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Promoting dietary guidelines and environmental sustainability in China

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ABSTRACT

Since 2015, the Chinese government has started actively promoting the Chinese Dietary Guidelines (CDGs), which target not only health but also sustainable food consumption and production. This paper first illustrates the deviations of Chinese people's diets from the CDGs; it then explores how reducing the deviations can influence environmental sustainability (i.e., greenhouse gas emission, energy use, and blue water footprint), and lastly, it investigates key driving factors behind the deviations. Our results demonstrate that the overall impact of reducing the deviations (i.e., reducing meat/egg consumption and increasing fruit/vegetable/dairy consumption) can improve both diet quality and environmental sustainability. The results also imply that reducing cereal and fruit prices may facilitate achievement of both the CDGs' targets and environmental sustainability by reducing meat consumption and increasing fruit consumption. If the recommendation of the CDGs is followed with additional environmental costs, it will be important to discuss how to minimize them.

1. Introduction

In China, following its rapid economic development, dietary patterns have been drastically changing from its traditional diets (primarily of cereal products and starchy roots, with few animal source foods or caloric sweeteners) to diets that contain more energy-dense foods and are high in fat, particularly saturated fat, and low in carbohydrates (Curtis & McCluskey, 2007; Fu, Gandhi, Cao, Liu, & Zhou, 2012; Fuller, Beghin, & Rozelle, 2007; Liu, Parton, Zhou, & Cox, 2009; Logan & Jacka, 2014; Popkin, 2014; Rae, 1997; Shono, Suzuki, & Kaiser, 2000; Zhai et al., 2014; Zheng & Henneberry, 2009). Dietary change is often considered as a key driving force behind the recent increase of obesity and the prevalence of diet-related chronic diseases (e.g., type 2 diabetes and hypertension) in China (Du, Wang, Zhang, Zhai, & Popkin, 2014; Xu, Byles, Shi, & Hall, 2015; Xu, Hall, Byles, & Shi, 2015a, 2015b). Moreover, the dietary change may also influence environmental outcomes by changing agricultural production, which often causes substantial environment burdens, e.g., greenhouse gas (GHG) emissions such as methane and nitrous oxide and land degradation (Alexandratos & Bruinsma, 2012; Bruinsma, 2003; Shimokawa, 2016).

The health and environmental aspects of the dietary changes have been explicitly and implicitly addressed in the Chinese Dietary Guidelines (CDGs), which aim to provide guidance for individuals and policy makers to achieve healthy and sustainable food consumption and production. In 2015, the Chinese government started more actively promoting the CDGs to increase its social recognition (The State Council Information Office of the People's Republic of China, 2015). At the same time, compared to environmental outcomes, health outcomes tend to be emphasized as the influences of promoting dietary guidelines in China and other

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countries (Diethelm et al., 2012; Harnack, Nicodemus, Jacobs, & Folsom, 2002; Stookey, Wang, Ge, Lin, & Popkin, 2000). In fact, to the best of our knowledge, environmental aspects have been hardly examined in the context of promoting dietary guidelines in China. To fill this gap, this paper explores the potential influences of the promotion of the CDGs on environmental sustainability.

More specifically, this paper starts by clarifying the deviations of Chinese people's diets from the recommended diet of the CDGs, using individual-level panel data from the China Health and Nutrition Survey (CHNS) over the period of 1991–2011. Second, it investigates how environmental burdens (GHG emissions, energy use, and blue water footprint[1]) could be influenced if people's diets were changed to the recommended diet of the CDGs. Lastly, we examine key driving factors behind the deviations from the recommended diet of the CDGs and discuss potential policy measures to facilitate both the recommended diet of the CDGs and environmental sustainability.

The rest of this paper is organized as follows. Section 2 presents an overview of the CDGs. Section 3 presents our data and descriptive analysis about actual diets and their deviations from the recommended diet of the CDGs in China. Section 4 estimates the influences of reducing the deviations from the CDGs on GHG emissions, energy use, and blue water footprint. Section 5 investigates the key socioeconomic factors that influence the deviations from the CDGs. The last section offers policy implications and concluding remarks.

2. Overview of the Chinese Dietary Guidelines

Motivated by the Food and Agricultural Organization (FAO)/World Health Organization's (WHO) World Declaration on Nutrition, the Chinese Nutrition Society published the CDGs in 1989 and revised them in 1997 and 2007 to incorporate the changes in nutritional status and food consumption patterns in China (Ge, 2011). The CDGs have become simpler but more specific in health targets and more visualized for easier promotion. Following the ten-year period, the latest CDGs were newly released on May 13th, 2016, with guidelines shortened to 6 points with a total of 48 words. The CDGs aim to 1) give guidance for the appropriate food consumption to maintain health and 2) provide principles for the government to develop agricultural production and intervene in the agricultural markets through food consumption adjustment (Chinese Nutrition Society). However, the CDGs currently tend to emphasize the first target (i.e., health aspects), and the second target is much less discussed in practice. Thus, more attention may be needed toward the second target — particularly interventions in agricultural production and markets to improve environmental sustainability.

In the 1989 version of the CDGs (hereafter the 1989 CDGs), there were eight general items covering general food consumption with a focus on maintaining food security. The health and environment targets were not the priority. The government's major task was feeding the population at that time. There was no obvious concern about the quality or safety of food consumption and no mention of anything about the balance of nutrition or dietary habits. The 1989 CDGs are comprehensive but general, providing the fundamental guidance for food consumption and indirectly for agricultural production.

Along with economic development, China's food consumption patterns and lifestyles became increasingly diverse in the 1990s. Accordingly, the 1997 version of the CDGs (hereafter, the 1997 CDGs) started to differentiate the guidance for different groups of people based on their specific features and needs. In addition to the general population, it includes guidance for seven particular population groups (infants, toddlers and preschool children, school age children, adolescents, pregnant women, lactating mothers and the aged). It is worth noting that the 1997 CDGs, for the first time, provided a recommendation about dairy and meat consumption. As Chinese people's calcium intake was lower than the WHO's (2002) recommended level (Ge, 2011), the CDGs recommended that Chinese people "consume milk, beans or dairy or bean products frequently". In contrast, Chinese people started consuming too much meat, and the CDGs thus started recommending an appropriate consumption of fish, poultry, eggs and lean meat for both urban and rural populations and a reduction of fatty meat and animal oil consumption for people in large cities. Lastly, the 1997 CDGs, for the first time, discussed food quality and safety issues. In addition to the descriptive content, the 1997 CDGs presented a dietary pagoda to visualize the recommended diet. The dietary pagoda locates different groups of food into different layers according to the required amount specified in a numerical range. However, the dietary pagoda in the 1997 CDGs did not give any numerical recommendations about food consumption amounts.

The next CDGs came out in 2007, with the Ministry of Health taking part. Its general target switched from the quantity to the quality of diet. This guidance kept the basic structure of the previous two versions and expanded widely in volume and coverage. Following the population groupings in the 1997 version, for the general population, the contents expanded to ten items, each containing core information, discussion, and reference materials. As a continuation of the 1997 version, the 2007 CDGs emphasized increasing consumption of dairy products by changing the suggestion from "frequently" to "every day". It also addressed the choice of snack foods (an indication of the increasing consumption of processed food because of changes of lifestyle). Two new items, physical exercises and sufficient water drinking, were emphasized and reflected in the dietary pagoda. Additionally, the dietary pagoda in the 2007 CDGs started presenting the numerical ranges of consumption amount for each food group. The numerical ranges are based on the energy level of the group consuming 1800 kcal to 2600 kcal (Table 1).

The latest 2016 CDGs were modified based on national nutrition surveys in 1982, 1992, 2002, and 2012, along with the 2015 national survey of nutrition and chronic disease. In this paper, we study the first three versions of the CDGs because of data availability; however, we offer a brief introduction to the 2016 CDGs as follows. Compared to the previous CDGs, the 2016 version

[1] Blue water footprint "refers to the volume of freshwater taken from the surface or ground to create a product, and which has then evaporated, been incorporated into the product, or been returned to a separate catchment from which it was originally withdrawn" (Tom, Fischbeck, & Hendrickson, 2016).

Table 1
Dietary recommendations in the 2007 CDG for general population (healthy adults aged 18–59 years old).
Source: The Chinese Nutrition Society, 2007.

	Energy levels per person per day						
	6700 kJ 1600 kcal	7550 kJ 1800 kcal	8350 kJ 2000 kcal	9200 kJ 2200 kcal	10,050 kJ 2400 kcal	10,900 kJ 2600 kcal	11,700 kJ 2800 kcal
Cereals (g/day)	225	250	300	300	350	400	450
Soybeans (g/day)	30	30	40	40	40	50	50
Vegetables (g/day)	300	300	350	400	450	500	500
Fruits (g/day)	200	200	300	300	400	400	500
Meat (g/day)	50	50	50	75	75	75	75
Dairy (g/day)	300	300	300	300	300	300	300
Eggs (g/day)	25	25	25	50	50	50	50
Seafood (g/day)	50	50	75	75	75	100	100
Cooking oil (g/day)	20	25	25	25	30	30	30
Salt (g/day)	6	6	6	6	6	6	6

further simplified the guidelines into 6 points with 48 words in total to facilitate its promotion and adoption. Specifically, the new CDGs change in the following five aspects: 1) emphasize the "balanced diet", encouraging more intake of fruits and vegetables and continuously encourage more intake of dairy and soybean products, given the limited improvement in the past 10 years; 2) expand the minimum age of the general population of the 2007 CDGs from 6-year-olds to 2-year-olds. Thus, the guidance applies to a more general population. In addition, the new CDGs attach special attention to the vegetarian group and encourage soybean product intake for them as a good substitute for animal protein; 3) because of increasing obesity and chronic diseases, the 2016 CDGs, for first time, emphasize the "healthy weight" conception; 4) following the 2015 WHO's guidance of sugar intake, the new CDGs, for the first time, limit the daily sugar intake for Chinese people; 5) in addition to the pagoda figure, the 2016 CDGs present two more figures: the CDGs balance accounting sheet and a dietary plate for children to further visualize the guidance.

To summarize, in the past 30 years, the CDGs have been revised following the consumption habits and nutrition requirements of Chinese people. The format has become simpler and easier to use for promotion. The government has made efforts to incorporate more specific content to improve applicability and usefulness for a wider range of people. The CDGs have also become more visualized and media-friendly so that they can be further promoted. In terms of the sustainability targets, the CDGs have mainly focused on health aspects, with most suggestions regarding food consumption and health. Given the current prevailing situation, the CDGs have limited impact on the agricultural production and market. Because not only health but also environmental aspects are critical for achieving more sustainable food consumption and production, the CDGs may need more direct and clearer arguments related to environmental sustainability.

3. Data and descriptive analysis

3.1. Data

We use eight waves of individual-level panel data from the CHNS from 1991 to 2011. Our analysis focuses on the general population defined in the CDGs—healthy adults aged from 18 to 59 years old—whose total daily calorie intake ranges from 1600 kcal to 2800 kcal. This is because the CDGs provide numerical recommendations for only this population (the so-called general population in the CDGs), and the numerical criteria were necessary to conduct our quantitative analysis. We included people who provided all information needed for our empirical analysis. Because fruit prices and dietary knowledge are available only beginning in 2004, we constructed two analytical samples: a full sample over the period 1991–2011 without fruit prices and dietary knowledge (33,673 adults) and a sample over the period 2004–2011 with fruit prices and dietary knowledge (17,039 adults). Although we use the full sample for our descriptive analysis, the number of observations in our regression analyses becomes half of the full sample size because our regression models include lagged variables.

We first construct daily intake of nine food groups defined in the CDGs: cereals, soybeans and soybean products, vegetables, fruits, meat, dairy products, eggs, seafood, and cooking oil. We used the 3-day average food intake data in the CHNS and the China Food Composition Tables. To convert the food groups in the composition tables into the nine food groups in the CDGs, we combine cereals, potatoes and other beans for "cereals", soybeans and nuts for "soybean products", green vegetables and other vegetables for "vegetables", and pork, chicken and beef for "meat". For other food groups in the CDGs, we simply use a single group in the composition tables that represents the same food group. In our descriptive analysis, we clarify trends in actual diets in China and how the actual diets deviate from the CDGs. Although the CDGs also make recommendations about daily salt intake, salt intake could not be constructed from the CHNS and the China Food Composition Tables.

As outcome variables in our regression analyses, we employ deviations from the CDGs' recommended range for the nine food groups. Suppose the actual intake level for food group i is f_i, and the CDGs' recommended range is $[lb_i, ub_i]$. Then, the outcome variable $dCDG_i$ is defined as:

Table 2
Summary statistics of key variables.

Variables	Mean	SD
Outcome variables		
Deviations from the CDG in		
Meat consumption (g)	70.10	128.95
Egg consumption (g)	− 5.14	64.56
Dairy consumption (g)	− 287.56	56.25
Fruit consumption (g)	− 152.52	128.81
Vegetable consumption (g)	− 28.73	150.28
Key explanatory variables		
Per capita household income	28,813.79	34,913.19
Food prices (yuan/kg)		
Cereals	3.36	0.96
Sugar	7.10	1.80
Eggs	10.95	4.30
Green vegetables	2.60	2.13
Cabbage	1.94	1.24
Pork	19.20	5.69
Chicken	18.71	7.35
Milk	5.33	4.66
Fish	12.55	4.80
Urbanization index	60.26	19.93
Observation number	33,673	
Key variables available only in and after 2004		
Dietary knowledge index	0.04	0.48
Fruit price (yuan/kg)	4.56	2.66
Observation number	17,083	

$$dCDG_i = \begin{cases} (f_i - ub) & \text{when } ub_i < f_i, \\ 0 & \text{when } lb_i \le f_i \le ub_i, \\ (f_i - lb) & \text{when } f_i < lb_i. \end{cases}$$

For example, the CDGs' recommended range for meat consumption f_{meat} is from 50 g to 75 g per day. Thus, the deviation of meat consumption $dCDG_{meat}$ is 0 as long as $50 \le f_{meat} \le 75$, $(f_{meat} - 75)$ when $f_{meat} > 75$, and $(f_{meat} - 50)$ when $f_{meat} < 50$.

Key explanatory variables in our regression analyses are income, food prices, urbanization, and dietary knowledge. Per capita household income (in 2011 yuan) is used to measure an income level. We use food prices for eight food categories (cereals, pork, chicken, beans, vegetables, eggs, oils, and fruit). Note that fruit prices are available only beginning in 2004, while other prices are available over the whole period. We use free market prices (2011 yuan per kg) collected at the community level. Urbanization is measured using the urbanization index constructed by the CHNS. Another key variable is dietary knowledge. To measure dietary knowledge, we follow Shimokawa (2013) and construct a summary index from the answers to the nine diet-related questions in the CHNS. In the questions, the subjects choose 'agree', 'disagree', or 'unknown' for each question. For each of the nine questions, we generate an indicator that takes the value 1 for the correct answer, − 1 for the incorrect answer and 0 for choosing 'unknown' based on the criteria in WHO (1998). We apply the principal component factor method to the nine indicators; we compute the average of all the principal component factors across these nine indicators, and the average is used as a summary index of dietary knowledge (DKI).

The CHNS also collected a wide range of socioeconomic factors. Our sample includes data on age, gender, education level, household size, proportion of age groups within a household, and residence (urban and province dummies). Table 2 presents summary statistics for the key variables.

3.2. Deviations of actual diets from the CDGs' recommended diets

The CDGs have suggested the amount of intake of the nine food groups for the general population based on their energy requirements, which are determined based on several factors such as the person's height, weight, gender, work type, and daily exercise hours. We follow the most specific classification of nine energy levels from the 2007 CDGs (Table 1) and focus on energy levels from 1600 kcal (lower bound) to 2800 kcal (upper bound) described in the dietary pagoda. Using the CHNS data over the period 1991–2011, this section describes transitions of three versions of the CDGs and the deviations of actual diets from the CDGs over time.

Table 3 presents the average daily consumption per person of nine food groups for the general population from 1991 to 2011. Among the nine food groups, the consumption of cereal, vegetables and oils have experienced a decreasing trend over the period. In contrast, the consumption of soybeans, fruits, seafood, meat, and dairy have been steadily increasing during the period. Overall, these changes in the consumption of the nine food groups except for meat and vegetables indicate improvement following the 2007 CDGs. In particular, fruit and egg consumption showed substantial improvement: fruit consumption increased by eight times, and egg consumption more than doubled. In contrast, the consumption of meat and vegetables increasingly deviated from the CDGs'

Table 3
Mean consumption of the 9 food groups in the general population (healthy adults aged 18–59 years old).
Source: Authors' calculation using the CHNS 1991–2011.

	All	1991	1993	1997	2000	2004	2006	2009	2011
Cereals (g/day)	394	407	406	399	396	405	382	377	383
Soybeans (g/day)	103	78	85	86	104	104	114	128	120
Vegetables (g/day)	329	331	343	349	376	332	320	305	279
Fruits (g/day)	61	18	20	22	36	40	92	101	151
Meat (g/day)	137	99	113	119	147	134	148	159	169
Dairy (g/day)	12	5	5	4	9	20	17	12	26
Eggs (g/day)	54	31	32	47	56	57	66	67	70
Seafood (g/day)	65	50	53	57	60	66	73	79	79
Oils (g/day)	0.32	0.50	0.61	0.36	0.34	0.32	0.37	0.08	0.07
Observation number	33,673	3860	3848	4251	4631	4301	3929	4221	4632

recommended range.

Next, we investigate the proportion of people whose consumption level is below, within, or above the CDGs' recommended range for the nine food groups. Table 4 presents the proportions for the whole sample in 1991, 2000, and 2011 separately. It demonstrates that there are substantial dietary problems in the consumption of vegetables, fruits, meats, dairy products, eggs and seafood. First, increasingly more people over-consumed meat, and the proportion of those who over-consumed reached 74.9% in 2011. In contrast, increasingly more people under-consumed vegetables, and the proportion reached 63.5% in 2011. Although fruit consumption showed substantial improvement, 71.5% of the sample was still under-consuming fruits in 2011. Dairy products and seafood were also under-consumed in most of the sample, and the situations improved slightly over this period. Lastly, egg consumption shifted from under-consumption to over-consumption during the period, while the proportion of people who satisfy the CDGs' recommended

Table 4
Proportions of people whose consumption level is under, within, and over the CDG's recommended range for 9 food groups.
Source: Authors' calculation using the CHNS 1991–2011.

	All	Year		
		1991	2000	2011
Cereals				
Under	4.7%	0.9%	1.8%	9.6%
Within	25.5%	15.6%	16.2%	35.3%
Over	69.8%	83.5%	82.0%	55.1%
Soybeans				
Under	40.6%	44.3%	40.5%	34.0%
Within	6.5%	8.3%	6.3%	8.1%
Over	52.9%	47.4%	53.2%	57.9%
Vegetables				
Under	50.5%	49.6%	37.9%	63.5%
Within	35.3%	35.1%	41.8%	28.3%
Over	14.2%	15.3%	20.3%	8.3%
Fruits				
Under	88.8%	97.4%	93.7%	71.5%
Within	7.6%	2.1%	4.5%	18.5%
Over	3.6%	0.5%	1.7%	10.1%
Meat				
Under	27.4%	38.7%	26.8%	14.4%
Within	8.5%	6.6%	9.0%	10.7%
Over	64.1%	54.7%	64.2%	74.9%
Dairy				
Under	99.6%	99.9%	99.5%	99.6%
Over	0.4%	0.1%	0.5%	0.4%
Egg				
Under	46.9%	65.3%	47.2%	30.4%
Within	14.3%	13.9%	16.5%	14.1%
Over	38.8%	20.8%	36.3%	55.4%
Seafood				
Under	64.0%	69.2%	66.7%	54.9%
Within	10.8%	10.1%	10.1%	15.4%
Over	25.2%	20.7%	23.2%	29.6%
Oils				
Under	99.6%	99.6%	99.6%	99.9%
Within	0.0%	0.1%	0.1%	0.0%
Over	0.4%	0.3%	0.3%	0.1%

range remained almost the same.

4. Environmental influences of promoting the CDGs' recommended diets

From Tables 2 and 4, five food groups show particularly problematic deviations from the CDGs' recommended diets (i.e., meat, egg, dairy, fruits, and vegetables). More specifically, the CDGs suggest that, on average, Chinese people should reduce the consumption of meat and eggs, while they should increase the consumption of fruits, vegetables, and dairy products. Because the direction of the deviations is different across food groups, the direction of improving diets also differs across food groups. In this section, we will discuss when diets are being improved either by reducing or increasing consumption and how the dietary changes can influence environmental sustainability through agricultural production and consumption in China.

As measures of environmental burdens related to agricultural production and consumption, we focus on the impacts on GHG emissions, energy use, and blue water footprint. These measures are selected because 1) relatively abundant data are available; 2) they are relatively common for a wide range of food products, and 3) they receive relatively more attention from various stakeholders such as researchers, policymakers, and the general public. To estimate the environmental influences of dietary changes following the CDGs, we will exploit the findings in Tom et al. (2016). They examined how much the three environmental measures are influenced by producing and consuming one calorie of food in a food supply system in the United States, and they estimated the per-calorie indexes of the influence for each of the major food groups (fruits, vegetables, dairy, grains, meat, poultry, eggs, seafood, nuts/seeds/soy, added sugars, solid fats, and oils). The indexes reflect various climates, transport modes and distances, food-related technology, and production methods by incorporating the estimates of average resource uses and emission intensity from previous studies primarily on advanced industrialized countries. Although the estimates are for the United States, they are the best and only estimates that connect food consumption and environmental burdens at the food group level. Given China's less efficient production technology and less integrated food supply system (Ross, 2015; Zhang, 2015) compared to the U.S., we treat their estimates as a lower bound of the per-calorie environmental burdens for China. That is, the actual environmental impacts of dietary changes in China may be larger than our estimates.

Table 5 summarizes our estimates of environmental burdens that can be induced by adjusting people's average diets to the CDGs' recommended diet in 2011. The first panel (panel (a)) presents the per-calorie indexes from Tom et al. (2016). For example, consuming 1000 cal of meat requires 16 kg of GHG emissions, 26 megajoules (mJ) of energy use, and 0.3 l of blue water footprint.

The environmental influences of dietary changes following the CDGs are calculated by multiplying the indexes by the average calorie changes required to adjust people's actual diets to the CDGs' recommended diet, where calorie changes can be either positive or negative depending on food groups (average changes in grams are presented in Table 2). Panel (b) presents the environmental influences per person per day for each food group, and panel (c) presents the nation-level environmental influences in China per year. Panel (d) presents the sum of the nation-level environmental influences of all food groups per year, which represents the overall environmental influences of dietary changes following the CDGs in 2011.

The results in Table 5 provide four important findings. First, decreasing meat consumption following the CDGs is consistent with

Table 5
Environmental impacts of adjusting people's average diets to the dietary guidelines' diets in China in 2011.

	Food groups				
	Meat	Egg	Dairy	Fruits	Vegetable
(a) Environmental burdens of consuming each food group (Tom et al., 2016; Heller & Keoleian, 2015)					
GHG emission (kg/cal)	0.016	0.004	0.009	0.002	0.001
Energy use (mJ/cal)	0.026	0.004	0.012	0.045	0.033
Blue water footprint (liters/kcal)	0.3	0.2	0.164	0.32	0.18
(b) Individual-level environmental burdens by following the CDG in 2011 (per person per day)					
GHG emission (g)	− 4.99	− 0.06	1.61	0.05	0.02
Energy use (kJ)	− 7.96	− 0.06	2.11	1.13	0.78
Blue water footprint (liters)	− 91.89	− 3.04	27.85	8	4.25
(c) Nation-level environmental burdens by following the CDG in 2011 (per year)					
GHG emission (Gg)	− 2447.9	− 31.4	790.1	24.9	11.0
Energy use (tJ)	− 3907.1	− 29.1	1036	551.9	382.1
Blue water footprint (tliters)	− 45.1	− 1.5	13.7	3.9	2.1
(d) Nation-level total environmental burdens of all food groups (per year)					
GHG emission (Gg)	− 1653.4				
Energy use (tJ)	− 1966.1				
Blue water footprint (tliters)	− 26.9				

Note:
- Panels (b) to (d) are authors' estimations based on the previous studies' estimates in panel (a).
- kJ is kilojoule = 10^3 J; tJ is terajoule = 10^{12} J; tliter is teraliters = 10^{12} l; Gg is gigagram = 10^9 g = 1000 t.
- Blue water footprint "refers to the volume of freshwater taken from the surface or ground to create a product, and which has then evaporated, been incorporated into the product, or been returned to a separate catchment from which it was originally withdrawn" (Tom et al., 2016).

the goal of facilitating environmental sustainability. The livestock sector is one of the most damaging industries for the environment in China. The major pollutions of this sector are from animal wastes, antibiotics and hormones, chemicals from tanneries, fertilizers, and the pesticides used to spray feed crops (Matthews, 2006). Specifically, to the GHG emissions, livestock production accounts approximately 80% of the agricultural sector and approximately 18% of the total global GHG emissions, through enteric fermentation and manure management (McMichael, Powles, Butler, & Uauy, 2007; Springmann, Godfray, Rayner, & Scarborough, 2016; Stehfest et al., 2009). GHG is emitted at every stage of livestock production (O'Riordan, 2015). These facts are reflected in the indexes in Table 5, where meat production emits the most GHG (0.016 kg/cal) followed by dairy production (0.009 kg/cal). Thus, if meat consumption were reduced to the CDGs' recommended level in 2011, the dietary change would reduce GHG emissions by 4.99 g per person per day and by 2447.94 gigagrams (Gg) in China per year. In addition to GHG emissions, the reduction in meat consumption would reduce energy use by 3907.10 terajoules (tJ) and blue water footprint by 45.1 teraliters (tl) in China per year.

Second, increasing dairy consumption following the CDGs would induce the largest increase in environmental burdens among all food groups, which conflicts with the goal of improving environmental sustainability. Large amounts of manure, urine, and breeding wastewater produced from dairy farms cause severe environmental pollution (Li, 2007; Xu, Liu, Xu, & Tao, 2012). If dairy consumption were increased to the CDGs' recommended level, the dietary change would increase GHG emissions by 790.08 Gg, energy use by 1036.03 tJ, and blue water footprint by 13.67 tliters in China per year.

Third, increasing fruit and vegetable consumption following the CDGs would also substantially increase environmental burdens, although the total burden of increasing fruit and vegetable consumption is smaller than that of increasing dairy products. It is also worth noting that the per-calorie indexes of energy use and blue water footprint are high for fruit and vegetable production. This is because fruits and vegetables have the lowest calorie densities relative to other food groups despite different production locations and methods (Tom et al., 2016). Table 5 shows that if fruit and vegetable consumption were increased to the CDGs' recommended level, the dietary changes would increase GHG emission by 35.9 Gg, energy use by 934.02 tJ, and blue water footprint by 6.00 tliters in China per year.

Lastly, decreasing egg consumption following the CDGs would reduce the environment burdens, but the influences are much smaller than those of other recommended dietary changes. Similar to the cattle raising industry, the poultry raising industry pollutes water, air, and soil by chicken discharge and wastes released in production. The wide usage of antibiotics in poultry feeding results in more devastating environment damage in water and soil in the long run (Wang, 2014). According to Table 5, if egg consumption were reduced to the CDGs' recommended level, the dietary change would reduce GHG emissions by 31.4 Gg, energy use by 29.1 tJ, and blue water footprint by 1.5 tliters in China per year.

In summary, there are three important implications: 1) reducing meat and egg consumption will be strongly justified by improving both diet quality and environmental sustainability; 2) increasing fruit and vegetable consumption can be justified by balancing between diet quality benefits and environmental costs, and 3) increasing dairy consumption may be least justifiable considering its substantial environmental costs, and it is necessary to minimize the related environmental costs. At the same time, despite the different implications across food groups, the overall environmental burdens would decrease in China by adjusting people's diets to the CDGs' recommended diet. Panel (d) in Table 5 shows that the overall dietary change (the sum of changes in all food groups) would contribute to reducing GHG emissions by 1653.39 Gg, energy use by 1966.14 tJ, and blue water footprint 26.90 tliters in China in 2011. Therefore, overall, promoting the CDGs may improve both diet quality and environmental sustainability in China. It is also worth noting that the overall reduction in environmental burdens crucially depends on the reduction of meat consumption. Thus, without reducing meat consumption, promoting the CDGs may cause increasing environmental burdens and conflict with the goal of environmental sustainability. Further improvement in agricultural production, management, and transportation will be necessary to reduce the environmental costs of promoting the CDGs.

5. Driving factors behind the deviations from the CDGs' recommended diet

We first describe our estimation strategy to investigate key determinants of the deviations from the CDGs' recommended diet. Second, we present the estimation results applying the strategy to the CHNS data.

5.1. Estimation strategy

To investigate how key socioeconomic factors are associated with the deviations of actual diets from the CDGs, we start from the following basic model:

$$\begin{aligned} dCDG_{\mathrm{fihvt}} = \alpha + \beta_{\mathrm{y}}\mathrm{In}(y_{\mathrm{hvt}}) + \beta_{\mathrm{DKI}}\mathrm{DKI}_{\mathrm{ihvt}} + \beta_{\mathrm{FP}}\mathrm{In}(\mathrm{FP}_{\mathrm{vt}}) + \beta_{\mathrm{uind}}\mathrm{In}(\mathrm{uind}_{\mathrm{vt}}) \\ + \alpha_{\mathrm{X}}\mathrm{X}_{\mathrm{ihvt}} + \mathrm{a}_{\mathrm{i}} + \varepsilon_{\mathrm{ihvt}}, \end{aligned} \quad (1)$$

where $dCDG_{\mathrm{fihvt}}$ is the deviation from the CDGs' recommendation for food group f of individual i in household h in community v at time t. $\ln(y_{\mathrm{hvt}})$ is the logarithm of per capita household income for household h in community v at time t. $\mathrm{DKI}_{\mathrm{ihvt}}$ is the dietary knowledge indicator of individual i in household h in community v at time t. $\ln(\mathrm{FP}_{\mathrm{vt}})$ is the vector of the logarithm of food prices in community v at time t. $\ln(\mathrm{uind}_{\mathrm{vt}})$ is the logarithm of the urbanization measure for community v at time t. $\mathrm{X}_{\mathrm{ihvt}}$ is the vector of individual-, household-, and community-level characteristics that may affect individual diets. a_{i} is time-constant unobserved factors, and $\varepsilon_{\mathrm{ihvt}}$ is a remaining error. Our main interests are the coefficients βs. If unobserved factors are not correlated with the explanatory variables, OLS estimation will provide us unbiased estimators of βs. However, we have good reasons to suspect that the OLS estimate can be biased. For example, a_{it} may include individual dietary preferences that may be stable over the years and likely to influence individual diets, which causes omitted variable bias.

Thus, we employ a fixed effects model to control for the time-constant unobserved factors a_{it}. Then, Eq. (1) can be transformed as follows:

$$\Delta dCDG_{fihvt} = \alpha + \beta_y \Delta \text{In}(y_{hvt}) + \beta_{FP} \Delta \text{In}(\text{FP}_{vt}) + \beta_{uind} \Delta \text{In}(\text{uind}_{vt}) + \beta_{DKI} \Delta \text{DKI}_{ihvt} + \alpha_X \Delta X_{ihvt} + \Delta \mu_{it} + \Delta \mu_{ht} + \Delta \mu_{vt} + \Delta \nu_{ihvt} \quad (2)$$

where Δ indicates a change in the variable from $t-1$ to t. $\Delta\mu_{it}$, $\Delta\mu_{ht}$, and $\Delta\mu_{vt}$ reflect changes in the unobserved time-variant dietary requirements specific to an individual, a household and a community, respectively. $\Delta\nu_{ihvt}$ is a remaining error.

To control for the effects of the remaining unobserved time-variant factors $\Delta\mu_{it}$, $\Delta\mu_{ht}$ and $\Delta\mu_{vt}$, we use the initial period characteristics of individuals, households and communities as proxies for these unobserved factors. That is, we assume that inter-temporal changes in unobserved dietary requirements and preferences may be similar within the group that shares the same initial conditions. More specifically, we include gender and age dummies at $t-1$ (A_{it-1}) for the individual-specific dietary requirement $\Delta\mu_{it}$, household demography at $t-1$ (S_{ht-1}) for the household-specific dietary requirement $\Delta\mu_{ht}$, and location dummies of residence at $t-1$ (R_{vt-1}) for the community-specific dietary requirement $\Delta\mu_{vt}$. Thus, for example, we expect that time-variant unobserved dietary requirements may be similar within a group of men who are 20 years old, single, and living in urban areas. Therefore, Eq. (2) can be rewritten as

$$\Delta dCDG_{fihvt} = \alpha + \beta_y \Delta \text{In}(y_{hvt}) + \beta_{FP} \Delta \text{In}(\text{FP}_{vt}) + \beta_{uind} \Delta \text{In}(\text{uind}_{vt}) + \beta_{DKI} \Delta \text{DKI}_{ihvt} + \alpha_X \Delta X_{ihvt} + \alpha_A A_{it-1} + \alpha_S S_{ht-1} + \alpha_R R_{vt-1} + \Delta \nu_{ihvt} \quad (3)$$

As the control variables in Eq. (3), we include the following variables measured at time $t-1$: a female dummy, age in years, ln (household size), proportions of age groups within a household (2–5 y, 6–11 y, 12–17 y, 18–24 y, 25–59 y, 60 y +), an indicator of primary or lower education, an urban dummy, and province dummies.

It is important to note that in our estimation results, a positive coefficient estimate may imply different impacts on the deviations across food groups depending on the initial average deviations (positive for meat/egg and negative for dairy/fruit). That is, a positive estimate indicates an increase in the deviation in meat and egg consumption, while a positive estimate indicates a decrease in the deviation in dairy, fruit, and vegetable consumption. A similar argument will be applied to a negative coefficient estimate. In addition, even if the effect of own price on its consumption is negative, the effect of own price on the deviations from the CDGs can be positive. For example, decreasing vegetable prices increases vegetable consumption (i.e., a negative own-price effect); the increasing consumption improves the situation of too-little vegetable consumption, and decreasing vegetable prices thus reduces the deviations from the CDGs in vegetable consumption (i.e., a positive relationship with the deviation).

We use three different samples because of data availability and research objectives. First, we present the results using a sample over the period 1991–2011 without fruit prices and dietary knowledge. Second, we employ a sample over the period 2004–2011 without fruit prices and dietary knowledge. Lastly, we focus on the people who need to improve their diets over the period 2004–2011 i.e., too much meat and egg consumption and too little dairy, fruit, and vegetable consumption.

5.2. Estimation results

5.2.1. Results for a sample over 1991–2011 without fruit prices and dietary knowledge

The main results are summarized in Table 6. We also estimate the model by gender (male/female) and residential areas (urban/

Table 6
Estimation results for the sample over 1991–2011.

		Dependent variable = deviations from the CDG interval in				
		Meat (g)	Egg (g)	Dairy (g)	Fruits (g)	Vegetable (g)
All	ln(pc hh income)	4.47***	2.58***	0.78**	2.35**	0.09
n = 21,686	ln(urbanization index)	37.20***	15.45***	2.09	0.01	− 23.68***
	ln(cereal price)	− 10.99***	− 5.62**	7.58***	− 0.91	− 21.64***
	ln(sugar price)	− 11.25***	10.24***	− 5.07***	24.55***	− 1.71
	ln(egg price)	− 3.34	− 10.38***	1.02	6.11	22.03***
	ln(green veg price)	1.08	1.66	− 0.25	− 6.27***	− 6.22***
	ln(cabbage price)	− 4.72***	1.10	− 1.27	− 2.49	− 5.20**
	ln(pork price)	− 15.37***	0.13	− 2.29	− 13.63***	− 5.40
	ln(chicken price)	3.29	1.31	1.12	13.11***	− 16.00***
	ln(milk price)	5.67***	− 1.41*	− 2.17***	1.01	10.10***
	ln(fish price)	− 3.22	2.32	0.47	− 7.61***	− 4.34**
	Other controls	Yes	Yes	Yes	Yes	Yes
	R-square	0.01	0.01	0.01	0.01	0.01

Note: All control variables in Eq. (3) are controlled in all models.
***, **, and * represent the 1%, the 5%, and the 10% significance level, respectively.

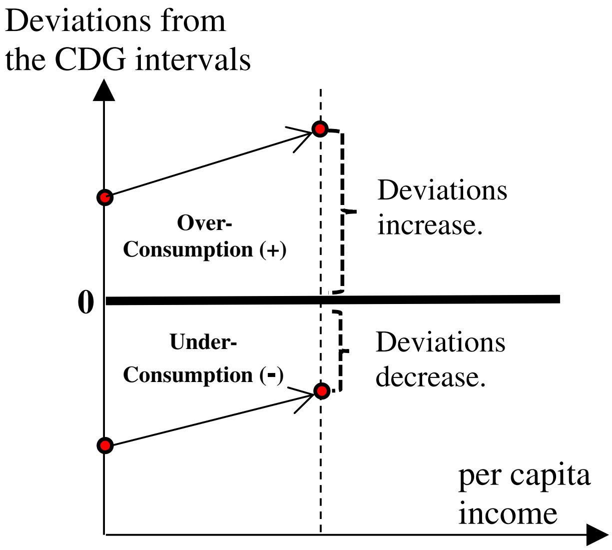

Fig. 1. Interpretation of a positive coefficient on per capita income.

rural), although the results are suppressed in this paper (available from the authors upon request). Overall, increasing per capita income had a positive effect on the consumption of meat, eggs, dairy, and fruits, while it had a statistically insignificant influence on vegetable consumption. Because average meat and egg consumption are too high (i.e., positive deviations) and dairy and fruit consumption are too low (i.e., negative deviations), increasing per capita income increased the deviations in meat and egg consumption, while it decreased the deviations in dairy and fruit consumptions (see Fig. 1). The magnitude of the effects tended to be larger in rural areas than in urban areas. Additionally, the effect was the largest for meat consumption among the food groups. For example, a ten-percent increase in per capita income increases the deviation in meat consumption by 0.45 g, and the effect is more significant in rural areas and among males compared to urban areas and females.

The effects of urbanization were similar to those of per capita income. On average, increasing urbanization increased the deviations in meat and egg consumption, while it decreased the deviations in dairy and fruit consumption, and the effect was the largest for meat consumption. A key difference from the effects of income is that increasing urbanization substantially increased the deviations in vegetable consumption. The effects were particularly large for the consumption of meat and vegetables. For example, a ten-percent increase in the urbanization index increases the deviation in meat and vegetable consumption by 3.72 g (5.3% of the mean level) and by 2.37 g (5.3% of the mean level), respectively. Another difference is that the effects tended to be larger in urban areas than in rural areas, while they were similar between gender groups.

While the effects of food prices were complex and had unclear patterns, we still observed three important patterns. First, cereal prices tended to be one of the most influential food prices for all food groups except for fruits, and the influences were larger among males than females and in rural areas than urban areas. In particular, decreasing cereal prices increased the deviations of meat and dairy consumption, while they decreased the deviations of vegetable and egg consumption. For example, a ten-percent decline in cereal price increases the deviations in meat consumption by 1.1 g (1.6% of the mean level) and decreases those in vegetable consumption by 2.2 g (7.7% of the mean level). Second, sugar prices were also influential for all food groups except for vegetables. The influence was particularly large for the deviations in fruit consumption; a ten-percent decline in sugar prices increased the deviations in fruit consumption by 2.5 g (1.6% of the mean level). Third, pork and chicken prices had substantial influences on the deviations in meat, fruit, and vegetable consumption. For example, a ten-percent decline in pork price increased the deviations in meat consumption by 1.54 g (2.2% of the mean level) and decreased those in fruit consumption by 1.36 g (0.9% of the mean level), and a ten-percent decline in chicken price increased the deviations in fruit consumption by 1.31 g (0.9% of the mean level) and decreased those in vegetable consumption by 1.60 g (5.6% of the mean level).

5.2.2. Results for a sample over 2004–2011 with fruit prices and dietary knowledge

Table 7 summarizes the main results for the sample over 2004–2011, which includes data for dietary knowledge and fruit prices. We find that improving dietary knowledge increased the deviations in meat and egg consumption. The tendency is particularly obvious in urban areas. For example, a one-standard deviation increase in DKI (SD = 0.59) increased the deviations in meat consumption by 7.2 g (= 12.02 ∗ 0.59) and those in egg consumption by 2.4 g (= 4.13 ∗ 0.59). For other food groups, dietary knowledge had a statistically or practically insignificant effect. These findings may imply a limited effect of improving knowledge in leading people to healthier diets.

Second, we find that the effects of per capita income on the deviations in meat, dairy, and fruit consumption became statistically insignificant, while the effects on egg consumption remained similar. In fact, once we applied the same models in Table 6 (without fruit prices and dietary knowledge) to the sample over the period 2004–2011, the results became similar to those in Table 7. Thus, the

Table 7
Estimation results for the sample over 2004–2011.

		Dependent variable = deviations from the CDG interval in				
		Meat (g)	Egg (g)	Dairy (g)	Fruits (g)	Vegetable (g)
All	DKI	12.02***	4.13**	− 2.40*	− 6.32	− 7.09
n = 8600	ln(pc hh income)	2.10	2.44***	0.78	− 0.27	− 1.90
	ln(urbanization index)	57.39***	17.55**	0.51	− 7.39	− 15.38
	ln(cereal price)	20.55	− 2.43	3.20	− 5.89	18.12
	ln(sugar price)	− 21.27***	13.21***	− 4.18	21.93***	6.29
	ln(egg price)	6.83	− 2.81	− 5.20*	13.09	23.86***
	ln(green veg price)	5.89	4.15**	0.71	− 20.67***	− 12.42***
	ln(cabbage price)	− 8.99***	0.45	− 2.46	− 14.26***	− 2.45
	ln(common fruit price)	12.02***	− 3.86	− 1.22	− 8.22*	− 8.03
	ln(pork price)	− 17.52	− 16.57***	− 12.69**	− 20.47	12.85
	ln(chicken price)	2.52	3.94*	0.45	20.04***	− 13.52***
	ln(milk price)	− 6.64*	− 7.63***	− 1.53	− 1.18	− 2.97
	ln(fish price)	− 9.96**	6.26***	− 1.23	− 7.97*	− 1.83
	Other controls	Yes	Yes	Yes	Yes	Yes
	R-square	0.02	0.01	0.00	0.02	0.01

Note: All control variables in Eq. (3) are controlled in all models.
***, **, and * represent the 1%, the 5%, and the 10% significance level, respectively.

difference between the results in Tables 6 and 7 may be attributable to the difference in the selected time period. Thus, the results imply that the effects of income on meat, dairy, and fruit consumption became smaller over time, while the effect on egg consumption was stable. In contrast, urbanization had larger influences on the deviations in meat and egg consumption than in Table 6 and a smaller influence on those in vegetable consumption. This may imply that the influence of urbanization on meat and egg consumption became larger over time, while its influence on vegetable consumption became smaller.

Lastly, we find three different patterns in the effects of food prices compared to the results in Table 6. First, fruit prices had a significant own-price effect on the deviations in fruit consumption, and the effect was larger in rural areas than urban areas, while it was similar between gender groups. For example, a ten-percent decrease in fruit prices decreased the deviation in fruit consumption by 0.8 g (1.5 g in rural areas). Second, fruit price also had a significant cross-price effect on the deviations in meat consumption, and the effect was larger in urban areas than rural areas, while it was similar between gender groups. For example, a ten-percent decrease in fruit prices decreased the deviations in meat consumption by 1.2 g (3.1 g in urban areas). Lastly, the influence of cereal prices became statistically insignificant for all food groups. This was probably because the proportion of cereals in people's diets has been decreasing (see Section 3.2). Note that because the results remained similar even without fruit prices and DKI as long as we use the sample over 2004–2011, the different results may be attributable to the difference in the selected time period.

Table 8
Estimation results for the people who need to improve their diets over 2004–2011.

		Dependent variable = deviations from the CDG interval in				
		Meat (g)	Egg (g)	Dairy (g)	Fruits (g)	Vegetable (g)
All	DKI	8.80	0.52	− 2.16*	1.38	− 7.26
	ln(pc hh income)	− 0.02	4.47***	0.67	1.67	− 1.38
	ln(urbanization index)	53.75***	24.70	− 1.07	− 26.38**	− 15.23
	ln(cereal price)	23.16*	− 6.90	2.70	− 24.29**	17.44
	ln(sugar price)	− 21.85***	11.77*	− 2.80	13.73*	3.82
	ln(egg price)	7.02	11.67	− 2.88	− 3.86	20.98**
	ln(green veg price)	7.28*	2.29	− 0.29	− 6.41*	− 11.97***
	ln(cabbage price)	− 10.59**	0.04	− 1.59	− 6.00**	0.12
	ln(common fruit price)	5.08	− 6.15	− 0.37	− 11.17***	− 12.38**
	ln(pork price)	− 24.30**	− 47.62***	− 11.17**	− 2.06	22.94**
	ln(chicken price)	4.17	12.26***	− 1.21	5.38	− 17.06***
	ln(milk price)	− 7.29	0.32	− 1.36	6.00	− 3.36
	ln(fish price)	− 13.93***	3.86	− 1.50	4.84	− 3.67
	Other controls	Yes	Yes	Yes	Yes	Yes
	R-square	0.03	0.03	0.01	0.08	0.02
	Observations	6182	3669	8247	6751	7223

Note: All control variables in Eq. (3) are controlled in all models.
***, **, and * represent the 1%, the 5%, and the 10% significance level, respectively.

5.2.3. Results for people who need to improve their diets over 2004–2011

Lastly, we focus on the people who particularly need to improve their diets, i.e., too much consumption of meat and eggs (positive deviations) and too little consumption of dairy, fruits, and vegetables (negative deviations). The main results are presented in Table 8. Overall, although the estimates were mostly similar to the results in Table 7, fewer estimates were statistically significant in Table 8. It is worth noting that the effect of fruit prices on the deviation in meat consumption became insignificant for all samples; the effect remained similar and statistically significant in urban areas.

At the same time, there are three key differences from Table 7. First, urbanization had a larger and significant effect on the deviation in fruit consumption. For example, a ten-percent increase in the urbanization index increased the deviation by 2.6 g. Second, cereal prices had a larger and significant influence on the deviations in fruit consumption. This pattern was particularly apparent in rural areas. For example, a ten-percent decrease in cereal prices decreased the deviations in fruit consumption by 2.4 g (2.9 g in rural areas). The result may imply that cereal prices can still be influential to promote healthier diets among the target people in rural areas but not in urban areas. Third, the effects of dietary knowledge on the deviations in meat consumption became smaller and insignificant in Table 8, particularly in urban areas. The results may imply that the counterintuitive effects of dietary knowledge in Table 7 may be driven by less problematic groups, such as those with too little meat consumption and too much fruit consumption. At the same time, the results still indicate the limited effects of improving dietary knowledge on actual diets.

6. Conclusions

This paper explored the potential influences of promoting the CDGs on environmental sustainability. We first illustrated problematic deviations in Chinese people's diets from the CDGs' recommended diet, i.e., the over-consumption of meat and eggs and the under-consumption of fruits, vegetables, and dairy products. Second, we evaluated how the dietary changes would influence GHG emissions, energy use, and blue water footprint if people's diets were changed to the CDGs' recommended diet. We found that the decrease in environmental burdens by reducing meat and egg consumption would be larger than the increase in environmental burdens by increasing fruit, vegetable, and dairy consumption, and the total effects of following the CDGs would thus improve environmental sustainability. Third, we found that the key socioeconomic factors increasing the deviations from the CDGs were increasing urbanization and increasing income, where urbanization had the largest influence. Our results also showed that reducing cereal and fruit prices would reduce meat consumption and increase fruit consumption. Contrary to our expectations, we found no beneficial effect of dietary knowledge or increasing meat prices on reducing the deviations from the CDGs.

In interpreting our results, two points are worth noting. First, to evaluate environmental impacts of dietary changes following the CDGs, we employ the indexes estimated for the U.S. food system. Because China's food system is much less efficient and induces more environmental costs compared to the U.S., our estimate probably underestimates the actual environmental impact for each food group. However, because both the reduction and the increase in environmental burdens are underestimated, it is not clear whether the total impact of following the CDGs is underestimated or not. Second, the problems of simultaneity and omitted variables for food consumption, income, and dietary knowledge remain important concerns for our findings, although we attempted our best given the available data. Despite the limitation, our findings can still be suggestive (rather than conclusive) for the Chinese government by clarifying the relationships between the CDGs and sustainable food consumption.

Our findings imply that reducing meat consumption is a particularly important target in the CDGs because of its dominant and beneficial influences on both health and the environment. Although meat prices tended to have insignificant own-price effect, we found significantly positive cross-price effects of cereal and fruit prices on meat consumption. Moreover, fruit prices had a significantly negative own-price effect, and cereal prices had a significantly negative cross-price effect on fruit consumption. Thus, reducing cereal and fruit prices may facilitate achievement of both the CDGs' targets and environmental sustainability by reducing meat consumption and increasing fruit consumption. At the same time, increasing agricultural production is inevitably followed by increasing environmental burdens (especially dairy products). Thus, when the CDGs recommend increasing dairy, fruit, and vegetable consumption, it may also be important to discuss how to manage increasing environmental burdens caused by following the recommendations. For example, more discussion may be needed on advancement in production technology, efficient management strategy, and relevant public supporting policy.

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