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Sustainable transformation pathways of Chinese food system for the environment, public health and inclusion

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DISCLAIMER

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Sustainable transformation pathways of Chinese food system for the environment, public health and inclusion

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Abbreviations

MAgPIE: Model of Agricultural Production and its Impact on the Environment

R&D: research and development

N: nitrogen

CNY: Chinese Yuan Renminbi

GHG: greenhouse gas

LULUC: land use and land-use change

NDCs: nationally determined contributions

SDG: sustainable development goal

CERN: Chinese Ecosystem Research Network

Sino BON: Chinese Biodiversity Observation Network

China BON: China Biodiversity Observation Network

SNUpE: soil nitrogen uptake efficiency

BII: the biodiversity intactness index

WDPA: World Database on Protected Areas

DID: difference-in-differences

CDG: Chinese dietary guidelines

YLL: year of life lost

AFOLU: agriculture, forestry, and other land use

Summary

There is a global consensus regarding the urgency for climate change mitigation and achieving a healthy, nature-positive, and inclusive food system. Following global sustainable development agenda, China is exploring effective policies and measures in various aspects. Prior studies have argued for the benefits of individual policies in terms of improving either health or the environment. However, an integrated analysis focusing on co-benefits and trade-offs among the environment, health, and economy is absent, and there is limited knowledge regarding the features of a sustainable transformation pathway of the Chinese food system in future. Using an agro-economic land system model—Model of Agricultural Production and its Impact on the Environment (MAgPIE), this country study incorporates China's policies into a sustainable food system transformation pathway and quantifies the impacts on the environmental, health, and economic outcomes.

Firstly, China's current situation and existing policies on nitrogen fertilizer use reduction, water resource conservation, greenhouse gas (GHG) emissions abatement, dietary pattern transition, biodiversity protection, and inclusive growth promotion to map the challenges and opportunities China faces in achieving sustainable development is summarized. Furthermore, two main scenarios including $BASE_{SSP2}$ and Chinese food system transformation pathway (FST_{SDP_China}); and three bundle scenarios named Diets, SustEnvironment, and InclusiveGrowth are introduced. Our results show that co-benefits among the environment, health, and inclusive growth can be achieved in the FST_{SDP_China} scenario. Incorporating China's fertilizer policies, FST_{SDP_China} achieves large reduction of fertilizer use, N surplus, and N pollution. Synergies between the environment and inclusion can be achieved with the necessary productivity growth and expanding agricultural research and development (R&D) investments in China. However, there are trade-offs between agricultural employment and the dietary transition towards a healthy and environment-positive food basket. The convergence to the Chinese Dietary Guidelines (CDG) contributes to achieving zero underweight and half obesity, but would lead to a large reduction of agricultural employment resulted from decreased demand for livestock. To address the dilemma faced even following the optimistic food system transformation pathway, the labor transfer issue deserves an in-depth investigation in the future.

1. Background

Despite facing resource constraints, China has made great progress in food security and poverty alleviation. However, the rapid but inefficient development of Chinese food system over the past decades has posed new challenges to the environment, public health, and economic development (Wang et al., 2022). With a concern for sustainability, the Chinese government has undertaken considerable efforts to build a healthy, nature-positive, and inclusive food system, and consequently released policies that cover various perspectives. An increasing number of studies have examined the effects of transforming the food system through individual policies and measures though, integrative analyses of the implementation of China's policies are still lacking. Therefore, this report first systematically reviews China's current status and related policies on nitrogen management, water usage, emission abatement, dietary transition, biodiversity, and inclusive growth, which can help understand China's practical experience and gaps, to lay a foundation for proposing potential food system transformation pathways that take into account China's national policies.

1.1. Toward nitrogen fertilizer use reduction

Nitrogen (N) management plays an essential role in the transition from traditional agricultural practices that feature high input and low efficiency to sustainable agricultural practices in China. China is the largest N fertilizer (referred to synthetic N fertilizer) consumer in the world. China's average N fertilizer intensity in 2015 was 226.0 kg/ha, 3.3 times higher than the global level (Figure 1). In contrast, the N use efficiency is half that of the global average, only reaching 0.25 in 2010 (Zhang et al., 2015). N fertilizer increases food production, however, has simultaneously damaged the environment severely over the past several decades, resulting in soil acidification, water pollution, and GHG emissions (Diaz and Rosenberg, 2008; Galloway et al., 2008; Guo et al., 2010), and adding pressure on the planetary boundary of nitrogen (Campbell et al., 2017; Gerten et al., 2020; Steffen et al., 2015).

With the rising concern regarding the overuse of N fertilizer, the Chinese government has undertaken great efforts to reform fertilizer policies, aiming to curb its use. To correct distortions in fertilizer prices, the fertilizer manufacturing subsidy was almost entirely removed by 2015. The Ministry of Agriculture and Rural Affairs issued the "Zero Growth in Synthetic Fertilizer Use" in 2015 to specify the manner in which fertilizer use could be reduced while enhancing its efficiency (Lin et al., 2022). Specifically, the government put in place four major measures: (1) formulating fertilization standards for different regions; (2) adjusting the structure of N, P, and K fertilizers and applying high-efficiency fertilizers; (3) improving fertilization methods; and (4) substituting synthetic fertilizer with organic manure (Wang et al., 2022).

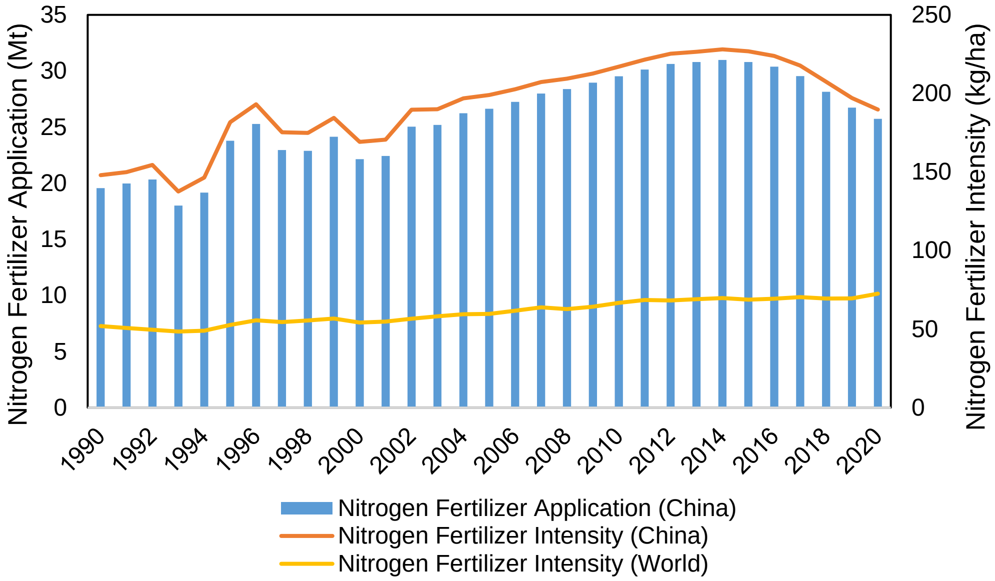

Figure 1. Nitrogen fertilizer application (China) and nitrogen fertilizer intensity (China and world) from 1990 to 2020. Data source: FAOSTAT.

1.2. Toward water saving

China has been facing increasingly severe water scarcity, feeding 22% of the world's population with only 6% of the global freshwater resources. One-third of the provinces face water scarcity, with their per capita water resources falling below the internationally recognized threshold of severe water scarcity (Liu et al., 2022). This water shortage is expected to persist through the following decades, accompanied by the uncertainty of climate change, water pollution, and growing food demand (Piao et al., 2010; Zhao et al., 2021).

To alleviate water scarcity, the 12th Five-Year Plan and No.1 Central Document in 2011 placed "water" at the top of the government's agenda (China Water Risk, 2013). In January 2012, the Chinese government issued a stringent water resource management system and initiated the three water red lines in terms of water caps, water use efficiency in industries and agriculture, and water quality for 2015, 2020, and 2030, respectively. Then each province set out provincial targets of three water red lines based on their water consumption. It was reported that the national and provincial three water red lines were all satisfied by 2015 and 2020 (Ministry of Water Resources, 2016; Ministry of Water Resources, 2021). Water saving is also regarded as the top priority in China's 14th Five-Year Plan (2021–2025). In October 2021, "The 14th Five-Year Water-Saving Society Construction Plan" was released, with the aim of promoting the further transformation of the intensive use of water resources in production and consumption.

The national targets of the three water red lines in the period 2015–2035 are as follows: (1) The country-wise water cap should be controlled within 635 billion cubic meters by 2015, 670 billion cubic meters by 2020, and 700 billion cubic meters by 2035. (2) The water consumption per 10,000 Chinese Yuan Renminbi (CNY) of industrial added value in 2020 should be reduced by 23% compared to 2015 and should be reduced by 16% by 2025 compared to 2020. The overall irrigation efficiency (defined as the ratio of the effective utilization of water, excluding deep seepage and field loss, to the total water intake of irrigation ditch) in China was expected to improve by more than 0.53, 0.55, 0.58, and 0.60 by 2015, 2020, 2025, and 2030, respectively. (3) The water quality compliance rate of the water function zones needs to be increased to 60%, 80%, and more than 95% by 2015, 2020, and 2030, respectively. The detailed targets and achieved values of the three water red lines are listed in Table 1.

Table 1. Targets and achieved values of China's three water red lines from 2015 to 2035.

Water red lines / Year	Water consumption (billion m^3)		Irrigation efficiency		Water consumption per 10,000 CNY of industrial added value		Water function zone compliance rate	
	Targets	Achieved	Targets	Achieved	Targets	Achieved	Targets	Achieved
2015	635	610.32	0.53	0.536	-30%	-36.7%	60%	70.8%
2020	670	581.29	0.55	0.565	-23%	-28%	80%	88.9%
2025	640		0.58		-16%		-	
2030	-		0.60		-		95%	
2035	700		-		-		-	

Notes: The targets of "Water consumption per 10,000 CNY of industrial added value" are compared with those at the end of the previous five-year plan.

1.3. Toward GHG emissions abatement

Food system plays a crucial role in the efforts toward emission reduction in China, accounting for approximately 20% of the national total GHG emissions in 2018 (Crippa et al., 2021) (Figure 2). Although land use and land-use change (LULUC) absorbed 1151 Mt of CO_2 in 2014, offsetting about 9% of the total GHG emissions that year and exceeding the value of emissions from agriculture (830 Mt CO_2eq) (The People's Republic of China Second Biennial Update Report on Climate Change, 2018), carbon neutrality within the Chinese food system remains unrealized. Simultaneously, the agricultural sector contributes to approximately 40% and 60% of the overall CH_4 and N_2O emissions, respectively, primarily caused by the overuse of agricultural chemicals, the excessive utilization of farmland resources, and the improper disposal of agricultural wastes (Koul et al., 2022; van Wesenbeeck et al., 2021).

In the past decade, China has paid considerable attention toward low-carbon and green agricultural practices. “The National Agricultural Sustainable Development Plan (2015–2030)”, released in 2015, is a milestone for low-carbon agriculture, as it is the first integrated policy document to establish an overarching framework that includes a wide variety of key policy areas and specific issues. In 2017, the State Council issued the “Opinions on Promoting Agricultural Green Development and Innovation Systems and Mechanisms”, which officially initiates green agriculture into the process of agricultural modernization (Zhang et al., 2022). In 2021, the green development of agriculture was comprehensively promoted with the release of “The 14th Five-Year National Agricultural Green Development Plan”. China’s updated nationally determined contributions (NDCs) announced in 2020, have pledged to achieve carbon peak and neutrality by 2030 and 2060, respectively. To achieve the targets, specific policies/measures regarding emission reduction and carbon sequestration were implemented from the perspectives of agricultural chemical usage, land conversion, agricultural waste disposal, livestock management, and energy saving. In 2022, combining these detailed policies and measures, the first systematic policy document regarding carbon neutrality in agriculture and rural areas, “Implementation Plan for Emission Reduction and Carbon Sequestration in Agriculture and Rural Areas” was jointly issued by the Ministry of Agriculture and Rural Affairs and the National Development and Reform Commission of China.

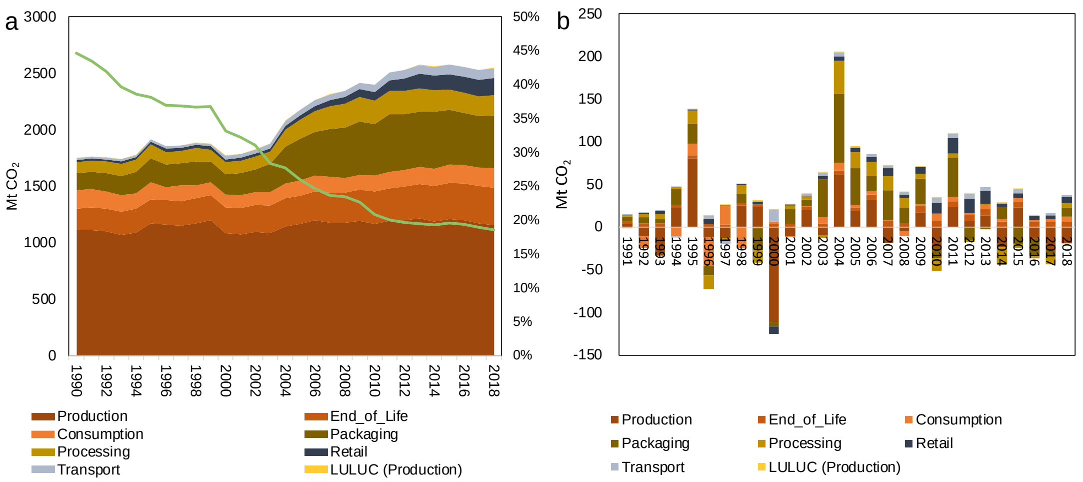

Figure 2. GHG emissions from different sources and corresponding changes in the Chinese food system between 1990 and 2018. a. GHG emissions from different sources in the Chinese food system between 1990 and 2018. Green line represents food system emission share, defined as the ratio of emissions from food system to the total GHG emissions in China. **b.** Absolute changes in GHG emissions from different sources in the Chinese food system between 1990 and 2018. The LULUC (production) refers to land use and land-use changes related to crop and livestock production activities, hence carbon removals in the remaining forest are excluded. Data source: EDGAR-Food database.

1.4. Toward dietary pattern transition and food waste reduction

China's food consumption patterns have undergone remarkable changes in recent decades (Wang et al., 2022). With increased economic growth, the diets of Chinese residents have become more diverse, however also highly energy-dense, indicated by a decrease in the consumption of staple foods and a substantial increase in the consumption of meat, eggs, milk, and edible oils (He et al., 2018a; Zhao et al., 2018) (Figure 3a). Excessive food waste has also become an issue that cannot be neglected in China, together with the increasing popularity of dining out and takeaways. According to Xue et al. (2021), approximately 349 Mt of annually produced food for human consumption is lost or wasted, 17% of which is attributed to the consumption stage, especially out-of-home plate waste. Despite achieving a reduction of malnutrition from 24% in the 1990s to 2.5% in 2019 (FAO, 2022), suboptimal diets have become a leading risk factor for mortality in China (Afshin et al., 2019). Micronutrient deficiency remains an issue in rural areas (Gao et al., 2020), whereas overnutrition is an emerging concern (Figure 3b), featured with increased risk of obesity, and related chronic diseases in the population (Pan et al., 2021). The increased intake of animal-based foods, together with severe food waste, further exacerbates the pressure on the environment and intensifies the competition for scarce resources (Liu et al., 2013; Song et al., 2015), contributing to increased GHG emissions (Xiong et al., 2020; Tilman and Clark, 2014), and demand for land and water (He et al., 2019; Weindl et al., 2017). In addition, production and employment throughout the food supply chain are closely linked to changes in food demand, affecting the economic structure and social stability (Allan et al., 2019).

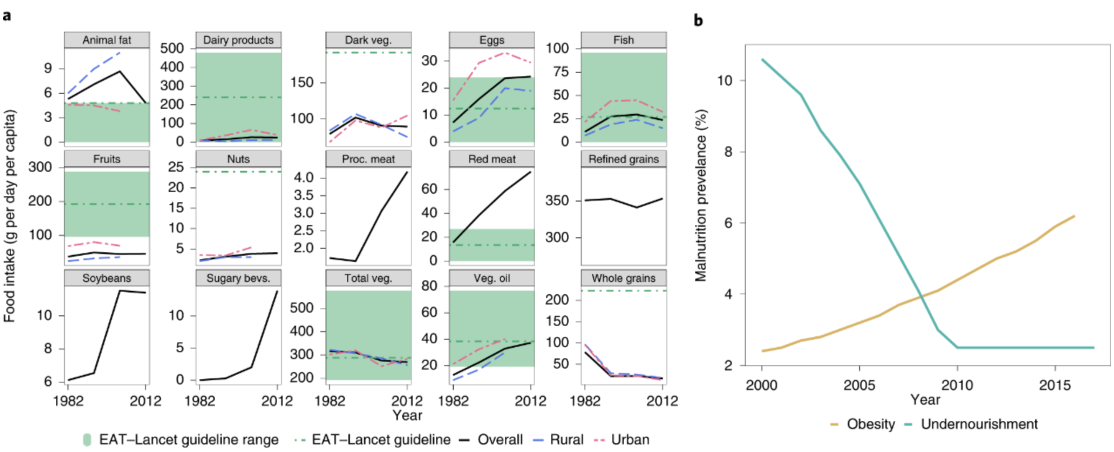

Figure 3. Food intake and malnutrition prevalence in China. Adopted from Wang et al. (2022a). **a.** Intake of different food groups among Chinese residents. 'Dairy products' indicates total dairy products; 'Red meat' includes ruminant meat and pork; 'Fish' includes fish, shellfish and other seafood; 'Sugary bevs.' indicates sugar-sweetened beverages; 'Dark veg.' indicates dark-colored vegetables, including dark-green, red and orange vegetables; and 'Veg. oil' indicates vegetable oils for cooking. The intake of refined and whole grains, red and processed meat, and sugar beverages was scaled to total energy of 2400 kcal. No related data are available for the intake of processed meat, red meat, refined grains, soybeans and sugar-sweetened beverages in urban and rural areas. **b.** Shares of undernourishment and obesity in

China’s total population (age ≥ 18 years old). The share of undernourishment is reported as < 2.5% after 2009-2011 based on FAOSTAT.

Owing to growing public health and environmental concerns, a number of studies have focused on the environmental and health impacts of the dietary transition among Chinese residents (He et al., 2018b; Yin et al., 2020). Based on pieces of evidence provided by such studies, the Chinese government became aware of the necessity to transform current food consumption patterns and started to incorporate environmental criteria into dietary guidelines. In June 2019, following “Healthy China Action (2019–2030)”, the Chinese Nutrition Society updated the “Chinese Dietary Guidelines” (first edition released in 1989), based on the latest scientific research and national context to provide specific dietary suggestions. The “Oriental Healthy Dietary Pattern” was proposed for the first time in the latest version released in April 2022 (Chinese Society of Nutrition, 2022), and residents were encouraged to consume more dairy products, whole grains, aquatic products, and eggs, while consuming less salt, in accordance with the EAT-Lancet dietary pattern (Willett et al., 2019). However, the inclusion perspective is rarely mentioned in the existing literature and policy documents (Wang et al., 2022). Further comprehensive understanding of the impact of dietary patterns on the environment, health, and inclusion is necessary for future research.

Reducing food waste is also an essential target for the global sustainable development goals (SDGs). As the world’s largest emerging economy, China has a high priority about food security and has been promoting the social consensus on reducing food waste. In recent years, research on the extent and causes of China’s food waste is proliferating, and the government has issued a series of waste reduction targeted policies and measures. Following the Global Sustainable Development Agenda, China announced its national plan in 2016, which stated that China would substantially reduce per capita food waste according to SDG12.3. A new round of the "Clear Your Plate" campaign, first proposed online in 2013, was initiated all over the country. Encouraged by this campaign, more restaurants began to offer half-portioned, smaller, and assorted dishes to reduce waste, and an increasing number of customers took home leftovers. Amid the global food security crisis during the COVID-19 pandemic and the Russia–Ukraine conflict, China has increased efforts to regulate food waste behaviors. On April 29, 2021, the Anti-Food Waste Law of The People's Republic of China was implemented, marking the nation’s first attempt to regulate food waste through law. However, China is yet to set a clear waste reduction target, and research on the potential benefits of reducing food waste for health, economic, and environmental sustainability is limited. It would be important to explore the extent to which a reduction in food waste can contribute toward sustainability based on different food waste scenarios, which can provide insights on targets and effective policy design.

1.5. Toward biodiversity protection

China is one of the most biodiverse countries in the world and owns nearly one-tenth of global species (Li et al., 2021; Xu et al., 2017). However, the rapid population growth and its profound changes to ecosystems, including land use change, spread of invasive species, pollution, and the overutilization of natural resources, have posed severe threats to biodiversity, about which the Chinese government is highly concerned. Through long-term explorations and practices, China has made progress in biodiversity protection framework, including biodiversity surveys and monitoring, *in-situ* and *ex-situ* conservation, ecological restoration, and public education (Wang et al., 2020). To establish comprehensive distribution species databases, a series of nationwide surveys have been carried out since the 1950s. Long-term biodiversity monitoring networks, such as Chinese Ecosystem Research Network (CERN), Chinese Biodiversity Observation Network (Sino BON), and China Biodiversity Observation Network (China BON), have been developed to help investigate the changes in biodiversity. In 2010, "China National Biodiversity Conservation Strategy and Action Plan (2011–2030)" was released, clarifying the specific measures for biodiversity protection for the next two decades. The strategy of ecological conservation red lines, initiated in 2014, has innovatively expanded the scope of protected areas to include key ecological functional areas and ecologically vulnerable areas, incorporating more than 25% of China's land area to be protected. Starting in 2015, China has launched 10 pilot national parks, which covers nearly 30% of the key terrestrial wildlife species found in China. In addition, 250 wildlife rescue centers and 200 botanical gardens have been established, where more than 60 types of endangered wildlife and 23 thousand species of plants are protected. In 2016, the 13th Five-Year Plan (2016–2020) emphasized the importance of strengthening ecological protection and restoration. "Options on Further Strengthening Biodiversity Protection" jointly issued by General Office of the Central Committee and General Office of the State Council in 2021 proposed the national targets of ensuring biodiversity, which are as follows: (1) Forest coverage should increase to 24.1% by 2025 and 26% by 2035. (2) Grassland coverage is expected to reach beyond 57% by 2025 and 60% by 2035. (3) Wetland protection rate should increase to 55% by 2025 and 60% by 2035. (4) Protection rate of national key wildlife species should reach 77% by 2025 and all national key wildlife and endangered species should be well protected by 2035.

1.6. Toward inclusive growth

Inclusive growth of China's agricultural and food systems is intimately tied to the social goals of equity and diversity (i.e., inclusion of different races, religions, genders, and disabilities) (International Food Policy Research Institute (IFPRI), 2020). It's also an important way for underprivileged groups to access public services and development opportunities (International Food Policy Research Institute (IFPRI), 2020). In order to achieve inclusive growth, China has made enormous efforts to promote the off-farm transfer of agricultural labor and increase investment in agricultural R&D.

The proportion of nonagricultural employment increased from 8% in 1978 to 39% in 2020 (Figure 4), and is projected to achieve a continually growth during the Chinese food system transformation. Transferring excessive agricultural labor and efficiently is not only related to the growth of rural household income (Ge et al., 2020), but also an important measure for narrowing the urban-rural income gap (Li, 1999). A series of policies were introduced in 2018, which can be categorized into two aspects: (1) broadening employment channels of the labor force, and (2) improving the labor quality. These measures could partly solve the problem of agricultural employment reduction during food system transformation, thereby contributing to inclusive growth (Babatunde and Qaim, 2010; Haggblade et al., 2010).

Investment in agricultural R&D is considered an effective measure for improving agricultural productivity (Alene and Coulibaly, 2009; Alston et al., 2009; Evenson and Gollin, 2003), which is of great importance for food and environmental security. From 2018 to 2022, ensuring food and environmental security has been a policy direction for China's agricultural R&D investment. China's agricultural R&D investment has increased by 40% from 5 billion USD in 2012 to 7 billion USD in 2020. An increase in agricultural R&D would inevitably impact the transformation of the Chinese food system and may exert further influence on the environment and inclusive growth.

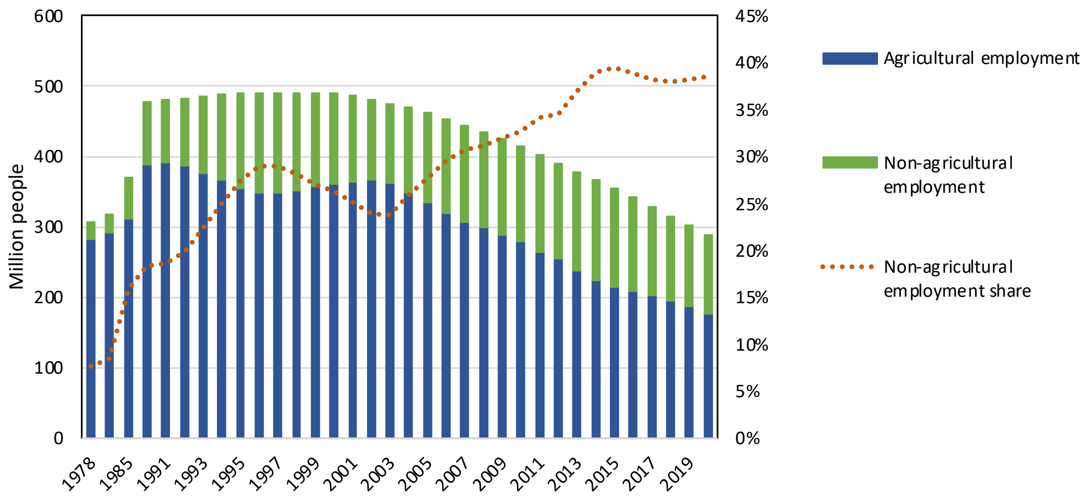

Figure 4. Employment of rural labor force in China from 1978 to 2020. Data source: China Rural Statistical Yearbook.

1.7. More efforts are needed for China towards a sustainable future

Despite all the discussed policies and measures, most of them are single-targeted without a systematic consideration of the resulting externalities, and therefore, effective measures to achieve changes considering large-scale group behaviors are lacking (Wang et al., 2022). A growing number of studies have examined the positive effects of individual policies on health or environmental outcomes (He et al., 2019; Liu et al., 2022); however, they rarely investigate the potential synergies and trade-offs among different policy baskets and the effects on the inclusive aspect. Can the combination of these policies achieve sustainable development, and how far is it? Are there synergies or trade-offs among different policies? What type of policy packages most closely delineate the pathway to sustainable food system development? These questions require more reliable and integrative academic evidence that combine different policies, aspects of health, environmental concerns, and inclusion. Furthermore, this is also critical for evaluating the effectiveness of current policies in China, understanding gaps and future directions, and designing systematic multi-objective policies.

2. Scenario Design

Enhanced comprehension of the co-benefits and trade-offs among the SDG indicators is achieved through the development of a comprehensive transformation scenario. The scenario spans the dimensions of health, inclusion, and the environment and is informed by the policy context of the Chinese food system in terms of socioeconomic drivers, diet, nitrogen, water, land, GHG emissions, biodiversity, etc. The detailed scenario specifications in China are listed in Table 2. In this study, the focus is primarily on the parameter settings of China. The settings in each dimension for the rest of the world are aligned with the FSEC global study. Additionally, the model assumptions and essential variables are validated to enforce the projection of current status in China (Figure A1-A5).

2.1. $BASE_{SSP2}$

The $BASE_{SSP2}$ scenario from the FSEC global study is used as the baseline. The rest of world shares a consistent pathway with China, except for some region-specific settings. The analysis focuses on on parameters that link to food system practices, including socioeconomic drivers, food demand, nitrogen, land, water, emissions, and biodiversity for China and tend to reflect the actual Chinese picture. The $BASE_{SSP2}$ scenario follows the middle-of-the-road shared socioeconomic pathway (SSP2) to project population development, GDP, and physical activity levels for China. Food demand and waste are endogenously generated, taking into account socioeconomic drivers and demographics derived from historical data to align with China’s food demand (FAO, 2016).

In terms of nitrogen management, soil N uptake efficiency (SNUpE, defined as the ratio of N outputs to N inputs) in China would increase from 0.41 in 2010 to 0.55 in 2050 is assumed. The fertilizer price is set at 930 USD/ton N. There is no additional land conservation plan or global afforestation target under the $BASE_{SSP2}$ scenario on land management besides the default protection from World Database on Protected Areas (WDPA) in China. For water management, non-agricultural water demand also follows the SSP2 projection. The $BASE_{SSP2}$ scenario does not consider emission pricing as China's current carbon emissions trading mechanism is premature. In $BASE_{SSP2}$ scenario, for each of the 71 biomes, the lower bound of the biodiversity intactness index (BII) is set to be 0.75 in the target year.

2.2. Food System Transformation in the context of a Sustainable Development Pathway in China (FST_{SDP_China})

The FST_{SDP_China} scenario is modified based on global measures for a comprehensive sustainable food system transformation (FST_{SDP}) to reflect China's specific efforts toward healthy diets, N management, and water management. For diets and food demand, a convergent transition is implemented from 2020 to 2050, aligning exogenous intake targets specified by the CDG. The effect of China's fertilizer policy reform into SNUpE using the N balance equation based on a difference-in-difference (DID) econometric method to explore the feasibility of "Zero Growth in Synthetic Fertilizer Use" in China is incorporated. SNUpE improves to 0.53 in 2020, and is projected to increase to 0.6 by 2050 at a constant rate. Meanwhile, due to the policy on the removal of fertilizer manufacturing subsidy, the fertilizer price is set at 930 USD/ton N. The rest of the world still follows the FST_{SDP}. The detailed SNUpE settings in China from 1995–2050 for the $BASE_{SSP2}$ and FST_{SDP_China} scenarios are shown in Figure A6.

2.3. Three bundle scenarios (Diets, Sustainable environment, Inclusive growth)

Three separate bundle scenarios, Diets, SustEnvironment, and InclusiveGrowth are introduced to represent single transformation schemes with respected to targeted measure areas with respect to the food system. The Diets scenario bundle aims to improve the health of the population through a sustainable dietary shift, incorporating a dietarystructure aligned with CDG and EAT-Lancet recommendations, while also targeting a reduction in food waste to 20% by the year 2050. The environmental protection focused scenario, SustEnvironment, encompasses measures such as pollutant pricing, land conservation, crop rotation, water conservation, no net loss of biodiversity, agricultural sector mitigation, nitrogen efficiency enhancement, and landscape protection. The third scenario bundle, InclusiveGrowth, refers to a food system considering the implementations by national institutions and governance measures, such as sustainable socio-economic pathways, promoting liberalized trade, facilitating energy transformation, and increased wood use for construction materials. These three scenarios focus on individual domains in the environment, health, or the economy and do not impose additional impacts on other parameters such that they are suitable for investigating synergies and trade-offs among relevant indicators.

Table 2. Key aspects in the scenario specifications.

Dimension	Parameter	Interventions
Drivers	Population, Economy, Physical activity level	SSP1
Diet	Food demand	Exogenous dietary targets aligned with the CDG; No underweight and half-overweight for the prevalence of malnutrition
	Food waste share	Transition towards exogenous food waste target
Nitrogen	SNUpE	0.41 in 2010, 0.53 in 2020, 0.60 in 2050, 0.72 in 2100
	Fertilizer price	930 USD/ton N
Land	Land conservation	Land conservation; Emission prices for emissions from peatlands; crop rotations; landscape protection;
	Afforestation	Maximum 500 Mha afforestation globally; NDC target of 137.47 Mha for China; carbon price on C in aboveground vegetation in non-agricultural land
Water	Non-agricultural water demand	SSP1; minimum environmental water flow requirements
Emission	Pricing policy	All pollutant types from all sources
Biodiversity	Biodiversity intactness index	0.75
Agriculture production	Agro-mitigation	Technical measures are adopted for mitigation; intensified livestock system; improved animal waste management; carbon price on soil carbon
Trade liberalization	Trade barrier reduction	10% in 2030, 20% in 2050 for livestock and secondary products; 20% for crops in 2030, 30% in 2050.
Minimum wage	Agricultural wages	A global minimum wage increases wages in the lower income countries.
Capital substitution	Capital costs	In countries with high capital intensity, capital is substituted by labor.
Bioplastics and timber cities	Biomass demand	Increase biomass demand for bioplastic production. Increasing wood used as construction material for cities.
Energy transition	Energy transition	Transformation in energy, transport, and urbanization.

Notes: The detailed settings of bundle scenarios are provided in the supplementary material of the global study.

3. Results

3.1. Co-benefits among the environment, health, and inclusive growth are achieved in the FST_{SDP_China} scenario

To explore a sustainable transformation pathway for China, the results between the $BASE_{SSP2}$ and FST_{SDP_China} scenarios are compared to discussthe co-benefits and trade-offs among the environment, health, and inclusion indicators (Figure 5). Compared to the $BASE_{SSP2}$ scenario, performances of the FST_{SDP_China} scenario is considerably better with respect to all indicators, except agricultural employment. The three policy bundles are further investigated, Diets, SustEnvironment, and InclusiveGrowth, to disentangle their individual effects. The model results indicate that they possess their own advantages and disadvantages for specific indicators compared with $BASE_{SSP2}$.

3.1.1. Public health

Double burden of malnutrition (Gao et al., 2020; Popkin et al., 2020) is inextricably linked to suboptimal diets, which should be responsible for the increasing burden of health (Afshin et al., 2019). The prevalence of underweight and obesity is selected, which is closely related to the prevalence of chronic diseases (Figure A7), aiming to reveal the health outcomes under different scenarios. In the $BASE_{SSP2}$ scenario, the double burden of malnutrition remains a major issue, affecting millions of people in China. The underweight population approximately decreases by half from 43 million in 2020 to 25 million in 2050, whereas the obese population increases from 133 million to 202 million between 2020 and 2050, primarily due to unhealthy diets. In contrast, underweight can be eliminated and obesity can be almost halved in 2050 in Diets and FST_{SDP_China} scenarios by adopting healthier diet, which reduces the consumption of animal-sourced foods and encourages the consumption of nutritious and healthy vegetables, fruits, and plant-based proteins. However, when only incorporating the socioeconomic pathway changes into the baseline, the underweight population in 2050 barely decreases (25.28 to 25.20 million) under the InclusiveGrowth scenario, whereas the obese population increases in 2050 (202 to 227 million). Due to improved diets, the projected premature mortality will decrease to 13 million in Diets. Combined with the socioeconomic transition, FST_{SDP_China} witnesses a total reduction of 29 million years of life lost (YLLs) relative to $BASE_{SSP2}$.

3.1.2. The environment

Five environmental indicators are focused upon in this study: BII, Shannon crop area diversity index, nitrogen surplus, water environmental flow violations, and the GHG emissions in the agriculture, forestry, and other land use (AFOLU) sector. Specifically, the Shannon crop area diversity index reflects the diversity of crops cultivated, and water environmental flow violations measure the severity of regional water scarcity. In the $BASE_{SSP2}$ scenario, there are small variations in these indicators from 2020 to 2050, whereas in the combined scenario, that is, FST_{SDP_China}, these indicators show an overall improvement.

In the $BASE_{SSP2}$ scenario, BII increases slightly from 73.9 in 2020 to 74.3 in 2050. Following the growth and expansion of natural vegetation with high biodiversity intensity, in the FST_{SDP_China} scenario, BII increases to 75.5 by 2050 with decreases in agricultural land area (518.59 Mha in 2020 to 442.97 Mha in 2050) and wetlands (165.75 Mha in 2020 to 100.43 Mha in 2050) and an expansion of forest (230.77 Mha in 2020 to 369.83 Mha in 2050), which partly contributed by stringent fertilizer prices and improved SNUpE. Surprisingly, despite focusing on environmental protection, the SustEnvironment scenario shows less progress in biodiversity than the FST_{SDP_China} scenario, reflecting the necessity for combining policies to achieve synergies.

Compared with $BASE_{SSP2}$, the Shannon crop area diversity index decreases in the SustEnvironment scenario. As an unintentional outcome, the stricter biodiversity and land protection policies and penalty rules for excessive crop rotation under these three scenarios hinder crop diversification. Rotation and fallow constraints are incentivized to keep a reasonable crop diversity via premier. Additionally, the FST_{SDP_China} scenario with higher SNUpE significantly reduce the nitrogen surplus, which is further explained in detail in section 3.3.

Violation of water environmental flow remains a struggle for China under the $BASE_{SSP2}$ scenario, increasing from 16 km^3 to 23 km^3 from 2020 to 2050. However, the excessive water demand drops to 0 by 2050 in the SustEnvironment and FST_{SDP_China} scenarios, owing to increasingly stringent water conservation policies and the shift in food demand, substantially improving China's water environmental flow.

In the $BASE_{SSP2}$ scenario, the GHG emissions in the AFOLU sector decrease from 1.6 Gt CO_2eq in 2020 to 0.7 Gt CO_2eq in 2050, which can be attributed to the shrinkage of agricultural land and targeted afforestation in the NDC. In the FST_{SDP_China}, the GHG emissions in 2050 decrease to -0.6 Gt CO_2eq, owing to the further efforts on GHG mitigation in the AFOLU sector.

3.1.3. Inclusion

The indicators food expenditure, the number of people in the low-income group (i.e., below 3.2 USD_{11PPP}/capita/day), agricultural employment, agricultural wages, bioeconomy supply, and production costs are selected to represent inclusion. In the $BASE_{SSP2}$ scenario, the food expenditure per capita in China is 702 USD per year in 2020 and grows slightly to 757 USD per year by 2050. Due to the adoption of the CDG diet, the FST_{SDP_China} scenarios reduce the per capita food intake, especially with regard to livestock consumption, contributing to a large reduction (459 USD per year) in food expenditure. The agricultural wage index highly depends on Chinese GDP projections under different SSPs. In the $BASE_{SSP2}$ scenario, this index in 2050 is 2.86 times higher than that in 2020. In FST_{SDP_China}, it is 3.90 times higher in 2050 than the baseline scenario in 2020. Additionally, owing to the reduction in agricultural production, agricultural costs are substantially reduced by 127 billion USD under the FST_{SDP_China} scenarios, compared with the $BASE_{SSP2}$.

Furthermore, a substantial reduction in agricultural employment is identified. In the $BASE_{SSP2}$ scenario, agricultural employment will reduce by 93 million in 2050, relative to that in 2020, and a further reduction (15 million) can be achieved in 2050 under the FST_{SDP_China} scenario. This may be driven by three reasons: (1) The labor force from production side reduces dramatically accompanied with decreased demand of livestock products. (2) The labor productivity in the crop sector in 2050 shows a higher increase degree in the FST_{SDP_China} scenario than that in 2020, compared with the increase in the $BASE_{SSP2}$ scenario (Figure 10). (3) The share of capital cost of input factor cost in 2050 is 35% higher than that in 2020 under the FST_{SDP_China} scenario, reflecting a high level of mechanization in agricultural production. Based on increased labor productivity and high agricultural mechanization level in the FST_{SDP_China} scenario, high-quality employment of the agricultural labor force can be achieved.

Figure 5. Health, environment, and inclusion indicators of China across the $BASE_{SSP2}$, FST_{SDP_China}, and three bundle scenarios. The grey cells indicate that no extra policy measures are included for the corresponding variables in this scenario.

3.2. Trade-offs and synergies between health, the environment, and inclusion

The trade-offs and synergies between indicators in three dimensions (i.e., health, the environment, and inclusion) are further explored. The trade-offs imply a contradiction between policy measures focusing on different perspectives, whereas the synergies imply the potential for achieving co-benefits between dimensions.

Among the three bundled scenarios of measures, the scenario targeting dietary change demonstrates the highest level of synergies. Progressing towards diets that closely adhere to the CDG synergistically improves nutritional and health outcomes (Figure 6a), contributes to povertyreduction (Figure 6c) and yields positive effects on the environmental dimension (Figure 6b, 6d). The shift to diets with increased consumption of plant-sourced food leads to GHG mitigation in the AFOLU sector (Figure 6d).

However, trade-offs exist between agricultural employment and the dietary transition toward a healthy and environment-positive food basket. Due to the implementation of the CDG diet, China can achieve a large reduction in premature mortality by 2050 in the Diets scenario, however with a sharp drop in agricultural employment (Figure 6g). This can be associated with the decreased livestock demand caused by lower agricultural product consumption. Due to the decreased production and higher mechanization level, more agricultural labor transfers to other sectors. Despite the declining trend of agricultural labor in $BASE_{SSP2}$ in the historical period, the extra shrinkage due to dietary transition ought to be thoroughly studied.

Synergies between the environment and inclusion can be achieved with the modest productivity growth in China. With increasing agricultural productivity, BII improves from 74.3 to 74.9 under the SustEnvironment scenario compared to $BASE_{SSP2}$ while does not require an increase in labor employed in the agricultural sector (Figure 6h). Agricultural employment increases from 47 to 57 million.

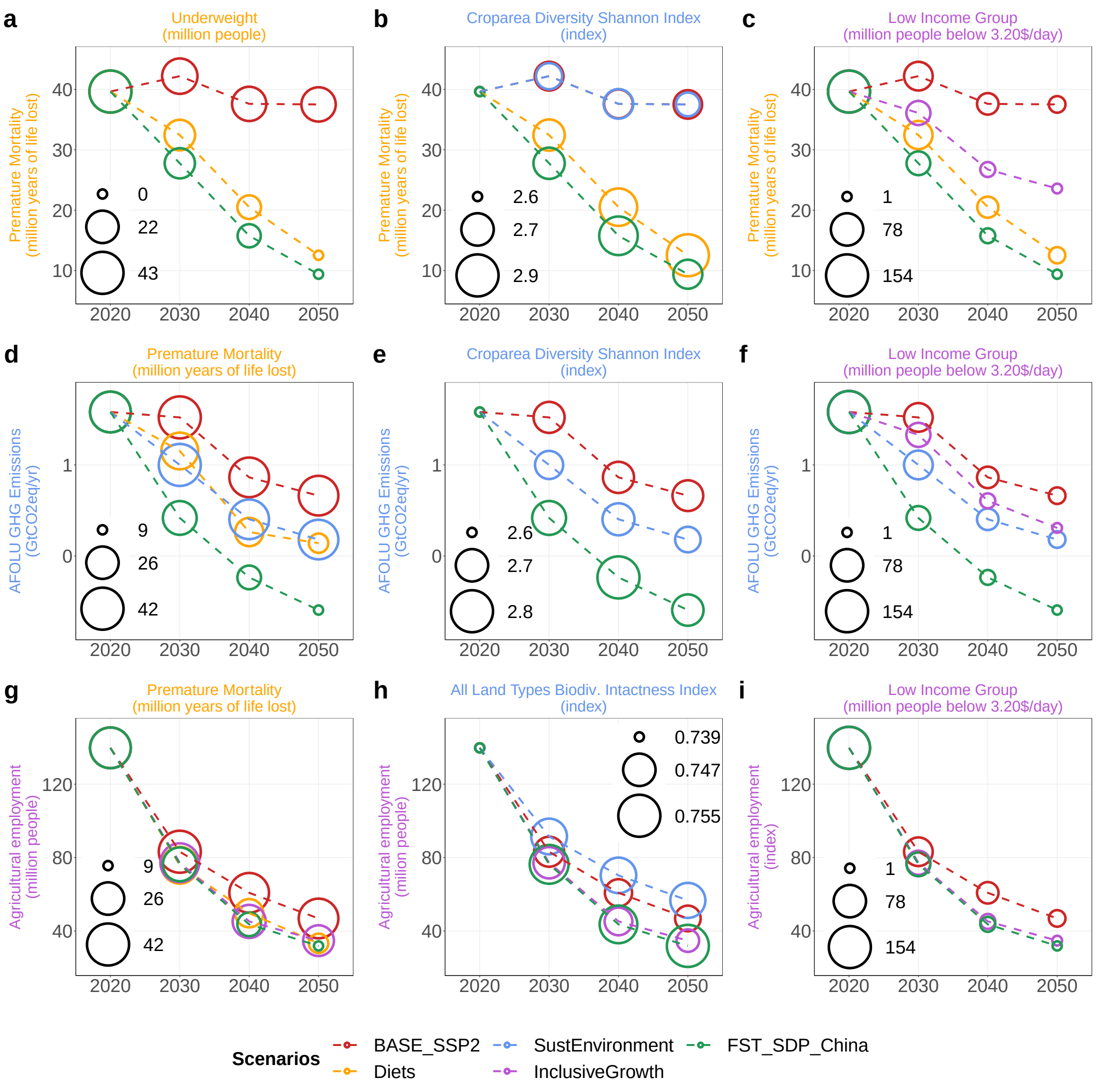

Figure 6. Interactions between indicators related to health, environment, and inclusion in Chinese food system. **a**. Interaction of prevalence of underweight and premature mortality under $\text{BASE}_{\text{SSP2}}$, Diets, and $\text{FST}_{\text{SDP\_China}}$. **B**. Interaction of premature mortality and croparea diversity under $\text{BASE}_{\text{SSP2}}$, Diets, SustEnvironment, and $\text{FST}_{\text{SDP\_China}}$. **c**. Interaction of premature mortality and low-income population under $\text{BASE}_{\text{SSP2}}$, Diets, InclusiveGrowth, and $\text{FST}_{\text{SDP\_China}}$. **d**. Interaction of AFOLU GHG emissions and premature mortality under $\text{BASE}_{\text{SSP2}}$, Diets, SustEnvironment, and $\text{FST}_{\text{SDP\_China}}$. **e**. Interaction of AFOLU GHG emissions and croparea diversity under $\text{BASE}_{\text{SSP2}}$, SustEnvironment, and $\text{FST}_{\text{SDP\_China}}$. **f**. Interaction of AFOLU GHG emissions and low-income population under $\text{BASE}_{\text{SSP2}}$, SustEnvironment, InclusiveGrowth, and $\text{FST}_{\text{SDP\_China}}$. **g**. Interaction of premature mortality and agricultural employment under $\text{BASE}_{\text{SSP2}}$, Diets, InclusiveGrowth, and $\text{FST}_{\text{SDP\_China}}$. **h**. Interaction of agricultural employment and BII under $\text{BASE}_{\text{SSP2}}$, SustEnvironment, InclusiveGrowth, and $\text{FST}_{\text{SDP\_China}}$. **i**. Interaction of agricultural employment and low-income population under $\text{BASE}_{\text{SSP2}}$, InclusiveGrowth, and $\text{FST}_{\text{SDP\_China}}$.

3.3. Impacts on N fertilizer use, N surplus, and N pollution

China's fertilizer policies are incorporated into the FST_{SDP_China} scenario, and the impacts on N fertilizer use, N surplus, and N pollution are then analyzed specifically. Overall, the FST_{SDP_China} scenario shows the best performance owing to the enhancement of SNUpE and GHG pricing of all pollutant types.

3.3.1. N fertilizer use

In the $BASE_{SSP2}$ scenario, N fertilizer use in China attains its peak in 2010 at 30.5 Mt N and shows a steady decrease to 21.3 Mt N in 2050 (Figure 7a). Considering the ambitious SNUpE and GHG pricing, N fertilizer use amounts in the FST_{SDP_China} scenario show sharp declines. Corresponding to the SNUpE improvement and China's fertilizer policy reform in the FST_{SDP_China} scenario, N fertilizer use starts plummeting in 2015 and can be further reduced by 5.5 and 9 Mt N by 2030 and 2050, respectively, compared to the $BASE_{SSP2}$ scenario.

Decomposing the FST_{SDP_China} scenario into the three bundle scenarios, differentiated effects on fertilizer use are identified(Figure 7b). Specifically, compared with $BASE_{SSP2}$, fertilizer use in SustEnvironment scenario is 3.4 Mt N higher in 2050, which can be associated with an increase in land-use intensity resulting from the decreasing the arable land by 2.7%. In contrast, under the Diets scenario, a reduction of 4.4 Mt N fertilizer use compared with $BASE_{SSP2}$ are observed, owing to the adoption of the CDG diet and food waste reduction, only a marginal effect on fertilizer use is found in InclusiveGrowth scenario. When combining these three scenarios into FST_{SDP_China}, a larger effect on fertilizer reduction is found, suggesting that the achievement of environmental goals requires the cooperation of diet transformation and environmental policies.

3.3.2. N surplus

The N surplus pattern is similar to that of N fertilizer use (Figure 7c and 7d). Inefficient nitrogen use in $BASE_{SSP2}$ results in high fertilizer inputs and N surplus in agricultural production, which exacerbates soil and water pollution. With higher SNUpE (Figure A6), the N surplus can be reduced by 11.5 Mt N in 2030 in the FST_{SDP_China} scenario compared with $BASE_{SSP2}$. Regarding the three bundle scenarios, compared with $BASE_{SSP2}$, N surplus can decrease by 10.3 Mt N in 2050 in the SustEnvironment scenario, and it will decrease by 8.6 Mt N in the Diets scenario.

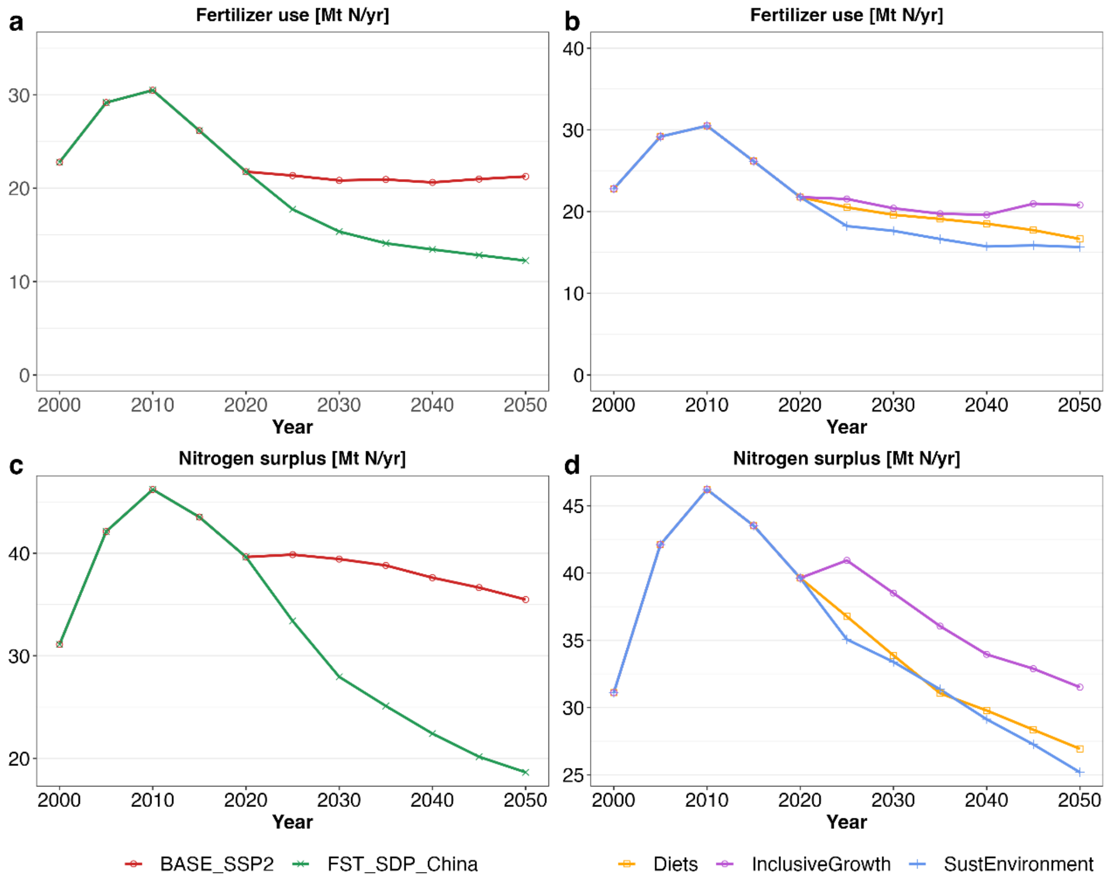

Figure 7. Nitrogen fertilizer use and nitrogen surplus across the main and bundle scenarios from 2000 to 2050 in China. a. N fertilizer use under $BASE_{SSP2}$ and FST_{SDP_China}. **b**. N fertilizer use under Diets, SustEnvironment, and InclusiveGrowth. **c**. N surplus under $BASE_{SSP2}$ and FST_{SDP_China}. **d**. N surplus under Diets, SustEnvironment, and InclusiveGrowth.

3.3.3. N pollution

The reduction in fertilizer use also results in lower N pollution (Figure 8). During 2020–2050, the cumulative N_2O, NH_3-N, NO_2-N, and NO_3-N emissions in $BASE_{SSP2}$ amounts to 10.8 Gt CO_2eq, 227.1 Mt N, 7.4 Mt N, and 365.6 Mt N, respectively. Relative to the $BASE_{SSP2}$ scenario, the cumulative N_2O emissions can be reduced by 49.1% in the FST_{SDP_China} scenario, respectively, from 2020 to 2050. Similarly, the cumulative NH_3-N, NO_2-N, and NO_3-N emissions can be reduced by 52.1%, 54.1%, and 50.1%, respectively.

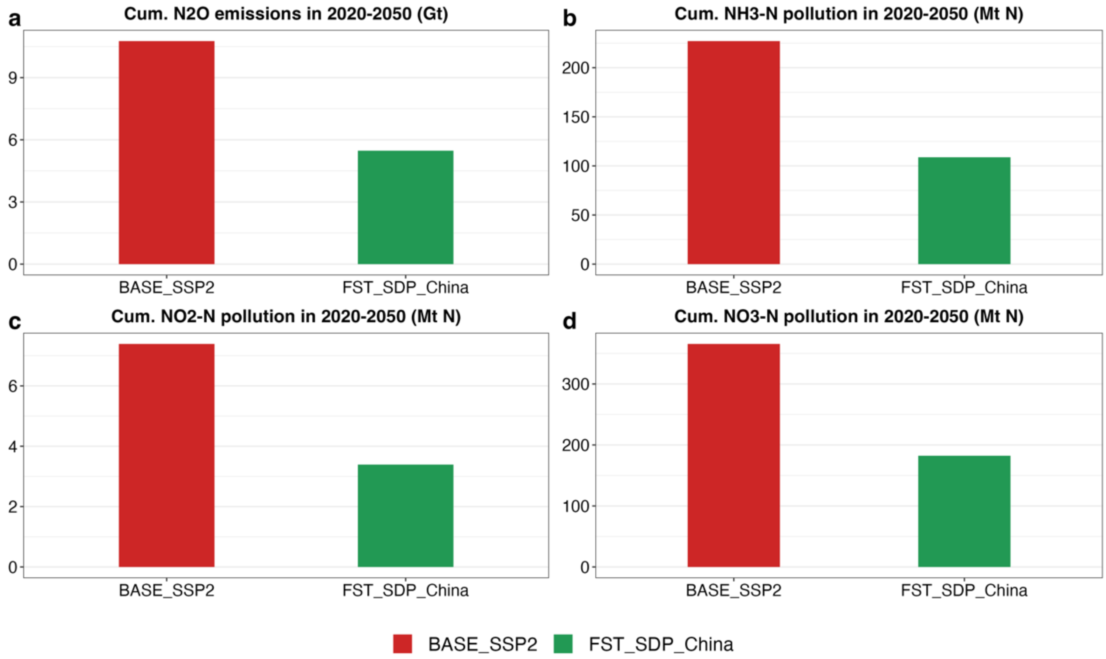

Figure 8. Cumulative N pollution between 2020–2050 in China across the $BASE_{SSP2}$ and FST_{SDP_China} scenarios. a. Cumulative N_2O emissions. **b**. Cumulative NH_3-N pollution. **c**. Cumulative NO_2-N pollution. **d**. Cumulative NO_3-N pollution.

3.4. Impacts on land-use intensity and labor productivity

The land-use intensity experiences a growth from 2000 to 2050 in all scenarios. However, the growth rate varies among the scenarios. SustEnvironment scenario shows the highest increase in land-use intensity, followed by FST_{SDP_China}, InclusiveGrowth, and $BASE_{SSP2}$, while Diets has the lowest land-use intensity (Figure 9a). The demand and environmental protection measures are directly tied to the change in land-use intensity. In scenarios with higher environmental protection requirements, due to the necessity for environmental protection, more cropland conservation could be observed (Figure 9c), requiring higher land-use intensity to satisfy the demand for crops (Figure 9b).

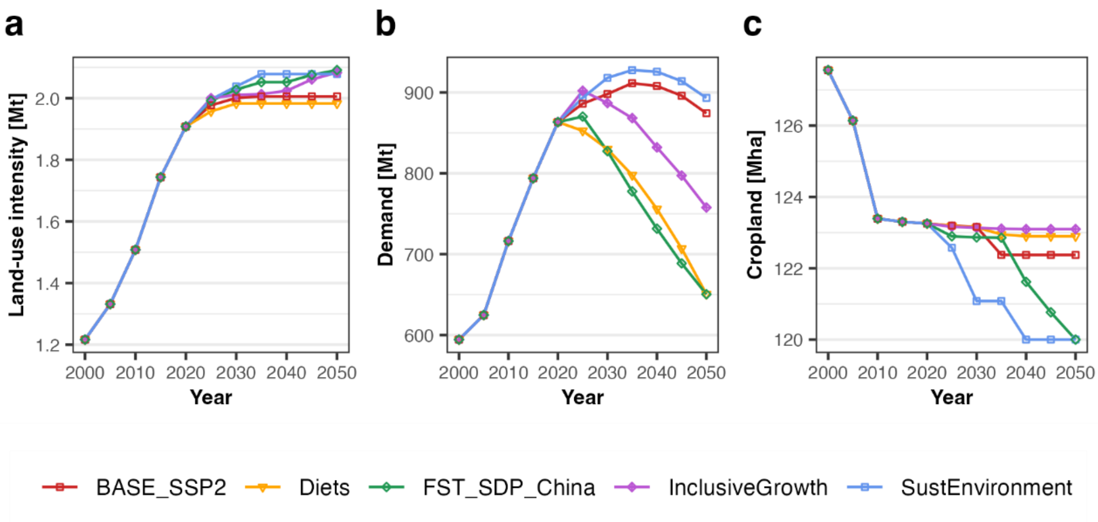

Figure 9. Indicators related to China's agricultural production between 2000–2050 across scenarios. a. Land-use intensity; **b**. Demand for crops; **c**. Cropland area.

FST_{SDP_China} exhibits a higher labor productivity growth (402.4%) than the $BASE_{SSP2}$ (206%) (Figure 10). In the case of better economic development, it is more conducive to the improvement of agricultural labor productivity. This is due to the social development path of SSP1 is followed by the FST_{SDP_China}, accompanied by the changes in the dietary structure brought about by the transformation of the food system changes the crop planting structure, which leads to a rapid increase in labor productivity in the crop sector.

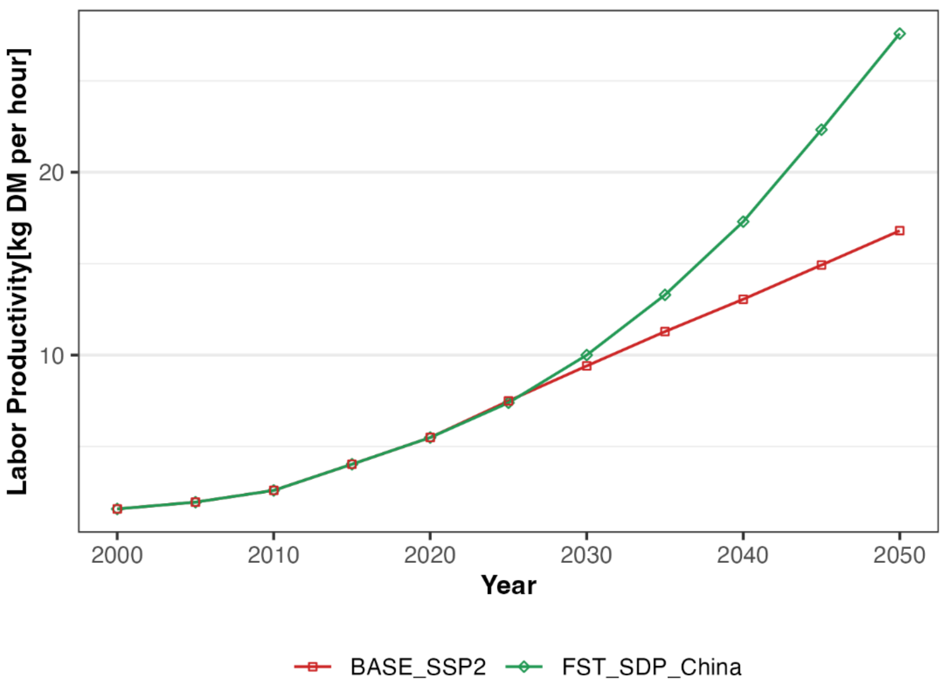

Figure 10. Labor productivity of China across the across the $BASE_{SSP2}$ and FST_{SDP_China}.

4. Discussion

Aiming to provide a model-based food system transformation pathway for China, this study incorporates China's policies into global food system transformation pathways and analyzes the synergies and trade-offs among health, the environment, and inclusion. China can achieve win–win outcomes in terms of health and the environment by adopting a comprehensive food system transformation pathway, and correcting fertilizer price distortion and repurposing the agricultural subsidies towards enhancing SNUpE, which appear to be effective options for agricultural sustainable development. With the necessary productivity growth and expanding agricultural R&D investments, along with dietary pattern change, synergies between the environment and inclusion can be observed in China.

However, China may face a dilemma due to the outflow of agricultural employment even following the most optimistic food system transformation pathway. The analysis shows that there would be a large loss of employment mainly due to the reduction in agricultural production caused by the dietary transition. It is ambiguous for China whether the employment drop is an opportunity or a challenge. With the aging population as well as an increased level of agricultural mechanization and urbanization, the labor transfer from the agriculture sector to other sectors in China is inevitable, as reflected in the $\text{BASE}_{\text{SSP2}}$ scenario. Statistics show that the comprehensive mechanization rate (weighted average of machinery usage rates for ploughing, planting, and harvesting) in Chinese agricultural production activities grew to 72.03% in 2021 (Ministry of Agricultural and Rural affairs of China, 2022). In 2021, the proportion of China's population aged 60 and above exceeded 18%, whereas the urbanization rate attain 64.72% (National Bureau of Statistics of China, 2021). By shifting surplus labor to other sectors, farm size may increase, while those left behind can engage more with high value activities such as producing vegetables, fruits, beans, and seafood with increasing demand. This could be a great opportunity for China to increase farmers' income and promote common prosperity. Despite the possible benefits, the agricultural labor surplus due to dietary transition, environmental protection, and other actions remains an issue that requires attention. Such large agricultural employment drop poses formidable challenges to China's labor transfer, employment, and industrial development policy design. Our results indicate that under $\text{FST}_{\text{SDP\_China}}$, China would require additional policy measures to reallocate the surplus labor and guarantee public services such as medical, health care, and education simultaneously. The development of a social safety net to support the Chinese food system transformation toward healthy and sustainable deserves an in-depth discussion in government policymaking.

In addition, the transformation to an environment-positive food system in China requires a parallel effort in agricultural R&D that triggers increased land-use intensity. Stricter environmental regulations and conservation of natural vegetation limit the expansion of arable and pasture land, as well as encourage afforestation and reforestation. Increased investments in agricultural R&D to drive agricultural productivity are necessary to ensure food security and agricultural development. Furthermore, stable agricultural production can also ease the outflow of agricultural labor and reduce the pressure on China's government to meet inclusive development. The role of agricultural R&D inputs and technological advances in driving the Chinese food system transformation also merits further exploration.

In this study, the sustainable pathways for food system transformation in China by incorporating the most primary policies/measures in terms of diet, nitrogen, land, water, emissions, biodiversity, labor transfer, and agricultural R&D are explored. However, there are still plenty of policy measures concerning food system transformation in China that have not been captured in this study, such as the construction of high-standard farmland in China, the reformulation of agricultural support policies, and the development of agricultural mechanization. In future research, it is important to integrate more policies into the framework and examine their potential synergies and trade-offs. A better understanding of the interactions between multiple policy measures is necessary for top-level policy design and a combination of different measures implementation. For example, our results suggest that land policies alone can mitigate N pollution because of higher land-use intensity. However, N pollutants can be reduced significantly if the dietary transition is coupled with land policies. In addition, results show that fertilizer use reduction driven by higher SNUpE and fertilizer prices further decreases long-term agricultural water use, contributing to the achievement of water cap red lines from China's most stringent water resources management system. Future research incorporating China's specific water use targets based on the current model is required to estimate the combined impacts of nitrogen and water policies.

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Appendix

Table A1. Indicator description.

Dimension	Indicator	Unit	Definition
Health	Underweight	Million people	Number of adults with a BMI <18.5 (for people older 15 years) and children and adolescents with a BMI that is 2SD below normal (0-14 years).
	Obesity	Million people	Number of adults with a BMI >30 (for people older 15 years) and children and adolescents with a BMI that is 2SD above normal (0-14 years).
	Premature Mortality	Years of Life Lost (YLL)	Years of life lost (YLL) quantifies premature mortality by considering both the frequency and age at which deaths occur. In simple terms, one YLL signifies the loss of one year of life.
	Chinese Healthy Eating Index	Dietary score	Dietary score developed based on the Chinese Dietary Guideline (CDG) and Chinese dietary habits. Higher scores on the Chinese Healthy Eating Index (CHEI) signify a greater adherence to the CDG.
	EAT-Lancet Diet Index	Dietary score	Indicator developed to measure the adherence to the EAT-Lancet diet. Each food group is assigned a score ranging from 0 to 3, with a higher score reflecting greater adherence to the recommended intake targets.
Environment	All Land Types	Biodiversity Intactness Index	The Biodiversity Intactness index (BII) assesses changes in organism abundance by factoring in alterations in forest and non-forest vegetation cover, as well as the age class of natural vegetation. The reference land use (BII = 1) assumes an absence of human land use.
	Cropland Landscapes	Biodiversity Intactness Index	When calculating the BII for cropland landscapes, only cells containing a minimum of 100 hectares of cropland are taken into account.
	Hotspots Landscapes	Biodiversity Intactness Index	In the context of key conservation landscapes, our analysis specifically focused on cells located within biodiversity hotspots (BH) and intact forest landscapes (IFL).
	Croparea Diversity	Shannon Index	The Shannon crop diversity index is a metric for assessing crop diversity, considering both the variety and prevalence of different crop groups.
	Nitrogen Surplus	Million tons nitrogen per year	Nitrogen surplus in various land categories, including croplands, pastures, natural vegetation, and animal waste management, is quantified in teragrams of nitrogen (Tg Nr).
	Environmental Water Flow Violations	km^3 per year	Water withdrawals that surpass the quantity that can be extracted while considering the minimal environmental flow requirements

			of aquatic and riverine ecosystems are measured in cubic kilometers (km^3).
	AFOLU GHG Emissions	Gt CO_2eq per year	The measurement of greenhouse gas emissions stemming from land use and land-use changes is expressed in gigatons (Gt) of CO_2 equivalents.
Inclusion	Expenditure on agricultural products	USD per person per year	The per capita annual expenditure in USD05 MER on agricultural commodities earmarked for food consumption, without including the value-added within the supply chain, is calculated.
	Low Income Group	Million people	The count of individuals, in millions, whose per capita daily income falls below 3.20 USD11 $_{PPP}$ within each country, as determined by the World Bank's poverty lines estimation.
	Agricultural Employment	Million people	The number of individuals employed in agriculture, encompassing both crop and livestock production, is expressed in millions.
	Agricultural Wages	Index relative to 2020	This index quantifies the progression of wages in comparison to the year 2020, presented as a ratio.
	Bioeconomy Supply	Billion USD05/yr	This value stream extends from the food and land system to other economic sectors, encompassing the worth of bioenergy, bioplastics, timber, and the material utilization of products, all adjusted to fixed 2010 prices.
	Production Costs	Billion USD05/yr	This value stream covers the flow of resources from other economic sectors into the food and land system. It includes expenses such as labor and capital for agricultural production, research and development (R&D) investments, land expansion costs, and transportation expenses, all quantified in $USD05_{MER}$ per year.

Notes: This table is adopted from the supplementary material of the global study.

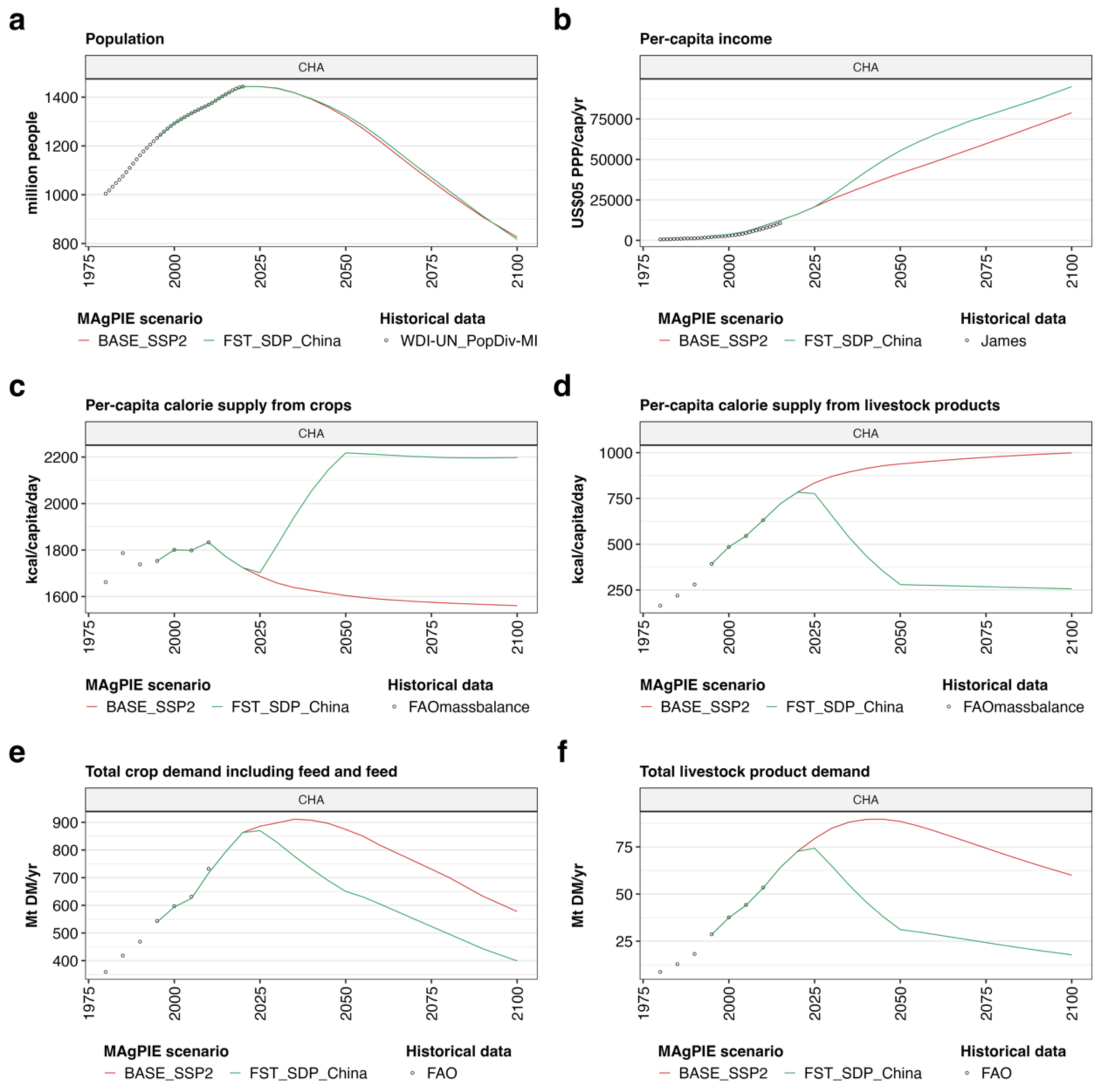

Figure A1. Validation of assumptions for China of MAgPIE.

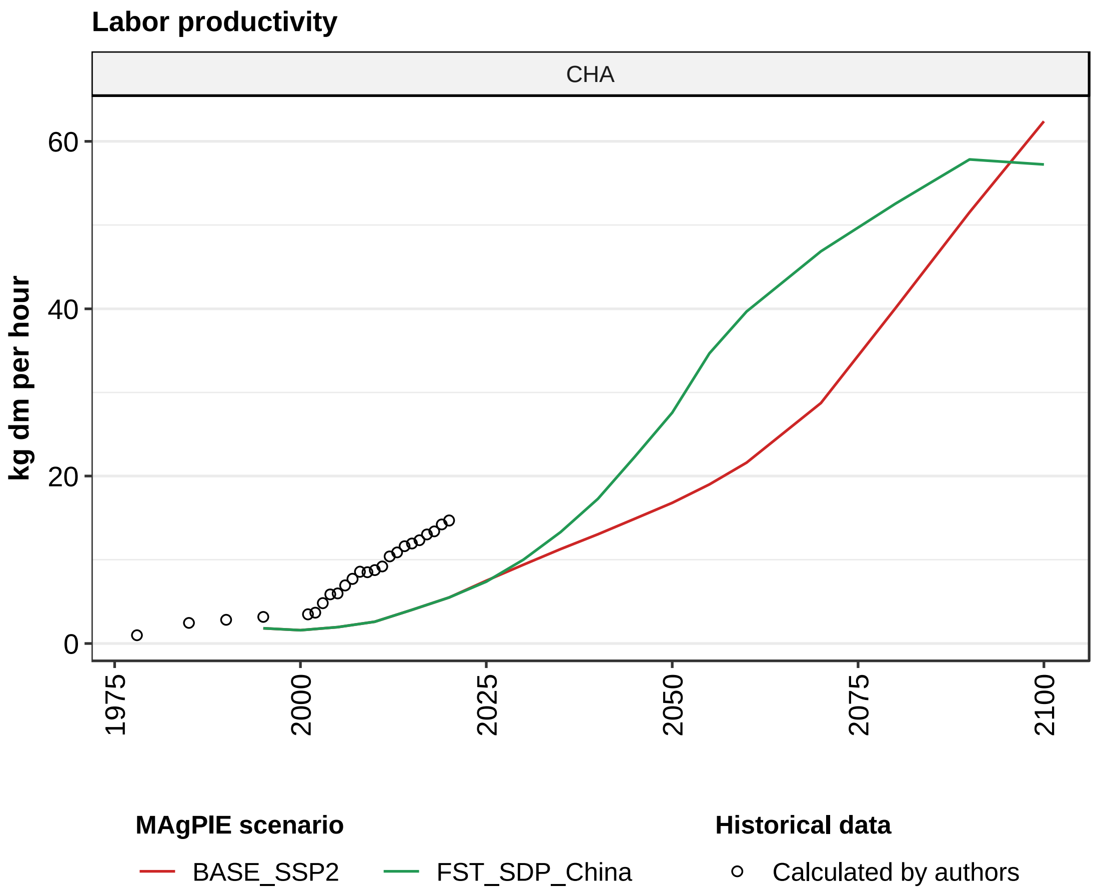

Figure A2. Validation of labor productivity in China. Notes: The historical data of China's labor productivity is calculated by authors based on Summary of National Agricultural Product Cost-benefit Data and China Statistical Yearbook.

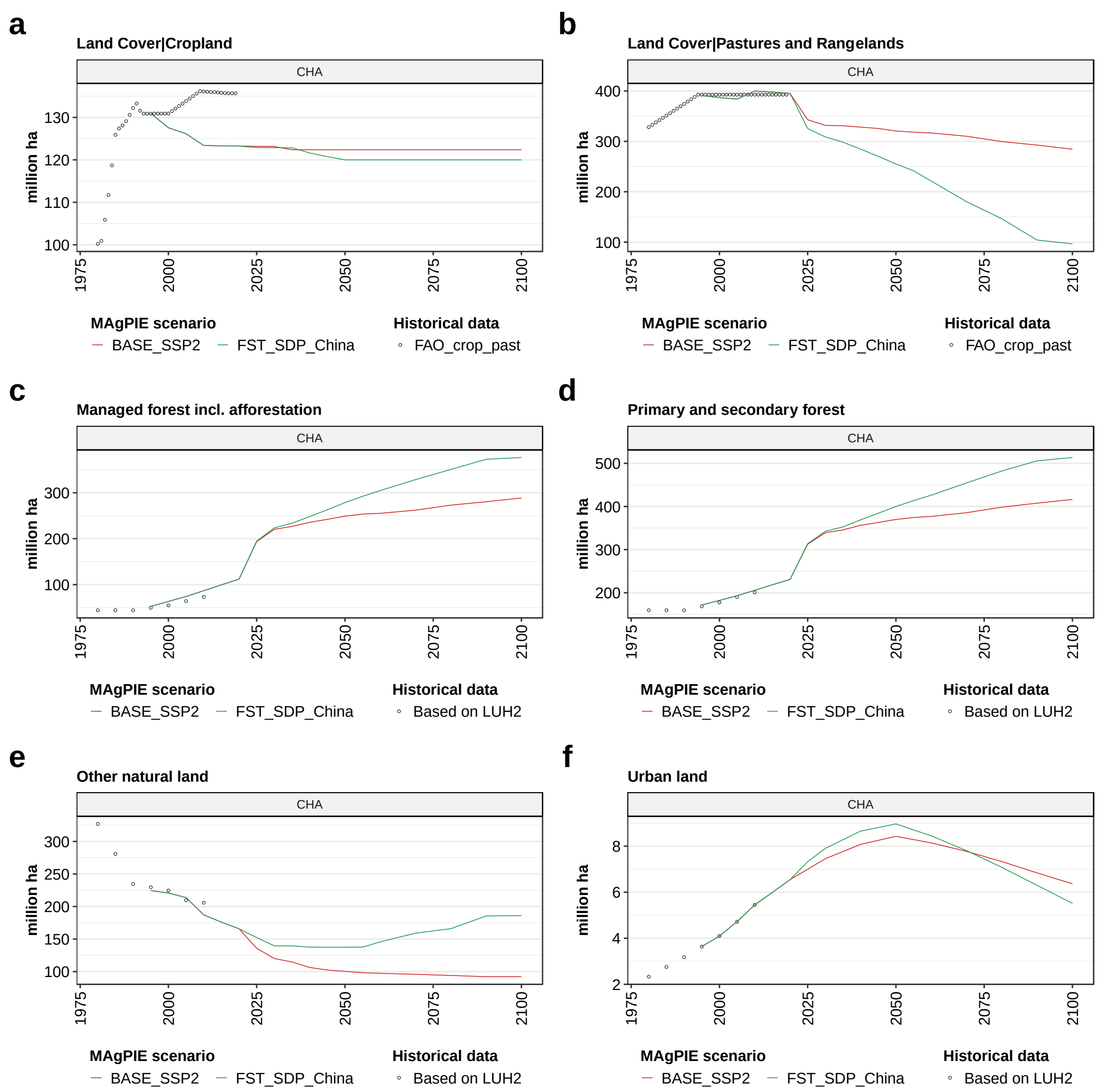

Figure A3. Validation of areas of different land types of China in MAgPIE.

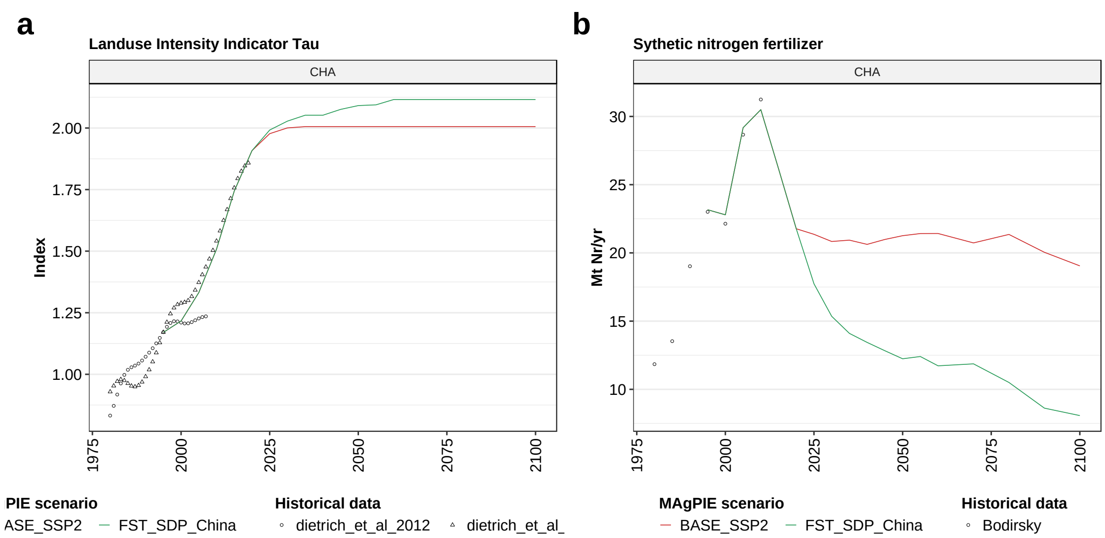

Figure A4. Validation of indicators related to productivity of China in MAgPIE.

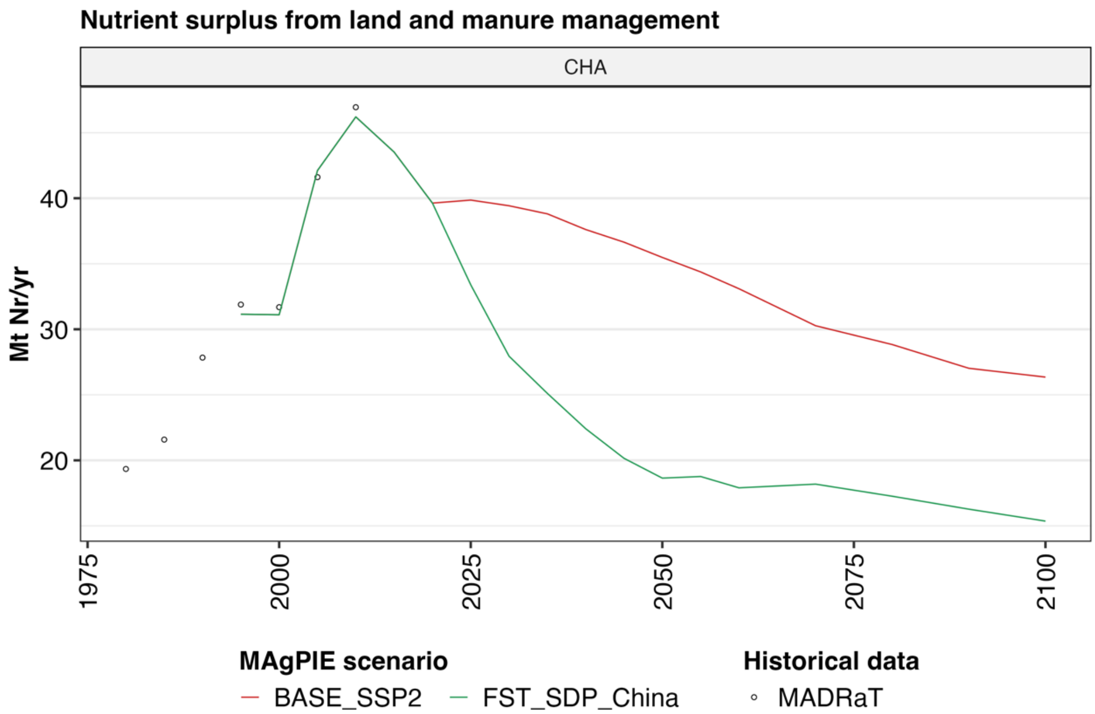

Figure A5. Validation of N surplus from land and manure management.

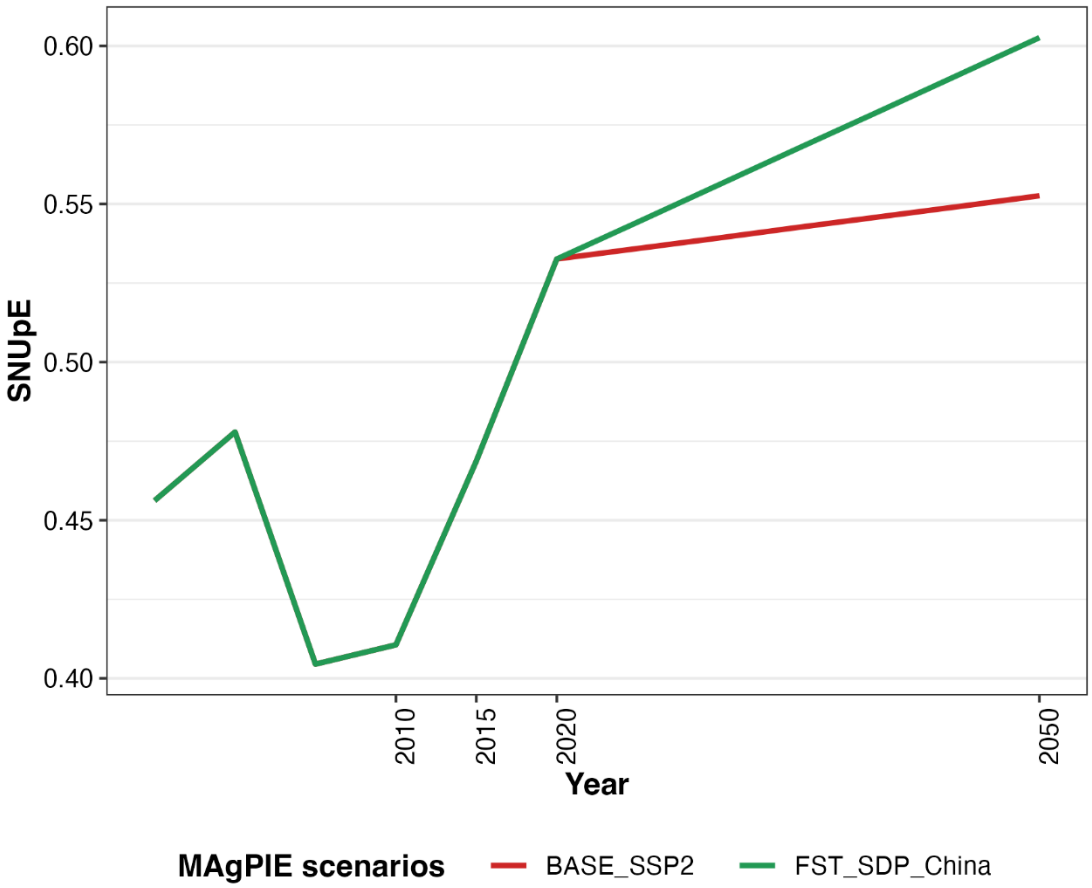

Figure A6. SNUpE settings in China across BASE$_{SSP2}$ and FST$_{SDP_China}$ scenarios.

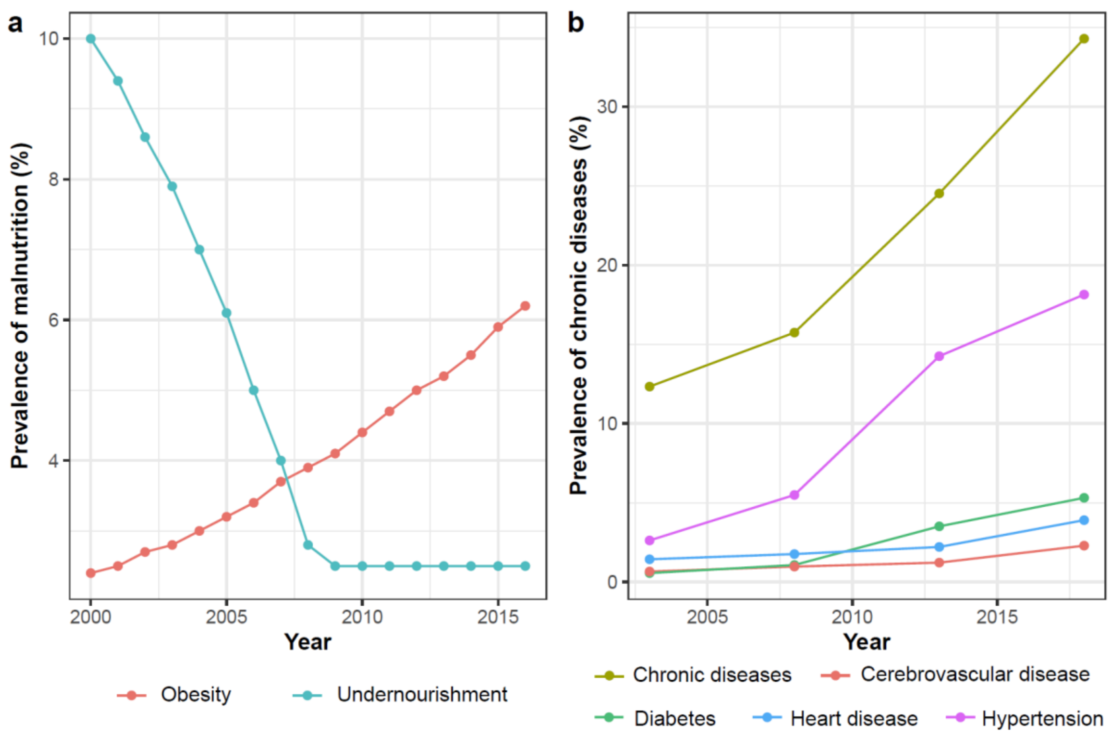

Figure A7. Prevalence of malnutrition and chronic diseases in China. a. Shares of undernourishment and obesity in China's total population (age ≥ 18 years old). The share of undernourishment is reported as <2.5% after 2009–2011 based on FAOSTAT. Adapted from Wang et al. (2022a). **b.** Prevalence of total and specific chronic diseases in China based on China Health Statistics Yearbook.