Chapter 5
Sustainable Food Supply Chain

1 The Vision

China has several aspirations that will require dramatic transformations in the country's agriculture and food ("agrifood") systems (Box 1). Two aspirations in particular stand out and are the focus of this Special Policy Study: (1) Peaking national carbon emissions before 2030 and achieving carbon neutrality before 2060, and (2) achieving food security and resilience.

Box 1 Agrifood System

As used in this Special Policy Study, the "agrifood system" encompasses both the "on-farm" agricultural and food production activities, as well as the inputs upon which this production depends (e.g., production of synthetic fertilizer), processing and packaging, distribution, retail, and consumption. Land-use and land-use change associated with the agricultural and food production activities is also included in the agri-food system.

1.1 Achieve Carbon Peak Before 2030 and Neutrality Before 2060

In 2020, the Chinese government announced an aspiration to peak national carbon emissions (Box 2) before 2030 and achieve carbon neutrality before 2060 [1]. To jump start this effort, *the 14th Five Year Plan for National Agriculture Green Development* calls for reducing greenhouse gas (GHG) emission and increasing carbon

China Council for International Cooperation on Environment and Development (CCICED) Secretariat, *Building an Inclusive, Green and Low-Carbon Economy*,
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sink capacity within the agriculture and land sector (Ministry of Agriculture and Rural Affairs [2]. Both policy ambitions align with China's vision of becoming an "Ecological Civilization" [2, 3].

Box 2 "Carbon" = "Greenhouse Gases"
As used by the Chinese government, the term "carbon" in the context of the 2060 neutrality ambition means carbon dioxide equivalent (CO_2e), which encompasses all greenhouse gases (GHGs). Therefore, this Special Policy Study will address all GHGs generated by the agrifood system, primarily carbon dioxide, methane, and nitrous oxide. This study will consider direct GHG emissions (and sinks) in China. In addition, this study will consider GHG implications associated with agriculture goods imported into China from overseas, although those emissions are beyond China's direct control. Food import is an integral part of China's food security, while China is committed to global emission reduction. China can play a positive role in reducing emissions of these overseas agriculture systems.

As for achieving carbon neutrality, China's agrifood system must feature prominently in the overall national plan to address climate change. As President Xi Jinping said, "Decreasing GHG emissions and increasing the carbon sink of the agriculture sector and the rural area are critical measures for achieving carbon peaking before 2030 and carbon neutrality before 2060. Scientific accounting, actionable proposals and efficient measures should be taken". China's domestic agrifood system generates 8% of the country's annual total GHG emissions, including 40% of the country's total methane emissions and 50% of its total nitrous oxide emissions [4]. These emissions will need to be significantly reduced. Moreover, carbon neutrality can only be achieved if China's remaining unabated emissions (from energy, industry, and/or agriculture sectors) are counterbalanced by a dramatic increase in the country's carbon sink (e.g., sequestering carbon dioxide via reforestation).

1.2 Achieve Food Security

In April of 2020, President Xi Jinping declared that "food security is an important foundation for national security" [5]. Later in December of 2020, he stated, "The food of the Chinese people must be made by and remain in the hands of the Chinese. Everyone needs to take responsibility for food security" [6]. In the same vein, China's new "dual circulation strategy" calls for greater self-reliance in terms of production and consumption (including of food) in order to reduce international supply chain uncertainties [7]. More recently, in March 2022, President Xi articulated the importance of adequate grain and other food supplies, better farmland management, and

application of new technologies in support of food security [8]. It is important to note that these are not calls for full self-sufficiency with regard to food or other commodities but rather one for an appropriate combination of self-sufficiency and open trade. In addition, the agrifood system—especially with respect to improving human health, accessing safe and nutritious food, and reducing agriculture-generated pollution—is an important component of China's efforts to achieve "common prosperity". These and other priorities highlight that ensuring a sustainable supply of primary products, including food, is a major strategic issue for the country.

Given the above, a key question the country faces is, "***How can China transform its agrifood system in a manner that simultaneously supports food security and contributes to carbon neutrality?***" This CCICED Special Policy Study attempts to provide an answer. The Study begins by outlining the nature and scale of the challenge—the current state of play and developments within China's agrifood system which pose obstacles to the achievement of these two aspirations. It continues by articulating the types of solutions that could address these obstacles. It concludes by proposing a suite of institutional innovations for pursuing smarter solutions. The report does not propose technical solutions to the myriad of food challenges a large, diverse country such as China is bound to have. In asking, "how could China implement these solutions?" the study highlights opportunities for institutional arrangements and leadership that can infuse the innovation and concerted effort needed to bring about the change at scale and within the timeframe sought.

The past two years have seen globally an unprecedented interest on the future food (particularly alternative proteins). A cursory review of studies and reports shows how much of this interest has been centered on China. We explicitly recognize the recent reports by Academy of Global Food Economics and Policy (AGFEP) given their comprehensiveness and sound analysis. We hope that our report adds value to our understanding of the future food in China and can help inform ongoing and future public and private sector policy discussions on these important issues for China.

2 The Challenge

In just 10 years, from 2000 to 2010, China also became one of the few developing countries where undernourishment is less than 2.5%. Daily calories supplied in that same period grew from 1800 to 3201 kcal/per person across the country and protein from 83 to 101 g/per person [9]. Most indicators of food availability and affordability are still growing, but, with that, the concern of policy makers and food experts about the hidden natural and social capital costs bankrolling this growth and the vulnerability of long supply chains. This section identifies the main challenges China will confront and be able to feed its population while protecting and restoring natural and social capital as the basis for a sustainable food system.

Last year and earlier this year, a consortium of leading academic institutions produced the China and Global Food Policy Report (2021 and 2022) which today are the most thorough and comprehensive account of China's food systems and future

scenarios. The SPS relies heavily on these reports [10, 11] data and analysis of current trends as well as scenarios for the medium to long term. The SPS's added value to this discussion is to focus on cross cutting and institutional issues that are critical to implement recommended actions.

2.1 Challenges to Achieving Carbon Neutrality (Aspiration 1)

China's agrifood system generated 1.09 billion tons of CO_2eq in 2018, the third annual highest level [10]. This amount represents 12% of the 13 billion tons of CO_2eq emitted by China that year, a substantial increase from the 1997 level of 0.94 billion tons CO_2eq. Today, China's food system carbon emissions make China the largest emitter in the sector, rivaling with India. But on a per capita basis, it is at 0.47 tons, one of the lowest emitters in terms of emissions from agricultural activities.

While GHG emissions from the country's agrifood system span multiple sources, the majority come from agricultural activities (Fig. 1). Among the latter, methane from ruminant livestock (enteric fermentation and manure) and rice paddies are the primary sources of GHGs.

China's agrifood system footprint also includes the GHG emissions of the food the country imports for domestic processing and/or consumption. Improvements in Chinese living standards and associated changes in diets (in particular rising animal product demand) are underway. Growing demand is difficult to satisfy solely by domestic production and supply, and therefore imports of a number of agricultural products have increased. For example, while Chinese consumer demand for beef in

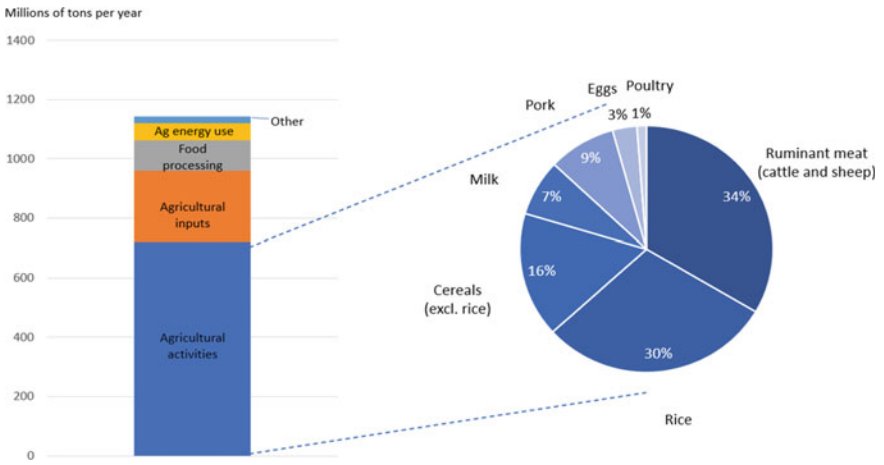

Fig. 1 Greenhouse gas emissions from China's agrifood system (2017). *Source* AGFEP, CARD, CIFAE, IAED, and IFPRI. 2021. 2021 China and Global Food Policy Report

2019 was 8.3 million tons, the country domestically could only supply 6.7 million tons [12].

The carbon footprint of China's agrifood system also includes GHG emissions from imported food used for domestic processing and/or consumption. With the improvement of Chinese people's living standard and shifts in diet (especially the increased demand for animal products), domestic production and supply cannot meet its growing demand. Therefore, the agricultural imports have increased accordingly. For example, China's consumption demand for beef in 2019 was 8.3 million tons, but China could only supply 6.7 million tons domestically [12].

Some of these imported foods are associated with a high climate footprint. For instance, beef, soybeans, and palm oil are leading direct causes of tropical deforestation [13]. Although the GHG emissions associated with the imports of agrifood products overseas should not be counted into the total emissions of China, the country can play an increasingly active role in global carbon emissions reduction through South-South cooperation in trade, foreign direct investment (FDI), and science and technology (S&T). This is consistent with President Xi Jinping's statement of the community with a shared future for mankind.

2.2 Challenges to Achieving Food Security and Resilience (Aspiration 2)

China's agrifood system faces at least four challenges to achieving food security.

2.2.1 Increased Environmental Pressures that Undermine Domestic Food Production Capability

- ***Farmland degradation***. Agricultural production over a long time period has resulted in loss of soil fertility and heavy-metal pollution. According to the Ministry of Agriculture and Rural Areas (MARA), of the more than 2 billion mu (133 million ha) of cultivated land in China, more than two-thirds is considered "low-quality" (i.e., fourth to tenth grade in a 5–10 scale) [14].
- ***Stressed domestic water supplies.*** China is one of the countries with the poorest per capita water resources in the world while also having the largest water consumption in the world. In 2018, China's total freshwater consumption was more than 600 billion m^3, with 369 billion m^3 of this (61%) being consumed by agriculture [15]. Due to regional and climate differences, the distribution across time and space of agricultural water resources is uneven, and the shortage of water negatively affects agricultural development in water-deficient areas [16].
- ***Increased risks from extreme weather due to climate change.*** Studies show that, on average, climate change will reduce food production, raise prices, increase net imports of most food, and lower China's overall food self-sufficiency [17]. At

present, the per unit yield of China's three major grain crops decreases by about 2.6% when temperatures rise by 0.1 °C, and every 1% increase in precipitation levels increases 0.4% of yields. Considering the impact of temperature and precipitation on grain yield, climate change will have a certain impact on China's food security, which may partially offset the positive effects brought by technological progress [18]. In addition, natural disasters and extreme weather events (e.g., floods, droughts, unseasonably high/low temperatures) due to climate change can cause a significant loss in domestic agricultural and food production. In 2018, about 140 million people were affected by natural disasters with a total loss of 4 billion yuan, while in 2019 about 20 million ha in China were affected by natural disasters [19].

- While women account for a growing share of agricultural workers, women are more vulnerable than men to the negative effects of environmental damage in much of the developing world [20]. Gender awareness of climate change is gradually being strengthened and improved in social welfare guarantee policies, specifically regarding women's vulnerabilities in China. But more needs to be done to integrate gender to food and climate security strategy.

2.2.2 Increased Pressures on International Food Imports into China

- ***Increased reliance on foreign imports***. Since China's accession to the World Trade Organization (WTO), the country's agricultural trade has entered an unprecedented stage of rapid development. While both agricultural imports and exports have grown, imports have grown much faster. Even with the EU countries taken as a whole, China is now the second-largest importer and fifth largest exporter of agricultural products in terms of economic value in the world, and its total trade volume of agricultural products has leaped to second place in the world [21]. In 2021, China imported 165 million tons of grain, an increase of 18% over the same period last year [22]. In particular, China's imports of soybean accounts for 86% of total domestic demands in 2021. Imported dairy products and beef contribute 35% and 24% of total supply amount respectively in 2020 [23].
- ***Disruptions to global supply chains due to COVID-19 and trade conflict***. Given China's increased reliance on international trade for agricultural products, recent sources of disruption may have negative consequences for Chinese food security aspirations. The COVID-19 pandemic had a huge disruption on international trade during 2020 and 2021. Ramifications are still being felt, and future implications are unknown. Protectionist-oriented trade disputes with the United States continue to impact agricultural trade, especially for commodities such as soybeans and maize where the United States previously was a major supplier. Moreover, the 2022 Russia-Ukraine crisis is impacting agricultural trade in terms of food price and availability, particularly given the scale of grains and vegetable oils previously exported from Russia and Ukraine onto the global market.
- ***Rise of sustainability expectations***. As outlined in a recent SPS on greening soft commodity value chains [24], "tomorrow's markets" are increasingly demanding

more sustainable food consumption and production. Domestic Chinese consumers appear to be moving in this direction. For instance, according to a survey conducted in 2022, more than 90% of consumers are willing to pay a premium for low-carbon food, and more than half of consumers are willing to pay a premium of more than 10% [25]. The business norms of multinational retailers and manufacturers of agricultural goods are rapidly shifting towards greater sustainability and are being applied equally across all geographies. Walmart's sustainability policies, for instance, apply to all Walmart stores [26]. These business norms include value chain policies. Walmart is working with its global suppliers to evaluate and share progress on key environmental and social issues in supply chains covering more than 100 product categories, including pulp, paper, and timber products [26]. The company applied this policy to all its stores worldwide; there was no separate policy for stores in Europe versus those in China. Financial markets are taking notice, too. A growing critical mass of institutional investors are developing investment guidelines to limit access to capital by borrowers whose investments in agricultural commodity production and trade result in tropical deforestation or high GHG emissions. In September 2019, for instance, 230 institutional investors representing $16.2 trillion in assets under management called on companies to take urgent action in light of the devastating forest fires in the Amazon [27].

2.2.3 Pressures on Pollution and Food Safety

- ***Pollution due to overapplication of fertilizers, pesticides, and plastic films***. According to the Bulletin of the First National Survey of Pollution Sources, agriculture was the main source of chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) in China in 2007—accounting for 44%, 57%, and 67% of these total national emissions, respectively. In the *2020 Bulletin of the Second National Survey of Pollution Sources*, the emissions of COD, TN, and TP from agricultural pollution sources had decreased by 19%, 48%, and 26%, respectively, by 2017 compared with 2007, but these are still the main pollution sources. In terms of fertilizer utilization rate by crops, the rate for rice, corn, and wheat in China was 38% in 2017, a significant gap compared with the utilization rate of 50–65% of food crops in Europe and the United States [28]. Low utilization rates mean that a lot of fertilizer ends up polluting the air (e.g., in the form of the GHG nitrous oxide) or waterways.
- ***Concerns about food contamination and safety***. In terms of crop production, excessive application of chemical fertilizers, pesticide residues, and heavy metal pollution threaten food safety, affect food quality, and can have a negative impact on dietary health. The risk of these pollutants exceeding health standards can restrict availability of safe and high-quality edible agricultural products. In terms of livestock, high stocking densities and risk of diseases can foster excessive antibiotic use. This in turn can result in the emergence of antimicrobial resistance, threatening both livestock and human health.

2.2.4 Impact on Food Consumption

- ***Persistent malnutrition***. China achieved zero rates of poverty in 2020. Despite this, malnutrition problems remain, including micronutrition deficiency caused by unbalanced diets (mainly due to the lack of vegetable and fruit consumption). It is noticed that certain population groups such as infants, women in childbearing age, and the elderly face anemia and other malnutrition (National Health Commission [29]. The AGFEP (2022) [11] found that the intake of fruits, dairy, and aquatic products among rural residents is deficient. Moreover, the intake of vitamin A, vitamin C, and calcium is insufficient, especially for rural populations. The diet of urban residents mainly has the challenge of mild excessive intake, while the diet of rural residents has the double burden of mild excessive intake of calories and insufficient intake of nutrients.
- ***Increase in share of population that is overweight or obese***. More than half of China's adult residents are overweight or obese, and the rate of overweight and obesity among children and adolescents has soared in recent decades [29]. Compared with the last decade, the dietary nutrition and health status of women have been greatly improved, but the intake of cooking oil and salt is still higher than the recommended value, and the overweight rate of women between 18 to 49 years old has increased significantly, reaching 30% [30].
- ***High rates of food loss and waste***. In 2016, the comprehensive loss rate of all links of China's grain varieties after delivery was as high as 18% [31]. Post-harvest losses for meat are around 6.6% for pork, 5–9% for chicken, 8% for beef, and 4% for mutton [32]. Food loss rate of fruits and vegetables during storage and distribution was 15% and 10%, respectively [33].
- ***Consumer food waste in China is high, too***. For example, the amount of food waste per person in school canteens (buffet meals) ranges from 61 to 74 g per meal, while restaurants range from 74 to 144 g per meal [34]. Based on a survey in Beijing, Shanghai, Chengdu, and Lhasa from 2013 to 2015, the food waste rate in China's catering industry is nearly 12%, and waste at large gatherings rises to as high as 38% [35].
- ***Increased plastic pollution (from packaging)***. China is the world's biggest plastic producer and consumer, and the food sector is a primary user. It is estimated that total plastic packaging for annual household packaging consumption is 5.4 million tons. A significant share of this plastic ends up as waste or even pollution.

3 The Solutions

A suite of solutions exist that can mitigate these challenges—reducing China's agri-food system's climate footprint while improving food security. These solutions would

help China *produce* more (and more nutritious) food, *protect* nature, *reduce* agrifood system inefficiencies and pollution, and *restore* degraded lands. These four categories of solutions should be implemented at the same time to avoid negative rebound effects.

3.1 Produce

Increasing China's ability to produce nutritious food while reducing the associated greenhouse gas emissions (and other forms of pollution) is an important pillar for achieving the two aspirations of carbon neutrality and food security. A range of technologies and practices exist to decouple food production from greenhouse gas emissions and pollution throughout the value chain (Table 1). These approaches address the main sources of greenhouse gas emissions from the agrifood system: ruminant livestock, rice, fertilizers, and agrifood-related energy use. These technologies and practices range from being "evolutionary" (e.g., they have been established for some time and merely need to scale adoption) to "revolutionary" (e.g., they are recent or future breakthrough innovations). Moreover, some offer opportunities for China to build a new industry to meet domestic (and increasing global) demand. For example, China could build an industry that manufactures plant-based alternative proteins (à la "Impossible Foods") or synthetic starches/proteins to meet growing Chinese demand (and at the same time reduce dependence on foreign food sources).

Complementing Table 1 are information and data technologies (e.g., land monitoring, agriculture input monitoring, early warning and response systems) that support implementation of the technologies and practices. Such information technologies also can integrate with risk-informed and shock-responsive social protection systems to strengthen risk management and early response capacities.

3.2 Protect

Protecting natural ecosystems and productive agricultural land from conversion to other uses are important components of achieving the two aspirations of carbon neutrality and food security.

- ***Avoid natural ecosystem conversion in China***. Avoiding loss of natural ecosystems such as forests, wetlands, and grasslands helps retain the size of China's terrestrial carbon sink. Conversely, conversion of these ecosystems into farmland, settlements, and other forms of development would increase China's land-related carbon emissions. China has a number of measures already in place to avoid such conversion, including drawing ecological "red lines" and incorporating them into the national spatial plan, creating national parks, and establishing an eco-compensation scheme.

Table 1 Technologies and practices to reduce GHG emissions from food production

GHG emissions source	Annual emissions at stake ($MtCO_2eq$)	Technologies and practices that can reduce those emissions by an amount TBD
Ruminant enteric fermentation (meat and milk)	180	• Utilize enteric methane inhibitor feed additives (e.g., 3-NOP, seaweeds) • Improve ruminant breeding
Livestock manure	140	• Separate solids from liquids and manage dry solids (reducing emissions in animal housing) • Acidify manure or other options for improved liquid manure management (reducing losses during manure storage) • Utilize digesters in warm locations with large lagoons and use the CH4 as biogas (at large-scale locations like communities or larger farms)
Livestock: cross-cutting (enteric fermentation, manure management)		• Boost ruminant livestock productivity and efficiency—reducing methane emissions per kg of meat and milk or per hectare of pasture—through improvements in: • Feed quality • Animal breeds • Veterinary care • Improve pasture and grazing management (e.g., rotational grazing, better grass mixes) • Produce plant-based or lab-grown alternative proteins (e.g., "Impossible Foods China") and/or synthetic starches and proteins

(continued)

Table 1 (continued)

GHG emissions source	Annual emissions at stake ($MtCO_2eq$)	Technologies and practices that can reduce those emissions by an amount TBD
Rice cultivation	150	• Promote System of Rice Intensification (SRI) • Accelerate yield gains to reduce needed flooded paddy area • Breed lower-methane-emitting rice • Remove rice straw from fields or incorporate it into soils in the off season • Reduce flooding periods (e.g., alternate wetting and drying, single mid-season water drawdown, dry seeding) • Use biodegradable plastic films for rice cultivation
Crops: cross-cutting	120	• Boost crop yields per hectare (thereby reducing cropland needs per given amount of crop production, reducing emissions per hectare and liberating land for restoration)
Fertilizers	160	• Reduce overapplication of fertilizers (e.g., "4R management" = right amount, right type, right time, and right places) • Increase plant absorption of fertilizers (nitrogen use efficiency) through management changes, nitrification inhibitors, and/or breeding biological nitrification inhibition into crops • Boost crop yields via better breeding and varieties (thus reducing need for more fertilizers) • Use nitrogen-fixing legumes in crop rotations and inter-cropping
Food processing and packaging	110	• Improve energy efficiency • Shift to renewable energy sources • Reduce food packaging

(continued)

Table 1 (continued)

GHG emissions source	Annual emissions at stake ($MtCO_2eq$)	Technologies and practices that can reduce those emissions by an amount TBD
Direct agriculture energy use	120	• Improve energy efficiency of farm equipment • Shift to renewable energy sources for farm equipment • Electrify farm equipment
Indirect agriculture energy use		• Reduce NH3 and N20 emissions during fertilizer manufacturing • Improve energy use efficiency during fertilizer, film, and pesticide production
Total	980	

Memo Annual emissions at stake are calculated figures from FAOSTAT 2021. The amount from this total to be potentially reduced through the technologies listed remains to be determined. Data obtained from FAOSTATS 2021

- ***Avoid triggering natural ecosystem conversion outside of China***. Besides protecting *domestic* natural ecosystems, it is also important that Chinese avoid imports of agricultural commodities (e.g., beef, soy, palm oil) associated with *international* ecosystem conversion and associated GHG emissions. Strategies include implementing "deforestation free" or "ecosystem conversion free" supply chain agreements with source country governments and companies, putting in place monitoring and tracking systems to support such agreements, and providing gender-responsive and inclusive technical and financial assistance to exporting countries to support their efforts to supply agricultural commodities while avoiding deforestation. China's "Food Silk Road" programs provide an opportune vehicle for putting in place such measures.
- ***Prevent loss of prime Chinese agricultural land***. Ensuring that productive Chinese croplands and grazing lands remain in production is a critical component of achieving domestic food security. Absent any changes in demand, loss of prime agricultural land reduces China's ability to feed itself and increases pressure to convert natural ecosystems into agricultural land—domestically and/or internationally. According to the Ministry of Natural Resources, China's farmland area decreased by 7.3 Mha from 2009 to 2019 [36]. Satellite imagery shows large areas of cropland loss throughout mainland China, especially in the eastern portion of the country, since 2000. A number of measures could counter this trend. For instance, the Chinese government has already set a "red line" of 120 million ha of cropland to prevent the "non-agriculturalization of arable land" [37].
- ***Prevent loss and degradation of freshwater resources***. Besides arable land, a critical resource for food production is freshwater. Like land, this resource needs to be conserved, especially since China on average is one of the most water-scarce

countries in the world [38]. The agriculture sector uses 62% of total freshwater consumption in China [39] and accounts for 50% of chemical oxygen demand, 47% of nitrogen pollution, and 67% of phosphorus pollution in China [40]. The effective utilization coefficient of farmland irrigation water is 0.56 [39], which is lower than that of developed countries (0.7–0.8) [15]. Measures for conserving clean freshwater resources for agriculture include water-efficient irrigation, more efficient water transmission and distribution infrastructure, drought and stress tolerant crop varieties, reduced fertilizer applications, and better recovery of livestock manure.

3.3 Reduce

Reducing inefficiencies and pollution in China's agrifood system and reducing levels of unhealthy diets can contribute to China achieving its carbon neutrality and food security aspirations. Five areas needing some form of "reduction" include:

- ***Reduce food loss and waste***. Reducing food loss and waste would provide a triple win of improved food security, reduced financial losses for farmers and consumers, and lower environmental impacts (e.g., GHG emissions, water consumption, pesticide/fertilizer pollution). Numerous approaches to reducing food loss and waste per stage of the food value chain exist [41], with many relevant for China. Modeling suggests that reducing Chinese food loss and waste relative to the baseline would lower the country's agricultural GHG emissions by 2.0–5.6% by 2030 and 4.0–7.0% by 2060 [10].
- ***Reduce chemical pollution from agricultural production***. Several approaches for doing so exist. For example, precision agriculture can increase the utilization rates of fertilizers and pesticides, thereby lowering the total amount of inputs applied and amount of runoff into the environment. Buffer zones of natural vegetation around farm fields and in riparian areas can reduce input runoff. In some situations, integrated pest management approaches can lower pollution while maintaining yields.
- ***Reduce use of plastics in agrifood system and increase rates of recycling***. Options include promoting the promulgation and implementation of new national standards for plastic films, improving plastic film thickness standards, increasing the tensile strength and elongation at break of plastic films, and ensuring the recyclability of plastic films from the source.
- ***Reduce inefficiencies and use of fossil fuels in agriculture energy***. Options include renewable energy sources for farm equipment, food storage, and transportation.
- ***Reduce consumption of unhealthy, unsustainable, carbon-intense diets***. A first step in improving the health and sustainability of Chinese diets is to encourage citizens to follow the Chinese Dietary Guidelines and, even better, the EAT-Lancet diet [42]. Such diets would reduce GHG emissions while ensuring nutritional requirements. Such a shift could reduce GHG emissions by 150 million to 200

million metric tons by 2030, a reduction of 18–25% [10]. Future Chinese nutrition and dietary guideline should take into consideration gender implications, sustainability, and climate change.

3.4 Restore

Restoration of natural ecosystems and agricultural soils are important components of achieving the two aspirations of carbon neutrality and food security.

- ***Restore natural ecosystems***. Restoring native ecosystems in China is the primary means of generating the "negative carbon emissions" the country needs to compensate for its difficult-to-abate agriculture and energy GHG emissions. Without such restoration, China will be unable to achieve "carbon neutrality" before 2060. Ecosystems to restore include forests (which have the largest carbon content per hectare), grasslands, and wetlands. Forests are particularly important because, among terrestrial ecosystems, they currently contribute about 80% of the country's annual carbon sequestration [4]. Targeting restoration in marginal areas such as slopes, riparian zones, and low-agriculture-productivity areas would reduce the risk of creating land-competition for food production. To maximize carbon sequestration, biodiversity benefits, and resilience to climate change, ecosystem restoration should prioritize a diversity of native flora and fauna; monoculture restoration efforts tend to generate fewer benefits and be more susceptible to collapse due to weather extremes or disease [43].
- Currently, forests occupy 23% of the country's land mass. China already has a stated goal of restoring "up to 25% of land area in forests" by 2030 [3]. Following through on this goal would lead to annual carbon sequestration on the order of 230 million tons per year by 2030 [43]. Some studies suggest a maximum potential of China's forest coverage to be 28–29% of national land area [43]. Achieving that level of forest coverage would boost China's carbon sink to 2.1 billion tons per year by the year 2060 [43].
- ***Restore degraded agricultural soils***. Restoring soil health can help reduce carbon losses to the atmosphere and reduce pollution of waterways. More importantly, it can contribute to the "Produce" strategy by improving long-term farm yields, moisture retention, soil organic matter, farmer livelihoods, and resilience. Likewise, it supports the "Protect" strategy by reducing the need to expand agricultural area to meet national food needs. Approaches to such restoration include agroforestry and silvopastures practices (integrating trees into croplands and grazing lands), reduced or conservation tillage, mulching, crop rotations, and cover crops. Ensuring that women farmers also have access to restoration techniques, given their concentration in agricultural activities and lesser access to technical training and information, would support expansion and widespread adoption of these practices.

- China is already taking some steps in this direction. For example, China has implemented a conservation tillage plan in the "black land" area in the northeast of the country. By 2030, the restored area will be 17 Mha [44]. Estimates are that organic matter in soil will increase by 10% after 5 years and by 52% after 15 years [45].

3.5 Quantification of Emissions Reduction Potential

This combination of solutions—produce, protect, reduce, and restore—could result in China's agrifood system contributing to national 2060 carbon neutrality. The level of contribution to neutrality will be a function of the degree of implementation. Figure 2 shows the impact on domestic Chinese GHG emissions of many of the "produce" and "reduce" strategies, against 3 implementation scenarios. Table 2 describes the scenario designs. Emission reductions would be even greater if the "protect" and "restore" strategies were pursued.

The scenarios highlight several important insights, including:

- Under BAU, GHG emissions from agrifood systems reaches 1.17 billion tons in 2030, an increase of 7.7% compared with 2020, and then they further decline to 1.09 billion tons in 2060, returning to their level of 2018.
- Measures such as improving agricultural technology, reducing food loss and waste, shifting dietary patterns, enhancing energy efficiency, and optimizing the energy consumption structure substantially reduce GHG emissions from agrifood systems.
- In the low, medium, and high scenarios, GHG emissions from agrifood systems in 2060 are 17–63% lower than under BAU and 19–63% lower than in 2020.

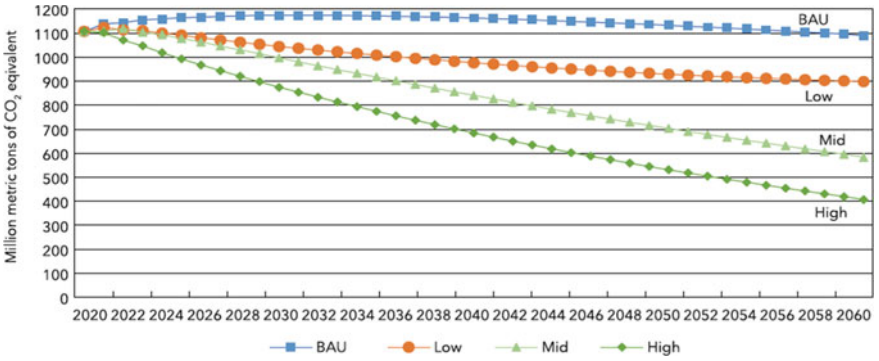

Fig. 2 Greenhouse gas emissions from agrifood systems in China under different scenarios, 2020–2060. *Source* Results of China Agricultural Sector Model (CAAS and IFPRI) and China Dynamic General Equilibrium Model (AGFEP, 2021). *Note* BAU = business as usual

Table 2 Scenario design for modeling greenhouse gas emission reduction of agricultural activities in China, 2020–2060

Area	High-level scenario	Medium-level scenario	Low-level scenario
BAU	Yields of rice, wheat, and maize in 2020 were 7, 5.7, and 6.3 tons/ha, respectively, which will be increased by 10%, 15%, and 25% in 2060, reaching 7.7, 6.6, and 7.9 tons/ha, respectively The loss and waste rate of rice, wheat, and maize is 15%; of vegetables and fruits are 55% and 50%, respectively; and of pork, beef, and mutton are 15%, 10%, and 10%, respectively Urban and rural residents' per capita consumption of livestock and poultry meat will be 223 g per day in 2060 In 2060, fertilizer use efficiency will be increased by 20%; the emission coefficient of rice fields will be reduced by 20%; the coefficients of carbon emissions from pork, mutton, and poultry meat will be reduced by 15%, 25%, and 30%, respectively; and the coefficients of carbon emissions from beef, poultry eggs, and milk will be reduced by 10%		
Tech-CR	Yield of rice, wheat, and maize in 2060 will be increased by 25%, 40%, and 50%, respectively, as compared with 2020; fertilizer use efficiency will be increased by 50%; and the coefficient on emissions from rice fields will be reduced by 50%	Yield of rice, wheat and maize in 2060 will be increased by 20%, 35% and 45%, respectively, as compared with 2020; fertilizer use efficiency will be increased by 40%; and coefficient of emission from rice fields will be reduced by 40%	Yield of rice, wheat and maize by 2060 will be increased by 15%, 25%, and 35%, respectively, as compared with 2020; fertilizer use efficiency will be increased by 30%; and coefficient of emission from rice fields will be reduced by 30%
Tech-LV	The coefficient of emissions from livestock products in 2060 will be reduced by 50%, with the feed conversion rate improved by 30%	The coefficient of emissions from livestock products in 2060 will be reduced by 40%, with the feed conversion rate improved by 20%	The coefficient of emissions from livestock products in 2060 will be reduced by 30%, with the feed conversion rate improved by 10%
Waste	The loss and waste rate of each product in 2060 will be 67% lower than that in 2020	The loss and waste rate of each product in 2060 will be 50% lower than that in 2020	The loss and waste rate of each product in 2060 will be 33% lower than that in 2020
Diets	Per capita consumption of livestock and poultry meat by urban and rural residents in 2060 will be reduced to the lower limit recommended by the dietary guidelines, of 40 g per day	Per capita consumption of livestock and poultry meat by urban and rural residents in 2060 will be reduced to the median level recommended by the dietary guidelines, of 60 g per day	Per capita consumption of livestock and poultry meat by urban and rural residents in 2060 will be reduced to the upper limit recommended by the dietary guidelines, of 75 g per day
Comb	Combination of the above scenarios	Combination of the above scenarios	Combination of the above scenarios

Source AGFEP (2021)

- The medium-level scenario would contribute to a reduction of 47% of GHG emissions in agrifood systems in 2060, compared with 2020.

4 Recommendations

Six policy, governance and institutional innovations are recommended to enable the leadership, innovation, and concerted effort to accelerate China's food system transformation. The arch of these recommendations is not linear, although a certain degree of sequencing will be needed. As stated above, the objective of this Special Policy Paper is not to formulate products or practices that can be deployed to achieve prescribed outcomes. The food system is a complex system that requires not a cluster of projects, but a process to engage the relevant institutions in developing solutions that respond to multiple interdependencies. These six recommendations are intended to create and support this process.

4.1 Develop a National Food System Transformation Strategy

To draw clear national objectives and paths to realistic, necessary, and sufficient outcomes, a "China National Food System Transformation Strategy" could define a 2060 vision and a 2030 Action Plan, which will need to be:

- Science-based—incorporating the latest technical advances supporting a food and land use system transformation and the approaches or tools for assessing and managing trade-offs between solutions and objectives.
- Accountable—internally coherent to deliver explicitly stated and measurable goals while supporting and relying on the relevant components of China's Carbon Neutrality Plan, 5-year plans, and the National Determined Contribution (NDC) to the Paris Agreement on climate change.
- Multisectoral—governed by an inter-ministerial committee to ensure various ministries and other relevant institutions contribute what is in their purview, address and manage trade-offs inherent to the solutions, and streamline decision-making.
- Gender responsive—as the different goals are agreed, the strategy will explicitly bring the voices of women in the establishment of a vision for the future food system and the charting of pathways to get there.

The strategy should ideally be driven by an inter-ministerial committee responsible for overseeing the development and implementation of the strategy, ensuring various ministries do what they need to do for their contribution to the strategy, discussing and managing trade-offs, and streamlining decision-making. The council could include representatives from ministries of agriculture, environment, trade, health and food safety, women, planning, and finance. The committee could be

the same one that was recommended by the 2020 CCICED Special Policy Study, "Greening China's Soft Commodity Value Chains", tasked with overseeing China's green value chain strategy. Thus, there would be one inter-ministerial committee for the entire agrifood system transition, covering domestic and international food systems.

Relevance of the recommendation. Food, as vitally important as it is, is for the most part not treated as a sector by most governments. Food is defined by the institutional and market forces impinging on it. Without a deliberate effort to make this institutional space coherent and oriented towards shared goals, it is unlikely that the challenges listed in Section II can be overcome. This is not a recommendation to create an additional bureaucratic structure, but to create a process to develop a vision shared by the relevant stakeholders and to identify the trade-offs across the sectors that need to be resolved if the food system outcomes are to be achieved.

4.2 Repurpose Agricultural Fiscal Incentives and Finance

To advance the solutions, China could launch a concerted effort to redirect significant financing in support of its national food and climate security goals. Much of this repurposed agriculture support should be geared toward research and development (R&D) for technology solutions that are not yet market ready, as well as toward deployment programs to increase market penetration of solutions that are already in the market. Such repurposing and design of cross-sectoral fiscal incentives can signal a shift away from traditional production toward better production efficiency, nutrition, and sustainability.

- Potential sources of public financing may include: (a) redirecting existing agricultural subsidies away from programs incentivizing agricultural practices that have proven unsustainable; and (b) taxing activities that increase the climate footprint of China's agrifood system.
- Potential uses of these resources may include: (a) financing solutions delineated in this study as framed by the National Food System Transformation Strategy; (b) funding of place-based ecological compensation programs, applying lessons learned from the inter-provincial ecological compensation mechanism used for the Xin'an River; and (c) and providing technical assistance to farmers for adoption of improved land-use management.
- Additional financing may be attracted from the private sector by the government providing policy and financial support (e.g., "first-loss" risk reduction) to encourage private sector companies and banks to invest in research, development, and/or deployment of solutions outlined in this study.

Relevance of the recommendation. Clearly, the transformation of China's food system will require substantial financing. New research will need to be funded, capacity to develop and apply new technologies will need to be enhanced, etc. But in many ways, stop funding or subsidizing that which moves the system away from

its desired outcomes is as, if not more, powerful to shift norms and help develop the behaviors that are needed to align investment with desired outcomes.

Parallel to this SPS, another study sponsored by the CCICED is being developed on Innovative green finance. The study on finance provides an in-depth assessment of the different mechanisms that can be established to bankroll the food transition, particularly as some of the solutions identified in our food paper represent opportunities for integrating climate with nature finance. A subsequent step in the development of this ideas could be a join seminar of the groups working on each of the two SPS and further identify areas of opportunity for mutual leverage.

4.3 Healthy Diets and Consumption

China's major food production and consumption transformation over the last three decades have been largely driven by specific changes in dietary preferences and affordable choices available. The overall trend in food consumption is characterized by a reduction in the consumption of basic grain staples and an increase in the consumption of animal-based food. While the rural population lags behind the urban population in these trends, most assessments indicate a significant growth potential in rural areas.

The major consequences of nutrition levels of these changes include an initial improvement on caloric and proteinic intake followed by an increase in cardiovascular disease and prevalence of obesity once a certain level of carbohydrates has been surpassed. The access to richer foods is largely facilitated by the processing and retailing of food products that tend to recreate the western diet, including a prevalence of processed and ultra-processed food. Up until now the government's dietary guidance has been limited, leaving the door open for supermarkets and other commercial retailers to shape the diet of many in China.

A dietary-guidance initiative could center on the development of a gender-responsive and inclusive national program for encouraging a healthy and sustainable diet (in accordance with recommended dietary guidelines), that takes into account the needs of a diversity of women and men from both rural and urban areas, based on, but not limited to:

- Strengthening awareness messaging, package labeling, and food marketing laws, etc.
- Linking a healthier diet with a sustainable production scheme aimed at increasing the production of fresh fruits and vegetables by Chinese smallholders (an oft overlooked sector) and increasing access to fresh fruits and vegetables by Chinese consumers
- Expanding the national Clean Plate Initiative to tackle food waste (and associated plastic waste) at retail (including the shopping environment), food service (including e-commerce), and household levels

- Promotion of alternatives to animal protein, particularly from beef, including synthetic meat, plant-based processed protein rich meals, etc.

Relevance of the recommendation. When well informed, citizens prioritize health and healthy lifestyles as a major factor in shaping their diets. Public health and the environment overlap around food in a significant way; decisions by food processors have health and environmental consequences at a significant scale. Food produced and processed as guided by the opportunities in the market need to be balanced with a non-commercial set of guidelines that consumers feel compelled to base their food choices on. Fortunately, in many ways what is good for health is also good for the environment. Getting the right alignment between what is marketed and what is nutritionally needed should be achievable in the short term, but for that to happen information, education and government incentives need to be adequately aligned.

4.4 Accelerate the Agrifood System Transformation Through Private Sector Leadership

In close coordination with public institutions, including the proposed National Food System Transformation Strategy and the inter-sectoral food system committee, the private sector could specifically help accelerate investment and innovation across the supply chain through:

- Supporting efficient but fair consolidation of farmland. Farm size is critical when deploying the adoption of new technologies at scale, with larger areas being preferred given the investments needed. Private companies could help create financial arrangements whereby small landholders can participate in collective efforts to achieve scale without risk of losing their land.
- Supporting food safety programs. While food safety is ultimately a responsibility of government at different jurisdictional levels, the private sector can make this task more manageable and efficient by introducing the traceability protocols and technology needed to manage integrated supply chains.
- Providing and enabling dietary guidance. While remaining commercially viable, large food retailers can play a significant role in educating and guiding consumers on practical ways to adhere to government-backed dietary guidelines.

This private sector initiative calls for the development of mechanisms that favor the exchange of information among supply chain actors, including the perspectives of women and other marginalized groups within the supply chain, agreement on standards, and feedback to government agency on policy application challenges and opportunities.

Relevance of the recommendation. The private sector has evident advantages in the pursuit of a secure, safe and sustainable food system. Through business consolidation, supply chains become more manageable and controllable. This is because fewer actors can exert influence at a scale that a highly fragmented producers base,

distribution and retail simply cannot. Businesses can innovate practices and products at a rapid rate to adapt both to regulations and consumer demand. By being a key point of contact between production and consumption, businesses are in a privileged position to educate and guide residents towards healthier and more sustainable consumption behaviors.

4.5 Incentivize Alternative Sources of Protein and Food Technology

Most analyses on the impact of diet and health and the environment conclude that reducing the amount of meat consumption is the single-most efficient way to curb the rapid growth rate of cardiovascular disease and carbon (particularly methane) emissions. Reduction on overall meat consumption should be part of a multi-faceted initiative to sensitize residents to the risks and impacts of meat consumption while actively seeking for and developing alternative sources of protein, including plant-based and synthetic meat. Such efforts are today being developed largely by private entrepreneurs facing a significant learning curve.

As stated above, the private sector efforts in this regard can be accelerated with the right policies and incentives in place. As a key stakeholder, the government should create the enabling conditions and incentives for Chinese companies to become major global manufacturers of alternative proteins (e.g., plant-based meats like *Impossible Foods*, lab-grown meats) and alternative starches. Doing so the government will be helping:

- Meet growing domestic and foreign demand for protein
- Address climate change and land competition
- Create an entire new industrial sector for China that China could lead the world on.

Relevance of the recommendation. A significant accelerator of the desired transformation of the food system in China will be innovation and technological leadership. China as a food powerhouse in the world is in a unique position to develop its own food revolution given the virtuous cycle shaped by tradition and innovation. Moving away from the position of "taker" of western food habits to one where China sets the future of protein uptake, for instance, can have tremendous positive impact both domestically and globally.

4.6 Green International Food Value Chains

China could pursue a program to ensure that the food it imports is low carbon, thereby helping reduce food supply GHG emission. The 2021 report of the CCICED Special Policy Study, "Greening China's Soft Commodity Value Chains", identified several

measures for this program. Food and other agricultural goods are the dominant form of "soft commodity" (Box 3). The recommendations from the 2020 Study were approved and endorsed by the China Council in 2020. These recommendations are a critical component for sustainable food supply chains overall and would help meet China's food and climate security goals. As such, the 2020 recommendations are worth reinforcing in this current Special Policy Study:

4.6.1 Establish a National Green Value Chain Strategy and Provide Policy/Institutional Support

- Announce a new Chinese policy initiative on greening soft commodity value chains
- Establish an Inter-Ministerial Committee (see above)
- Establish a "Global Green Value Chain Institute"

4.6.2 Adopt Mandatory and Voluntary Measures to "Green" Soft Commodity Value Chains

- Strengthen measures to reduce the import of soft commodities from illegal sources
- Strengthen due diligence and traceability systems
- Invest in domestic capacity to rationalize food value chains and improve sustainable diets

4.6.3 Leverage Existing Chinese Policy Levers and Initiatives Including the Belt and Road Initiative

- Incorporate green value chain measures into trade agreements
- Increase Chinese South-South development assistance to support green soft commodity value chains
- Integrate finance for green soft commodity value chains with green finance and the work of the BRI International Green Development Coalition

Box 3 What Are "Soft Commodities"?

"Soft commodities" refer to raw materials and their derivatives that are grown or produced by the agriculture and forestry industries. These include plant- and animal-derived material for use as food, fiber, feed, medicines, cosmetics, detergents, and fuels. These contrast with "hard commodities", which are raw materials and their derivatives that are extracted or mined, such as metals, oil, and natural gas.

In parallel to this SPS, another CCICED study has been developed on Sustainable Trade and investment. There are several points of overlap between green supply chains and trade and investment. For instance, how to use and work within trade rules to ensure that environmental and climatic priorities can coexist with fluid trade, for the benefit of importer and exporter. It is in the best interest of traders to lift the standards of the commodities they trade around the globe. The study on trade provides an excellent analysis of synergies that food mediates between trade and the environment, but also of the difficulties and frictions that can occur in trying to resolve trade-offs across countries without positive cooperation.

5 Concluding Remarks

Combined, these six policy, governance, and institutional recommendations would set China's agrifood system on a path to simultaneously achieve food security and carbon neutrality. Each of these recommendations is within China's power to implement. And each would generate many co-benefits including improved human health and new Chinese industries.

The time to act on these recommendations is now. The emerging global food crisis triggered by the Russia-Ukraine conflict, inflation, and climate-induced crop failures is putting food security near the top of national agendas. These recommendations ensure that when China addresses the near-term food challenge it does so in a way that addresses the long-term challenge of climate change.

For China, as for the world, food security and climate security must go hand in hand.

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