decreases in grains and meat consumption alongside increases in fruit, vegetables, aquatic products, and egg intakes (Figure 5). However, the rural and urban diets in 2019 were somewhat more similar to the healthy diet recommended by Willett et al., (2019).

We conduct sensitivity analysis Supplemental Information and synthesize the results of environmental impacts and nutritional quality from the EINQA model in relation to existing dietary guidelines for China and international societies so that new dietary recommendations can be proposed, which can address these

Food	DG-R	DG-U	NP-R	NP-U	Willett-R	Willett-U	WHO-R	WHO-U
Grains	-36.2	8.0	-19.8	24.4	-70.1	-25.9	-118.3	-74.1
Vegetables	56.5	44.5	50.5	38.5	20.0	8.0	56.5	44.5
Fruits	61.1	39.5	20.7	-0.9	33.7	12.1	61.1	39.5
Pork	-6.7	-6.8	-1.5	-1.6	-17.6	-17.7	-6.7	-6.8
Beef	-0.1	-1.8	0.3	-1.4	0.4	-1.3	-0.1	-1.8
Lamb	-0.2	-0.6	0.1	-0.3	-0.1	-0.5	-0.2	-0.6
Poultry	-4.4	-5.8	-2.3	-3.7	-5.3	-6.7	-4.5	-5.9
Aquatic products	11.4	4.3	8.4	1.3	0.6	-6.5	11.4	4.3
Eggs	11.4	9.5	6.4	4.5	-4.9	-6.8	6.8	4.9
Total (milk excluded)	92.7	90.8	62.8	60.8	-43.2	-45.2	6.1	4.1
Milk	102.2	92.8	28.7	19.3	84.0	74.6	102.2	92.8
Total	195.0	183.6	91.5	80.1	40.8	29.4	108.3	96.9

Figure 5. Differences (in kg per capita per year) between China’s rural and urban diets in 2019 (R_2019 and U_2019) and other dietary recommendations, including Chinese Dietary Guidelines (DG), Chinese National Nutrition Plan (2017–2030) (NP), the Healthy Diet recommended by Willett et al., and the World Health Organization recommendations (WHO)

Note: Negative values (in red) indicate relatively greater intakes in China’s actual 2019 diet that would be reduced under the respective new recommendations, while positive ones (in blue) indicate relatively lower intakes in the 2019 diet that would be increased under the new recommendations. Note that the “Total” change values are heavily influenced by milk, which is partly an effect of there being additional categories in the dietary recommendations (e.g., condensed milk, cream, and cheese) relative to the base values that only include milk for drinking, thus change values for milk are slightly inflated and reported separately.

multiple dimensions (Figure 6). Since it is difficult to change dietary habits, we use the existing dietary recommendations as major references to develop our proposed dietary recommendation by considering the potentially limited acceptability of several dietary scenarios (Cobiac et al., 2019). An updated version of DG was issued by the Chinese Nutrition Society in June 2022, which highlights the role of greater food diversity. This updated DG is slightly different from its early version. For instance, grain intake is suggested to be decreased by approximately 20% in this updated DG. However, this does not influence our proposed guideline since we also suggest much lower grain consumption. Additionally, existing dietary recommendations define nutritional adequacy as the sufficient intake of essential nutrients needed to fulfill nutritional requirements for optimal health (Castro-Quezada et al., 2014). In this regard, previous studies show that people with different diet habits, ages, and genders may have different nutritional requirements (and resulting in different environmental impacts). For example, Rao (2020) addressed how it is urgent to achieve food and nutrition security for women in South Asia. Similarly, Raza et al. (2020) described how food systems influence the diets of children and adolescents at the global level.

The detailed recommendations for different food items in this proposed new dietary guideline are listed in the Method details. Compared with China’s two dietary recommendations (DG and NP), our proposed new dietary recommendations suggest the following proportions of the total food intake: grains (33%–55%), pork (24%–45%), poultry (10%–36%), lamb (13%–46%), fruits (10%–70%), vegetables (4%–8%), and aquatic products (10%–30%). The diet adjustments for rural residents are different from those for urban residents. For example, urban residents’ intakes of grains, poultry, and lamb should be decreased by approximately 1.5 times, 1.3 times, and 3.5 times, respectively, compared with those for rural residents. By contrast, rural residents’ intakes of fruit and aquatic products need to be increased by approximately 1.5 times to 2 times, compared with those for urban residents. But for other food items, including vegetables, pork, and eggs, we suggest similar intakes for both rural and urban residents in our dietary recommendations. Moreover, this guideline is slightly different from the two international dietary recommendations (the one from Willett et al. (2019) and the one from World Health Organization (1998)). Under this guideline, both rural and urban residents would have similar annual food consumption, with a figure of 370–390 kg per capita. Such amounts are comparable to other recent studies. For example, Xin et al. (2018) estimated that China’s food consumption would increase by 7% in 2030 based on population age structure. Sheng and Song (2019) also predicted that China’s food demand would increase by 33% in 2050 due to urbanization, income, and population changes.

We further compare the derived environmental impacts and nutritional quality under six different diet scenarios (DG, NP, Willett, WHO, R_normal/U_normal, and R_new/U_new) with those from the 2019











	Food	R_new	U_new	DG	NP	Willett	WHO
	Grains	219 (150-287)	166 (111-221)	325 (250-400)	370	232	100 (50-150)
	Vegetable	382 (355-410)	415 (388-442)	400 (300-500)	384	300 (200-600)	400 (300-500)
	Fruit	245 (217-272)	276 (249-304)	275 (200-350)	164	200 (100-300)	275 (200-350)
	Pork	28 (14-42)	28 (15-42)	37 (26-48)	51	7 (0-14)	37
	Beef	4 (4-5)	3 (2-4)	3 (2-4)	4	4	3
	Lamb	2 (1-2)	2 (1-2)	2 (2-3)	3	3	2
	Poultry	14 (11-16)	13 (9-18)	15 (11-20)	21	29 (0-58)	15
	Aquatic products	56 (54-59)	64 (59-68)	58 (40-75)	49	28 (0-100)	58 (40-75)
	Eggs	48 (43-54)	51 (27-71)	58 (40-75)	44	13 (0-25)	45 (40-50)
	Milk	20	46	300	99	250 (0-500)	300

Figure 6. New dietary recommendations (in g per capita per day) for China's rural residents (R_new) and urban residents (U_new) based on this study and comparisons with existing national and international recommendations

Note: Values in brackets are the minimum and maximum amounts of food intakes for each recommendation. Since milk in the existing dietary recommendations includes all the dairy products (e.g. condensed milk, cream, and cheese) in addition to milk for drinking (the only category covered in China's food intake statistics), milk intake was not adjusted.

urban and rural diets (R_2019 and U_2019) (Figures 7A and 7B). To illustrate the differences between the new dietary guidelines (R_new and U_new), we further compare them with other recommendations (Figures S1A and S1B). Our results reflect that environmental impacts and nutritional quality will be increased by 5% and 7% under the future normal scenario in 2030 (R_normal and U_normal) (OECD/FAO, 2021) relative to those of the 2019 rural and urban diets. Environmental impacts under various recommended diets can be reduced by 37%–50% compared with the 2019 rural and urban diets. But our proposed new dietary recommendations can lead to the highest reductions, except for EU values and AP values. The EU values under our recommended rural and urban diets are slightly higher than those in Willett et al. (2019), while the AP values under our recommended rural and urban diets are slightly higher than those in WHO. In terms of nutritional quality, the values under our recommended rural and urban diets can be increased by 12%–20%. Finally, in comparison with the future normal scenario in 2030 (OECD/FAO, 2021), our proposed new dietary recommendation can result in much lower environmental impacts (approximately 40% lower than the future normal scenario in 2030) and improved nutritional quality (8%–15%). This is mainly due to the lower absolute food intake and lower increases in food intake under our proposed dietary recommendations.

In general, our proposed dietary recommendations can address both environmental sustainability and nutrition concerns by balancing current overconsumption of grains and meats with greater intakes of vegetables, fruits, and aquatic products. Such recommendations could lead to the reduction of environmental impacts. For example, GWP and EU values can be reduced by nearly half compared to the baseline values. Similar to previous studies, we found that reduction of red meat consumption (e.g., pork, beef, and lamb) can help mitigate greenhouse gas emissions (Springmann et al., 2020). However, such recommendations currently do not exist in China. Consequently, it is critical to prepare such policies by considering the Chinese realities. First, nutrition experts and governmental officials should incorporate environmental impacts into current national dietary guidelines. Public food procurement standards should be established so that major public institutions, including governments, schools, military groups, state-owned enterprises, and hospitals, can purchase food items by following our proposed new dietary recommendation. Second, regional disparities should be considered so that region-specific perspectives can be addressed, such as regional cultural preferences, as well as locally produced food versus food delivered from other regions.

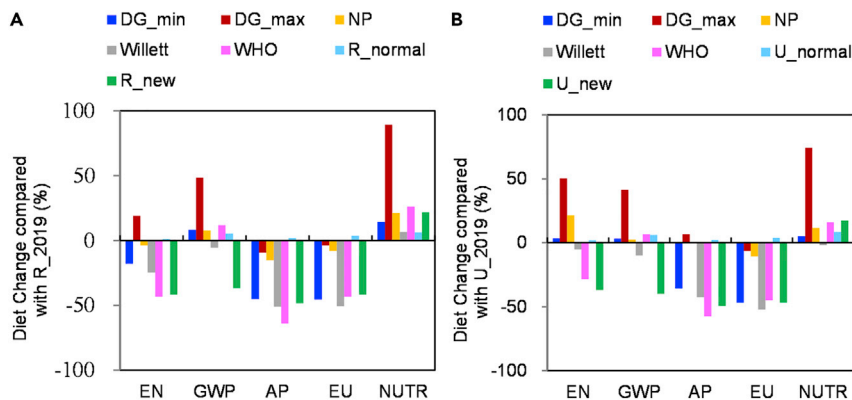


Figure 7. Changes in environmental impacts (EN, GWP, AP, and EU) and nutritional qualities (NUTR) for six dietary scenarios compared with China's rural and urban diets in 2019

(A) Changes of the six diet scenarios compared with R_2019; (B) Changes of the six diet scenarios compared with U_2019. Note: a. China's rural and urban diets for the year 2019 (R_2019 and U_2019) are the baseline references to other diets. b. The six scenarios include those with minimum and maximum values under Chinese Dietary Guidelines (DG_min and DG_max), the scenario under Chinese National Nutrition Plan (NP), the scenario proposed by Willett et al. (Willett), the scenario recommended by World Health Organization (WHO), the future normal scenario for year 2030 (R_normal and U_normal), and our proposed scenario under China's new dietary guidelines (R_new and U_new). c. Future normal scenario is based on projecting current rural and urban diets to the year 2030. Key data for this scenario were collected from Organization for Economic Co-operation and Development (OECD) and Food and Agriculture Organization of the United Nations (FAO).

Third, capacity-building efforts should be initiated to educate the general public around such new dietary recommendations and the importance of changes in certain food consumption behaviors, such as avoidance of food waste, adjustment of food intakes, and consumption of local food. In addition, it is necessary to consider different food needs between rural and urban residents since they may have different food culture and preferences. Finally, it is crucial to acknowledge regional variation in diets and consumption patterns in China since this could have corresponding implications for nutrition and sustainability (Lucas et al., 2020; Springmann et al., 2020) that are difficult to capture in a national study. For example, Chapa et al. (2020) evaluated environmental performances of different dietary patterns in Mediterranean countries. Based upon the recognition of changing consumption patterns, Mackie and Wemhoff (2020) further compared greenhouse gas emissions associated with food from other regions versus local food in the United States. Therefore, further investigation of the effects of such factors could provide valuable insights. Finally, China has experienced rapid urbanization during the last four decades, which has significantly affected food production and consumption. Our findings stress the need to consider different food requirements among rural and urban residents so that their specific nutrition demands can be met with least environmental impacts.

Limitations of this study

Limited by data availability, we have not further divided some food items, such as grains, vegetables, fruit, and aquatic products. In addition, we only considered rural residents and urban residents in this study. Future studies may consider dividing consumers according to their diet habits, ages, and genders, which can provide valuable results to prepare more specific policies for different communities. In addition, we designed our new dietary guideline by referring to several current dietary recommendations, including both national and international ones. These two recommendations have different dietary patterns due to different dietary habits. We tried to reduce this uncertainty by referring to more national dietary recommendations and extending the study period to 40 years. Finally, our new dietary guideline only provides an intake range for each food item. Each consumer can determine his/her diet based upon his/her own needs.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

Supplemental information can be found online at <https://doi.org/10.1016/j.isci.2022.105048>.

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AUTHOR CONTRIBUTIONS

Conceptualization: H.W., Y.G., and G.K.M. Methodology: H.W., Y.G., G.K.M., and J.N.G. Formal analysis, investigation, and visualization: H.W., Y.G., X.L., L.Z., and S.J. Supervision: Y.G. and G.K.M. Funding acquisition: H.W., Y.G., and G.K.M. Writing - original draft: H.W., G.K.M., and Y.G. Writing - review and editing: H.W., Y.G., G.K.M., J.N.G., H.W., Y.G., X.L., L.Z., and S.J.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Food consumption dataset	National Bureau of Statistics of China (NBSC)	http://www.stats.gov.cn/tjsj/ndsj/
Agricultural production dataset	Price Department of the National Development and Re-form Commission (PDNDRC)	http://www.stats.gov.cn/tjsj/
Food Composition Databases	United States Department of Agriculture (USDA)	https://ndb.nal.usda.gov/ndb/search/list
Software and algorithms		
ArcGIS	Environmental Systems Research Institute, Inc.	https://www.esri.com/zh-cn/arcgis/about-arcgis/overview

RESOURCE AVAILABILITY

Lead contact

Further information and requests should be directed to and will be fulfilled by the lead contact, Yong Geng (ygeng@sjtu.edu.cn).

Materials availability

This study did not generate new materials.

Data and code availability

- This paper analyzes existing, publicly available data. These accession numbers for the datasets are listed in the [key resources table](#) and [method details](#).
- This paper does not report original code.
- Any additional information required to reanalyze the data reported in this paper is available from the [lead contact](#) upon request.

METHOD DETAILS

System definition

Based on partial LCA, the EINQA model is used to evaluate environmental impacts derived from food production and uncover the potential nutritional characteristics of dietary patterns in China for the period of 1980–2019. In this study, we focus on the farm-to-gate processes. Food production mainly includes crop farming, livestock production, and primary processing of agricultural products. We do not consider the impacts generated from producing fertilizers or other chemical inputs; the impacts embodied in producing crop-based animal fodders (which are highly variable across livestock species and can also vary substantially over time ([Bouwman et al., 2005](#))) and fodders for aquacultural animals ([Fry et al., 2016](#)) due to the lack of appropriate data. Moreover, we do not cover the waste disposal process as well. We examine nine plant types (rice, wheat, maize, bean, cotton, peanut, rapeseed, vegetables, and fruits), four animal types (pig, cattle, sheep, and poultry), and 10 final food items (grains, vegetables, fruits, pork, beef, lamb, poultry, aquatic products, eggs, and milk).

Ten major food items are investigated based on governmental statistics ([National Bureau of Statistics of China, 1981-2020](#)), comprising over 90% of the Chinese diet ([Table S4](#)). We then link these food items to agricultural nutrient use and food nutritional characteristics for the years 1980, 1985, 1990, 1995, 2000, 2015, and 2019 (see [Table S1](#) for details). We separately analyze dietary patterns for urban and rural residents so that urban-rural differences can be identified ([National Bureau of Statistics of China, 1981-2020](#)). Due to data availability, 31 Chinese provinces are included in this study, while Hong Kong, Macao,

and Taiwan are excluded since such data are not available. Detailed model parameters are listed in Table S1.

Data

The basic data were collected from the governmental statistics (National Bureau of Statistics of China, 1981-2020; Price Department of the National Development and Reform Commission, 2003; 2001-2016), and governmental reports (General Office of the State Council of the People's Republic of China, 2014; Chinese Nutrition Society, 2016), covering consumption of the 10 food items, sown areas and harvest/production of each crop, and application rates of chemical fertilizer for each crop, etc. By using these data, the analysis is then conducted mainly based on linking to the environmental data (LCA) and nutritional data. The LCA data includes variables such as: N/P/C-derived energy consumptions and emissions from farming and breeding, ratios of cultivated/bred grains/livestock to consumed grains/poultry, energy equivalent of feed consumed per livestock, weight per livestock, electricity consumption for processing of 1 kg of food, conversion coefficient of electricity to energy, characterization factors, N/P loss rate of processing grains, and N/P discharge from slaughtering 1 kg of livestock. These data were collected from relevant literatures. While other data, including conversion ratios of N to N-containing gases (e.g., N₂O, NH₃, and NO_x), P-containing rate of P₂O₅ and characterization factor of CH₄ to CO₂, were calculated by molecular formulas directly.

Concerning the nutritional data, the daily/maximum recommendations of intakes of nutrients were referred to Drewnowski's study (Drewnowski, 2009). And the contents of nutrients in 100g of food were mainly derived from the USDA (U.S. Department of Agriculture) Food Composition Database (United States Department of Agriculture, 2018). The data referring to national and international dietary recommendations including Chinese Dietary Guidelines (DG), Chinese National Nutrition Plan (NP), Healthy Diets from Sustainable Food System recommended by Willett et al., (2019)⁰, and World Health Organization recommendations (WHO) were collected from official databases (Chinese Nutrition Society, 2016; General Office of the State Council of the People's Republic of China, 2014; United States Department of Agriculture, 2018; World Health Organization, 1998). Detailed data are available in the Supplemental Information (Tables S2, S3, S4, S5, S6, S7 and S8).

Environmental impacts calculations

We evaluate the potential nutrient-related environmental impacts linked to production and processing of major food items. We select the annual per capita food consumption as the functional unit (FU). Four environmental impacts resulted from N, P, and C flows are investigated, including energy consumption, global warming potential, acidification potential, and eutrophication potential (Wu et al., 2018).

Each impact category (e.g., climate change potential) is accounted by multiplying the corresponding environmental indicators (e.g., CO₂, CH₄, and N₂O) with the characterization factors that represent the potential of one single emission or resource consumption contributing to the respective impact category (ISO, 2006). These environmental impacts can be calculated by using Equation (1):

$$en_i^j = \left(\sum_{k=1}^n EN_k / Q_i \right) c_i r_i f_k (i = 1, 2, 3, \dots, 10) \quad (\text{Equation 1})$$

where en_i^j represents environmental impact j for producing food item i , generated from the annual per capita food consumption, EN_k is the total energy/emission k contributed by producing the total crop/livestock, Q_i is the total crop/livestock produced, c_i is the amount of per capita food consumption for food item i , r_i is the amount of crop/livestock used to produce per unit food item i , and f_k represents the characterizing factor of consumed energy/emission k to the corresponding environmental impact j .

Accordingly, we focus on impacts from energy consumption and direct agricultural emissions originating from these three nutrients (e.g., CO₂, CH₄, NH₃, N₂O, NO_x, P loss, etc.). In our study, energy consumption is mainly related to the application of chemical fertilizers (nitrogen fertilizer and phosphorus fertilizer), seeds, manure, and crop residue, as well as nutrient-containing fodders. Energy consumed in food processing mainly relates to electricity use.

Part of the calculation of EN_k in the crop farming and livestock and poultry production was previously developed by Wu et al. (2018). Our improvements here include but are not limited to the following aspects: (1)

more nutrient-related processes, not only crop farming, livestock and poultry production, but also food primary processing, (2) combining N, P, and C to analyze their corresponding environmental impacts, (3) shift from production-consumption to consumption-production, meaning that all the environmental impacts are back-calculated based on the per capita consumed food items (such as grain and fruit), not according to the general raw materials (such as crops and livestock). As the calculations of some energy consumption/emissions related to N and P in crop farming and livestock and poultry production have been described in [Wu et al. \(2018\)](#), here we only explain those related to N in these two processes, and those related to N, P, and C in primary food processing. The calculation equations of these energies/emissions are listed in [Table S1](#). In particular, energies/emissions from crop farming, livestock and poultry production, and crop processing are calculated based on ratios of the amounts of crops/livestock/poultry used to produce the related food items per unit weight, while those generated from processing meat and other animal products (pork, beef, lamb, poultry, eggs, and milk) are evaluated according to the per capita consumed amount of food items.

In the following section, we outline the details of these processes and impacts:

- (a) C-related emissions in crop farming. Besides N_2O resulting from fertilizer application illustrated in [Wu et al. \(2018\)](#), CO_2 is also emitted from synthetic fertilizer nitrogen (urea) application ([IPCC et al., 2007](#)).
- (b) C-related emissions in livestock and poultry production. There are CH_4 emissions from both manure management and enteric fermentation, in addition to N_2O emission from manure management. However, we do not consider energy consumption and CO_2 emission from producing eggs and milk, in part, due to the lack of relevant data.
- (c) C/N/P-related energy consumption and emissions in primary food processing. The primary food processing mainly includes crops processing, livestock and poultry slaughtering, eggs collection, and milk production. We neglect energy consumption and emissions from processing vegetables, fruit and aquatic products. The main energy used in such processing is electricity, which is converted into CO_2 emissions; however, the acid gas emitted from food processing is marginal and not included in this study. The N/P related losses during primary food processing mainly includes N and P losses in crop processing, and N, P, and NH_3-N losses in livestock and poultry slaughtering, which are assumed to be discharged into local water ([Ma et al., 2008, 2011](#)). As the nature of these losses from processing different food products varies considerably across the whole country, there are different standards of discharging these wastewaters. We assume that all the processing industries discharge their wastewater by following national wastewater discharge standards. These discharge levels and N/P concentrations for food processing were obtained from the corresponding discharge standards ([Document Compilation Committee of the 1st National Pollution Census, 2012; Huerta et al., 2016](#)).

Nutrient densities

We use the nutrient rich food index NRF9-3 ([Drewnowski, 2009; Fulgoni et al., 2009](#)) to assess the nutritional densities of the 10 food items ([Table 1](#)). Specifically, nine beneficial nutritional characteristics are considered (protein, fibre, calcium, iron, magnesium, potassium, and vitamins A, C, and E); in contrast, three avoidance dietary components are considered (saturated fat, carbohydrate, and sodium). We use carbohydrates as a proxy for added sugar as such data are available ([Yang et al., 2016](#)). The NRF9-3 for each food item is assessed as below:

$$NRF_i = \left(\sum_{m=1}^9 NE_m^i / DV_m \right) * 100 - \left(\sum_{n=1}^3 NL_n^i / RV_n \right) * 100 (i = 1, 2, 3, \dots, 10);$$

$$m = 1, 2, 3, \dots, 9; n = 1, 2, 3) \quad (\text{Equation 2})$$

In which $NRF_i (i = 1, 2, 3, \dots, 10)$ is nutrient quality index of food item i , $NE_m^i (i = 1, 2, 3, \dots, 10; m = 1, 2, 3, \dots, 9)$ means content of nutrient m in per 100g of food item i , $DV_m (m = 1, 2, 3, \dots, 9)$ is recommended daily intake of nutrient m , $NL_n^i (i = 1, 2, 3, \dots, 10; n = 1, 2, 3)$ represents content of limiting nutrient n in 100g of food item i , and $DV_n (n = 1, 2, 3)$ is the maximum recommended daily value of nutrient n .

The nutritional scores of different annual consumed food items are then aggregated to get the final diet nutritional quality score (NUTR). This procedure is performed for both rural and urban diets. The detailed calculation method is detailed in [Table S1](#).

In fact, there are two indicators to evaluate the nutritional qualities. One is nutrient rich food index (NRF9-3), another is nutrient quality index (NQI). The NRF9-3 ([Drewnowski, 2009](#)) is based on nine nutrients encouraged to consume in diet and three nutrients discouraged to consume. The NQI ([Sonesson et al., 2019](#)) considers the total consumption of nutrients in a diet in relation to their dietary needs. As the NQI value of every single food item is calculated based on the amounts of the food consumed, it changes across dietary patterns. Here, we used the NRF9-3 to assess the nutritional densities of the 10 food items. According to the nutrient rich food index NRF9-3, there are two calculation methods to assess the nutritional densities of food. One is to use the average recommended nutrients to minus the average limiting nutrients. Another is to use the total recommended nutrients to minus the total limiting nutrients. To avoid the negative values and be more understandable, we selected the second method.

Sensitivity analysis

For identifying key food items influencing these impacts and proposing optimization strategies, we conduct a sensitivity analysis by increasing and reducing each food item by 20% ([Table S8](#) and [Figure S2](#)).

All the impacts corresponding to the amount changes of every food item are calculated according to the EINQA model.

$$S_i^j = \left(C_i^j - U_i^j \right) * 100\% / U_i^j \quad (i = 1, 2, 3, \dots, 10; j = 1, 2, 3, 4, 5) \quad (\text{Equation 3})$$

where $S_i^j (i = 1, 2, 3, \dots, 10; j = 1, 2, 3, 4, 5)$ represents sensitivity of the target variable, which is the impact j to the controllable variable i , the amount of consumed food, $C_i^j (i = 1, 2, 3, \dots, 10; j = 1, 2, 3, 4, 5)$ is the environmental/nutritional impact j corresponding to the amount change of consumed food i , $U_i^j (i = 1, 2, 3, \dots, 10; j = 1, 2, 3, 4, 5)$ is the environmental/nutritional impact j in the base year of 2019.

The results show that the magnitude of grains, pork, and poultry in diets had the greatest impact on the four nutrient-related environmental impacts ([Figures S2A–D](#)) while nutritional quality (NUTR) was the most sensitive to the amounts of grains, fruit, and vegetables ([Figure S2E](#)). Eggs, fruit, beef, lamb, and aquatic products had relatively smaller environmental impacts linked to both rural and urban diets, while milk consumed by urban residents required more energy and therefore significantly influenced the GWP.

New dietary recommendations

We combine the results of sensitivity analysis, environmental impacts and nutritional quality to determine new dietary recommendations. Meanwhile, considering the dietary habits, which are difficult to change and limit the acceptability of some dietary scenarios, we combine the existing dietary recommendations as the constraints.

First, the results show meat and grain consumptions resulted in relatively higher environmental impacts than other food items on a per kg basis, while fruit and aquatic products have relatively higher nutrition densities than other food items. Thus, it is necessary to decrease meat and grain consumption and increase fruit and aquatic products consumption so that the sustainability and nutrition levels of our diets can be improved. Second, both environmental impacts and nutritional qualities of rural residents' diet need to be improved more than those of urban residents' diet. That means the food items for rural residents should be changed more than those for urban residents. Third, the sensitivity analysis shows that grains, pork, and poultry in diets contributed the most to the four environmental impacts, while nutritional quality (NUTR) was the most sensitive to the amounts of grains, fruit, and vegetables. Thus, changing intakes of these food items may be effective to improve the sustainability and nutrition levels of Chinese diets. Last, the food items especially grains, vegetables, and fruits currently consumed by Chinese rural residents are relatively different from these food items suggested by several dietary recommendations. Correspondingly, these food items should be stressed and adjusted for the Chinese residents.

The detailed recommendations of ten food items in the new dietary guideline are listed below.

Grains

Sensitivity analysis shows that grains consumption greatly influences the environment for both rural diet and urban diet, especially rural diet. Moreover, grains production has the largest energy intensity and the medium nutrition density, compared to other food items (–20 kg to –120 kg). Concerning current grains consumption in China, it is more than all the other four national and international dietary recommendations. Especially grains consumption in rural areas is almost twice than that in urban areas. Thus, grains consumption should be reduced greatly, especially for those rural residents. Here, we suggest to reduce grains consumption by 50 kg to 100 kg for rural residents, and 30 kg to 70 kg for urban residents.

Vegetables

Sensitivity analysis shows that vegetables have marginal effect on the environment, but have higher nutritional quality. Thus, increasing vegetables consumption will improve our nutrition, without significant environmental impact. Comparing with other dietary guidelines, vegetables consumptions are lower (–10 kg to –50 kg) in both rural and urban areas. In conclusion, both rural and urban residents should increase their vegetables consumption by 40 kg–60 kg.

Fruit

Sensitivity analysis shows that fruit has marginal effect on the environment, but greatly influence nutritional quality. Moreover, fruit has the largest nutrition density. However, fruit consumption is much lower in China than both the national and international dietary guidelines (–10 kg to –70 kg), especially in rural areas. Hence, we suggest to increase fruit consumption especially for rural residents. For instance, fruit consumption should be increased by 40 kg to 60 kg for rural residents, and 30 kg to 50 kg for urban residents.

Pork

The nutrition density of pork is relatively low among the ten food items. Sensitivity analysis shows that pork consumption has negligible impact on the nutritional quality, but has significant impact on the environment except for energy. While our consumption habits determine that both rural and urban pork consumption are similar and higher than the dietary recommendations (2 kg to 18 kg). Correspondingly, we suggest to reduce pork consumption by 5 kg to 15 kg for both rural and urban residents.

Beef

Beef has less impacts on the environment and the nutritional quality. The nutrition density of beef is higher than pork and lamb. Comparing with other dietary recommendations, Current beef consumptions for rural and urban residents are similar. Rural residents' beef consumption is a little bit lower (–0.3 kg to 0.4 kg), while urban residents' beef consumption is a little bit higher (1.3 kg to 1.8 kg). Hence, we suggest a slight increase of beef consumption by 0.1 kg to 0.5 kg for rural residents, and a slight decrease of beef consumption by 1.5 kg to 2.0 kg for urban residents.

Lamb

It shows that lamb has the smallest nutrition density. Like beef, lamb has negligible impacts on the environment and nutritional quality. China's current lamb consumption especially in urban areas is slightly higher than in other four dietary recommendations (0.1 kg to 0.6 kg). Therefore, we recommend that lamb consumption should be reduced by 0.1 kg to 0.5 kg for rural residents, and 0.5 kg to 1.0 kg for urban residents.

Poultry

The nutrition density of poultry is much higher than other meat products (pork, beef, and lamb). However, poultry greatly influence the environment, with higher figures of GWP, AP, and EU, especially EU. Comparing with other dietary recommendations, China's poultry consumption especially in the urban areas is 2 kg to 7 kg larger. Thus, we suggest that poultry consumption should be reduced by 4 kg to 6 kg for rural residents and 5 kg to 8 kg for urban residents.

Aquatic products

Aquatic products have much higher nutrition density, only lower than fruit. The consumption of aquatic products has marginal environmental impacts. Thus, it is necessary to increase aquatic products consumption. Moreover, it shows that aquatic products consumption of the recommended diets is 8 kg to 11 kg and

1 kg to 5 kg larger than that of both China's rural residents and urban residents. Correspondingly, we suggest to increase aquatic products consumption for both residents by 10 kg to 12 kg and 5 kg to 8 kg, respectively.

Eggs

Comparing with the nutrition densities of other food items, the nutrition density of eggs is not high. Meanwhile, eggs consumption has very marginal impacts on the environment and nutritional quality. Currently, eggs consumptions in both rural areas and urban areas are 6 kg to 11 kg and 5 kg to 10 kg lower than our dietary recommendations. Thus, eggs consumption should be increased by 6 kg to 10 kg for rural residents and 6 kg to 8 kg for urban residents.

Milk

Similar to eggs, milk consumption has marginal impacts on the environment and nutritional quality. Its nutrition density is lower than other food items. There are more milk products (e.g., condensed milk, cream, cheese). But the Chinese people normally consume milk only, with very less consumption on other milk products due to their food culture. Thus, we do not suggest any changes on such milk products.

We believe that the proposed dietary recommendations are applicable in China. There are three reasons: 1) We have evaluated the changes of environmental impacts and nutritional qualities for both rural and urban diets in China during the recent 40 years. We have also predicted the future dietary scenario for 2030 with the authority data. We presume that this trend could reflect the actual Chinese situations. 2) Considering the Chinese people's unwillingness of changing their traditional eating habits, we combined the existing national dietary recommendations as the baselines for comparisons. 3) We have considered and differentiated both China's rural and urban residents' diets, considering their different dietary patterns and relations to China's urbanization.