Tapping the emissions reduction potential of China's food and land use systems to achieve carbon neutrality

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The Food and Land Use Coalition

Contents

Authors

Helen Ding
World Resources Institute (WRI)

Aline Mosnier
Sustainable Development Solutions Network (SDSN)

Clara Douzal
Sustainable Development Solutions Network (SDSN)

Zhaohai Bai
Center for Agricultural Resources Research
Institute of Genetic and Developmental Biology
Chinese Academy of Sciences

Haijun Zhao
Food and Land Use Coalition (FOLU)

Seth Cook
Food and Land Use Coalition (FOLU)

Shenggen Fan
Academy of Global Food Economics and Policy
China Agricultural University

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Abstract

China's current long-term decarbonization pathways towards its 2060 carbon neutrality target primarily focus on energy and energy-related sectors. The climate mitigation potential in food and land use systems is largely overlooked owing to a dearth of scientific evidence and lack of a holistic policy framework. Based on a review of the literature and databases, this report shows that between 2005 and 2015, on-farm agricultural production was by far the largest source of emissions from China's food and land use systems (44%), followed by post-production and consumption (31%). The report identifies supply- and demand-oriented mitigation measures and associated co-benefits in China's food and land use systems, and also explores China's food and land use policy landscape to identify several institutional and policy barriers to carbon neutrality. China needs to develop coherent policies that will address food and land use emissions in a holistic manner while taking into consideration food security, health, environment protection, biodiversity, and climate targets. Actions towards these targets in turn will contribute to greater climate resilience, improved local livelihoods and human health, and long-term economic prosperity. To assist and facilitate China's transition from its current sector-focused approach to a holistic, systems approach, we propose actions for policymakers, researchers, and NGOs.

1. Introduction

The Intergovernmental Panel on Climate Change's special report of August 2021 (IPCC, 2021) presents new evidence suggesting that the 1.5°C target limit set out in the Paris Agreement will likely be reached or exceeded between 2030 and early 2050 unless concerted action is taken to significantly reduce greenhouse gas (GHG) emissions in the next decade (Levin et al., 2021). The first round of global commitments made in the Nationally Determined Contributions (NDCs) are not enough to limit global warming to 1.5°C (Climate Watch, 2021), and are more likely to contribute to 2.5°C to 3°C of warming by 2100 (Rogelj, et al., 2018). To stay on track for the 1.5°C target, countries will need to reduce the predicted 2030 GHG emissions by 55% (UNEP, 2021). However, the revised NDC commitments made prior to the 26th United Nations Climate Change Conference of the Parties (COP26) in November 2021 would only amount to a 7.5% reduction.

The agriculture and land use sector, commonly referred to as 'agriculture, forestry, and other land uses' (AFOLU), was responsible for 10–12 gigatonnes of carbon dioxide equivalent ($GtCO_2e$), about 25% of the annual total GHG flux (net emissions), between 2007 and 2016 (IPCC, 2019). Approximately half of these come from agriculture and half from land use, land use change and forestry (LULUCF) (IPCC, 2019). If emissions associated with the global food system are included, the food and land use system is responsible for one-third of global GHG emissions (IPCC, 2019; Roe et al., 2019; Tubiello et al., 2021; see also Box 1). It is estimated that transforming the land use sector and deploying measures in agriculture, forestry, wetlands and bioenergy could deliver over 30% (or 15 $GtCO_2e$ per year) of the global mitigation needed in 2050 (Roe et al., 2019). More specifically, these measures would include: (1) reducing GHG emissions by avoiding deforestation and degradation, improving agricultural practices, shifting to more plant-based diets and reducing food loss and waste; and (2) removing carbon through restoration, improving forest management and agroforestry, enhancing soil carbon sequestration, and deploying bioenergy and carbon capture and storage (BECCS).

Despite their large share of GHG emissions and their potential to sequester carbon, food and land use systems have not received sufficient attention from national policymakers (FOLU and SDSN, 2021). Few countries have provided clarity on their anticipated land-based mitigation (Fyson and Jeffery, 2019), and the full potential of forests for addressing climate change is largely untapped (WWF et al., 2020).[1]

On 28 October 2021, China released its revised NDC (UNFCCC, 2021). It aims to reach peak CO_2 emissions before 2030 and achieve carbon neutrality before 2060. The carbon neutrality goal was a political commitment of the central government, which shows the country's ambition on climate mitigation. To achieve this ambitious goal, it is essential that China's emissions from all sectors peak quickly. If this does not happen, China's cumulative emissions will be higher, creating substantial challenges for achieving carbon neutrality before 2060 (Energy Foundation China, 2020). Consequently, in the coming years, climate mitigation targets must be determined for all economic sectors based on sector specific research, including for food and land use systems. The significance of emissions from this sector is historically overshadowed by other key industry sectors such as energy, transport,

1 However, the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow could be a turning point, as forests were front and center throughout the conference. Among the significant announcements made at COP26 was the Glasgow Leaders' Declaration on Forests and Land Use, in which 137 countries committed to collectively end forest loss and land degradation by 2030 (Masood and Tollefson, 2021). Such actions relevant to food and land-use systems should be an integral part of NDCs and contribute to the carbon neutrality goal.

manufacturing, and construction. Hence, pursuing the national carbon neutrality goal presents a unique opportunity for China to develop an integrated approach by incorporating the food and land use system into its decarbonization pathways. In this regard, this paper highlights the climate mitigation potential of the food and land use system and outlines concrete actions that can be taken to achieve it, focusing on China's domestic climate footprint.[2]

The paper draws from secondary data, the literature and workshops with the Food and Land Use Coalition's (FOLU) China network of academics and civil society working in food and land use systems during the course of the research period (between 2020 and 2021). The paper first explores the role for China's food and land use systems in achieving its carbon neutrality ambition, including GHG accounting and mitigation options. It then goes on to explore China's food and land use policy landscape in relation to its carbon neutrality ambition. Based on the analysis and the feedback provided by workshop participants, the paper ends with specific actions for various stakeholders, including policymakers, researchers, and NGOs.

2 While it can be argued that the trade dimension and international climate footprint is also critical, this paper maintains a narrower focus on domestic emissions in order to illustrate how to account for AFOLU emissions vs other sectoral emissions. Transboundary emissions are complex and deserve a separate treatment, supported by modelling results. It is also important to note that emission reductions in other countries through decreased trade with China are not counted towards China's carbon neutrality goal, or towards any other countries' goals for that matter.

2. The role for China's food and land use systems in achieving its carbon neutrality ambition

Globally by 2050, the agriculture sector is likely to have the largest residual emissions (i.e., emissions remaining to be tackled) of any sector (IPCC, 2014). This is also the case for China (AGFEP et al., 2021). A recent study has suggested that even after accounting for a low-carbon transition in the energy system, plus the potential of carbon capture technology, there would remain between 0.3 billion and 3.1 billion tons of carbon to be sequestered in China every year to achieve carbon neutrality by 2060 (Yu et al., 2021). To this end, an integrated approach is needed to significantly cut emissions and increase carbon sinks in food and land use systems (Roe et al., 2019).

The Food and Land Use Coalition has put forward ten critical transitions needed to transform food systems (from production to consumption) in order to systemically address major global challenges such as GHG emissions, biodiversity and natural habitat loss, and malnutrition (FOLU, 2019). Such an approach will also be important to set China on course for carbon neutrality by 2060, while meeting other key objectives such as food security, environmental health, human health, biodiversity conservation, and building more resilient food systems in the face of climate change and other disasters.

However, a clear definition of system boundaries is lacking in China. To address GHG emissions in China's food and land use systems, an essential first step is to clearly define the system boundaries and ensure all emissions within the system are properly accounted for. In this section, we put forward a definition of the boundaries of China's food and land use systems for total emission accounting, following the IPCC guidelines. We also explore the potential for reducing emissions linked to consumption by tackling food loss, waste and unsustainable diets, as these measures can help China to peak emissions in its food and land use systems sooner and bring the country's carbon neutral goal within reach.

2.1. Understanding emissions from China's food and land use systems

The term 'food and land use systems' covers "every factor in the ways land is used and food is produced, stored, packed, processed, traded, distributed, marketed, consumed and disposed of" (FOLU, 2019). As such, emissions from these systems should not only encompass AFOLU emissions and sequestration related to food and non-food production, but also GHG emissions from energy, industry, transportation, and waste sectors related to food and agricultural production, processing, packaging, retail, transportation and the end of life of food products (Figure 1 and Box 1).

Box 1. Food and land use systems are responsible for one third of global anthropogenic GHG emissions

Of all the emission sources from food and land use systems, AFOLU activities such as agriculture, deforestation and land use change contribute the most, accounting for 71% of total system emissions at the global level (Crippa et al., 2021). The large majority of the AFOLU emissions are related to food production (agriculture) and related land use and land use change (LULUC). In comparison, non-food crops-related emissions only represent 2% of AFOLU emissions. Non-food crops refer to crops that are grown to produce goods for manufacturing, for example fiber for clothing, rather than food for consumption.

Of the estimated 18 $GtCO_2e$ attributable to the global food and land use system (about 30% of global total GHG emissions), about one-third comes from agriculture, one-third from LULUCF, and one-third from energy use in the food system, including the food production stages, input production, distribution, processing (Crippa et al., 2021).

In other words, while AFOLU[3] emissions are fully encompassed in food and land use systems, other IPCC GHG inventory categories (IPCC, 2006) also partly contribute to food and land use systems emissions. This makes it challenging to account for them all accurately. Based on the IPCC guidelines for GHG inventories, in this study we include the following (sub-)categories:

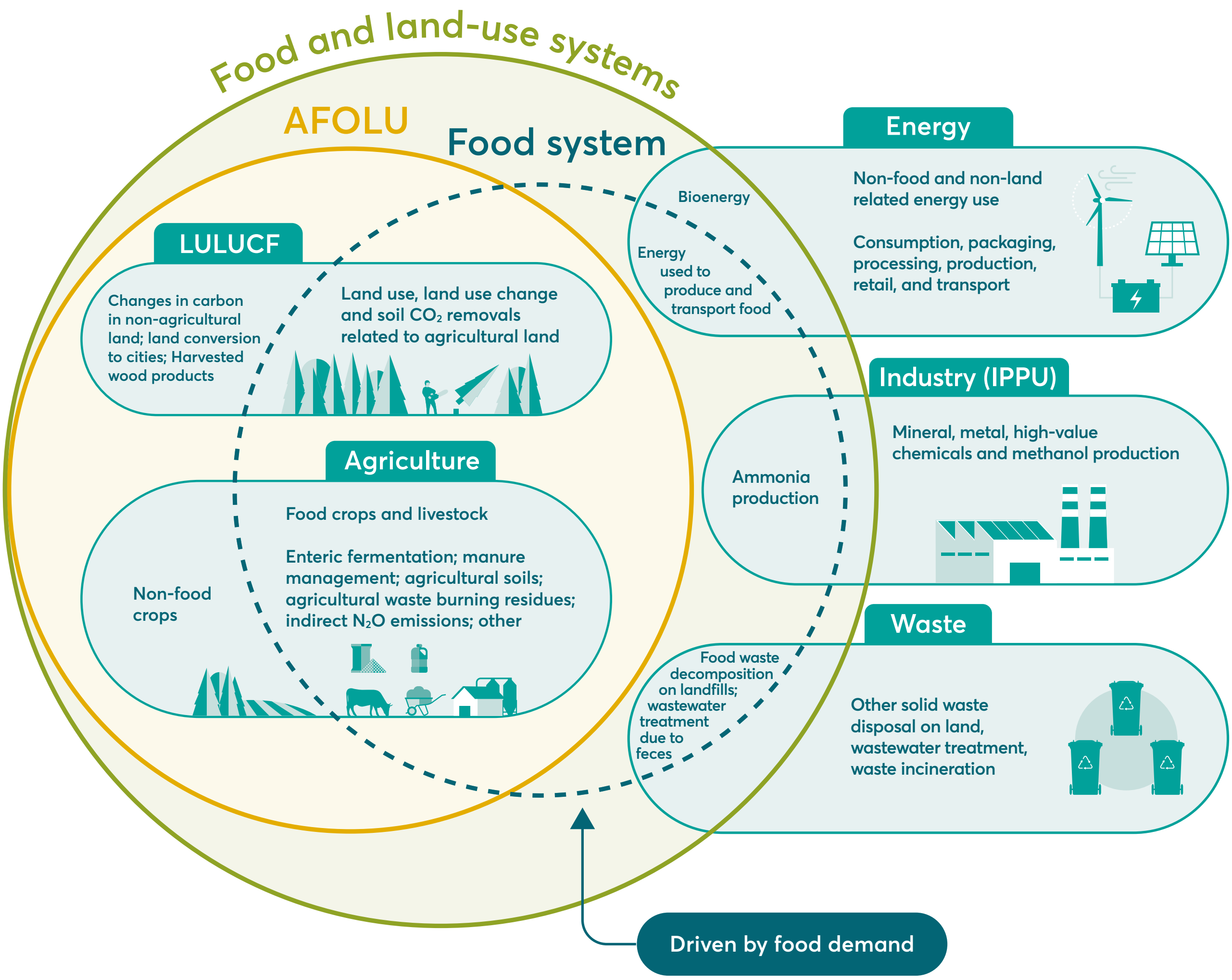
- **LULUCF:** all GHG emissions and sequestration from land use, land use change, and forestry.
- **Agriculture:** all GHG emissions and removals from agriculture within the farm gate.
- **Energy:** primarily GHG emissions related to energy use for food production and transportation along the entire food value chain, including on-farm energy use, as well as food consumption, packaging, processing, retail and transport. Emission savings from fossil energy substitution by bioenergy also fall under this category.
- **Industry:** only GHG emissions related to ammonia for fertilizer production.
- **Waste:** only GHG emissions from decomposition of food waste in landfill.

The advantages of using the IPCC guidelines for GHG inventories are that we ensure that there is no omission or double counting of GHG emissions, and that this is comparable with other countries. However, access to sufficient information to isolate the emissions from energy, industry and waste disposal related to food and land use systems can be challenging.

3 According to the UNFCCC classification, emissions from the AFOLU sector consist of two components: (1) emissions from agriculture, i.e. methane (CH_4) and nitrous oxide (N_2O), emissions from agricultural soils and livestock (Appendix Table), but excluding emissions already accounted for in other reporting categories, such as on-farm energy use; and (2) emissions from and sequestration related to land use, land-use change and forestry (LULUCF). Reporting categories for LULUCF differ between Annex 1 and Non-Annex 1 parties of the UNFCCC (Appendix Table 1). China is a non-Annex 1 country, but uses the Annex 1 categories for its historical GHG emissions reporting to the UNFCCC.

Finally, food demand is an external driver of total GHG emissions in the food and land use system (Figure 1), as changes in demand can directly influence the inputs and outputs of the food production system and associated emissions. For instance, lower overall food demand reduces agricultural production and associated GHG emissions. Similarly, dietary shifts towards more plant-based diets will reduce food's carbon footprint.

Figure 1. System boundaries for accounting for GHG emissions and sequestration from food and land use



Note: The intersection of the various circles shows overlaps between different definitions: for example, the intersection of the yellow AFOLU circle and the green food system circle corresponds to the GHG sources from AFOLU that are considered in the food system total accounting. Thus, emissions from forest removals in remaining forest land are excluded from the food systems accounting (but included in the land use systems accounting as part of LULUCF), as these are not typically related to crop and livestock production. Food and land use systems encompass all emissions and sequestration from AFOLU plus GHG emissions related to the food supply chain activities in the energy, industry, and waste categories.

AFOLU: agriculture, forestry, and other land uses; Emission savings from fossil energy substitution by bioenergy; IPPU: industrial processes and product use including processing, refrigeration and solid fuel cookstoves; LULUCF: land use, land use change and forestry

Source: Authors, based on Crippa et al., (2021) and the IPCC Guidelines for GHG Inventories (IPCC, 2006)

Building on this accounting method and the latest FAOSTAT data (FAOSTAT, 2022), FOLU's partners in China have estimated the GHG emissions from China's food and land use system. The food and land use system emissions and removals are classified into six main categories (Figure 2):

1) Emissions from agricultural production (methane - CH_4, nitrous oxide - N_2O), such as from rice production, livestock enteric fermentation, and fertilizer use; as well as emissions (CO_2) from direct on-farm energy use (including diesel for tractors and transport, etc.);

2) CO_2 emissions from land conversion;

3) CO_2 emissions from agricultural pre-production activities, such as manufacturing of fertilizers and on-farm electricity use;

4) CO_2 emissions from the post-harvest food supply chain, including food packaging, processing, transport and storage, consumption and food wholesale and retail;

5) CO_2 emissions from the food system waste disposal;

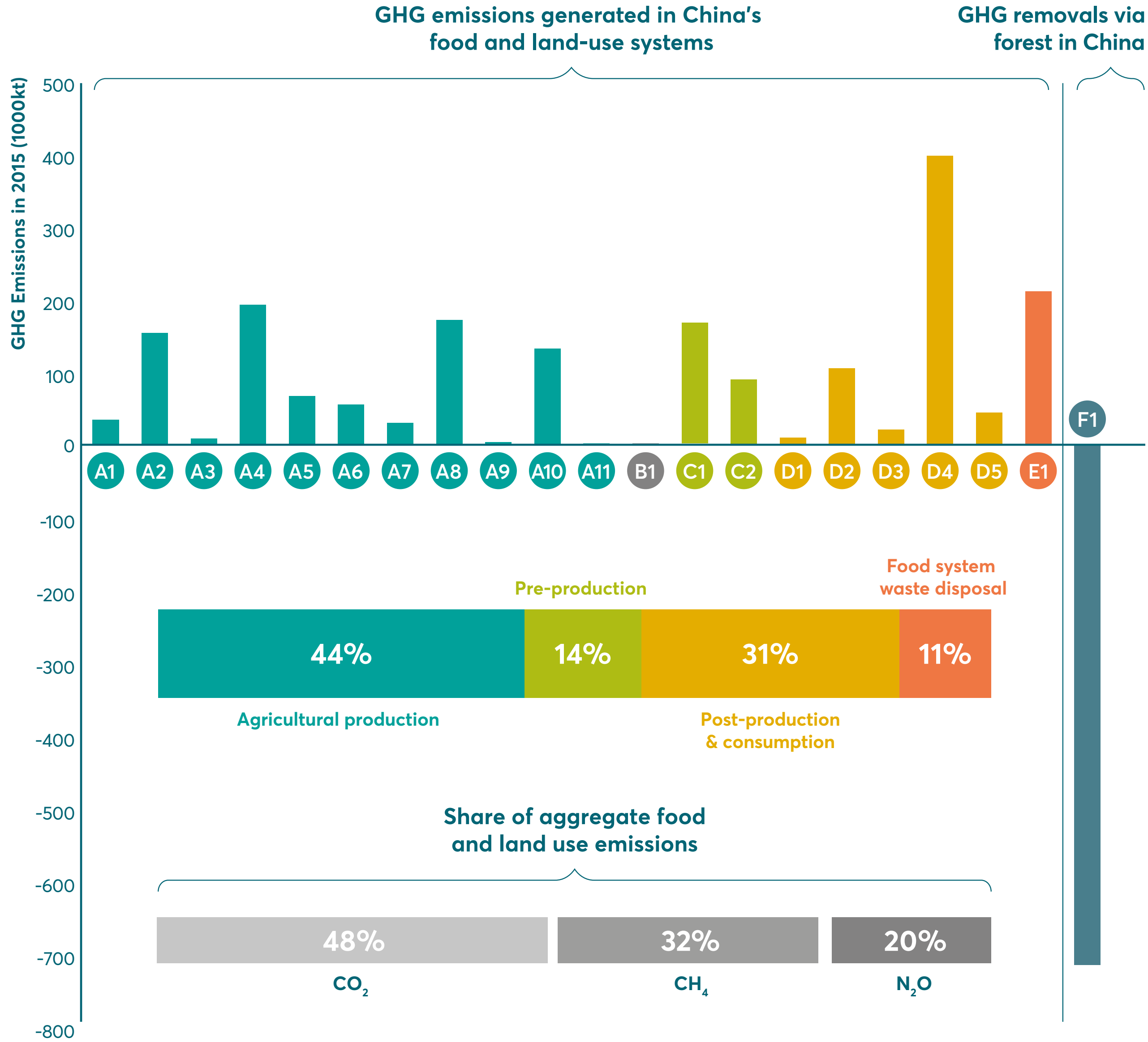
6) CO_2 net removals from forest ecosystems in China.

Our analysis revealed that total net GHG emissions from China's food and land use system (including net removals from forests) averaged 1,164 $MtCO_2e$ every year between 2005 and 2015, or 10% of total emissions in China.[4] Figure 2 shows that 52% of the GHG emissions from China's food and land use systems are CH_4 and N_2O emissions. On-farm CH_4 and N_2O emissions largely come from enteric fermentation, rice cultivation and synthetic fertilizer applications. Taken together, on-farm agricultural production represented the largest portion (44%) of all GHG emissions from China's food and land use system. Post-production (food packaging, processing, delivering) and consumption represent the second largest share, at 31%. Pre-production activities were responsible for 14% of emissions.

When disaggregating these into component subcategories, the food consumption sector was by far the largest emitter, followed by food waste disposal, enteric fermentation, synthetic nitrogen fertilizer application, fertilizer manufacture and rice cultivation (FAOSTAT, 2022). Finally, carbon removals (or sequestration) from forests (mainly from major afforestation efforts undertaken in the past two decades) play a significant role in mitigating GHG emissions from food and land use systems. Without forest carbon sinks, the annual combined gross emissions from the food and land use systems would have been 1,875 $MtCO_2e$, or 17% of China's total GHG emissions.

4 Total net GHG emissions from China (incl. LULUCF) are estimated at 11.11 $GtCO_2e$ in 2015 (https://www.climatewatchdata.org/).

Figure 2. Estimated GHG emissions and removals by China's food and land use systems in 2015



Subsectors

A1	Crop residues	A8	Synthetic fertilizers	D1	Food processing
A2	Rice cultivation	A9	Drained organic soils	D2	Food packaging
A3	Burning crop-residues	A10	On-farm energy use	D3	Food retail
A4	Enteric fermentation	A11	Savanna fires	D4	Food household consumption
A5	Manure management	B1	Land conversion	D5	Food transport
A6	Manure left on pasture	C1	Fertilizers manufacturing	E1	Food systems waste disposal
A7	Manure applied to soils	C2	On-farm electricity use	F1	Forest carbon sequestration (excl. emissions from forest fires)

Source: FAOSTAT, 2022. (See Annex 1 in this report for detailed emission data)

2.2. Tackling emissions from China's food and land use systems

The analysis above provides a critical foundation for better understanding emissions from China's food and land use systems by disaggregating and accounting for the various categories. It highlights that even when taking into account removals from afforestation, the residual net emissions from food and land use systems are still substantial. This suggests that China must strengthen its efforts to cut emissions from its food and land use systems while continuing to explore options that will enlarge its carbon sequestration capacity to counterbalance the residual emissions. Available mitigation options may include the following:

- **Reducing GHG emissions.** China could accelerate investment in new techniques and practices that can significantly cut emissions from agricultural production, from the value chains for food supply and consumption, and from total agricultural energy use.

- **Increasing carbon removals.** China could continue to explore solutions for increasing carbon sinks in forests, croplands and grazing lands to neutralize the residual net emissions from agriculture. Despite the clear policy target to increase forest stocks by 6 billion m^3 by 2030 (UNFCCC, 2021), expanding forest cover to sequester more carbon is limited by land suitability and other competing land uses, such as food production and urban sprawl. Therefore, more research is needed into the potential for increasing soil carbon content in croplands and grazing lands through climate smart agricultural practices, such as no-till/minimum tillage, agroforestry, silvopasture, rotational grazing, etc.

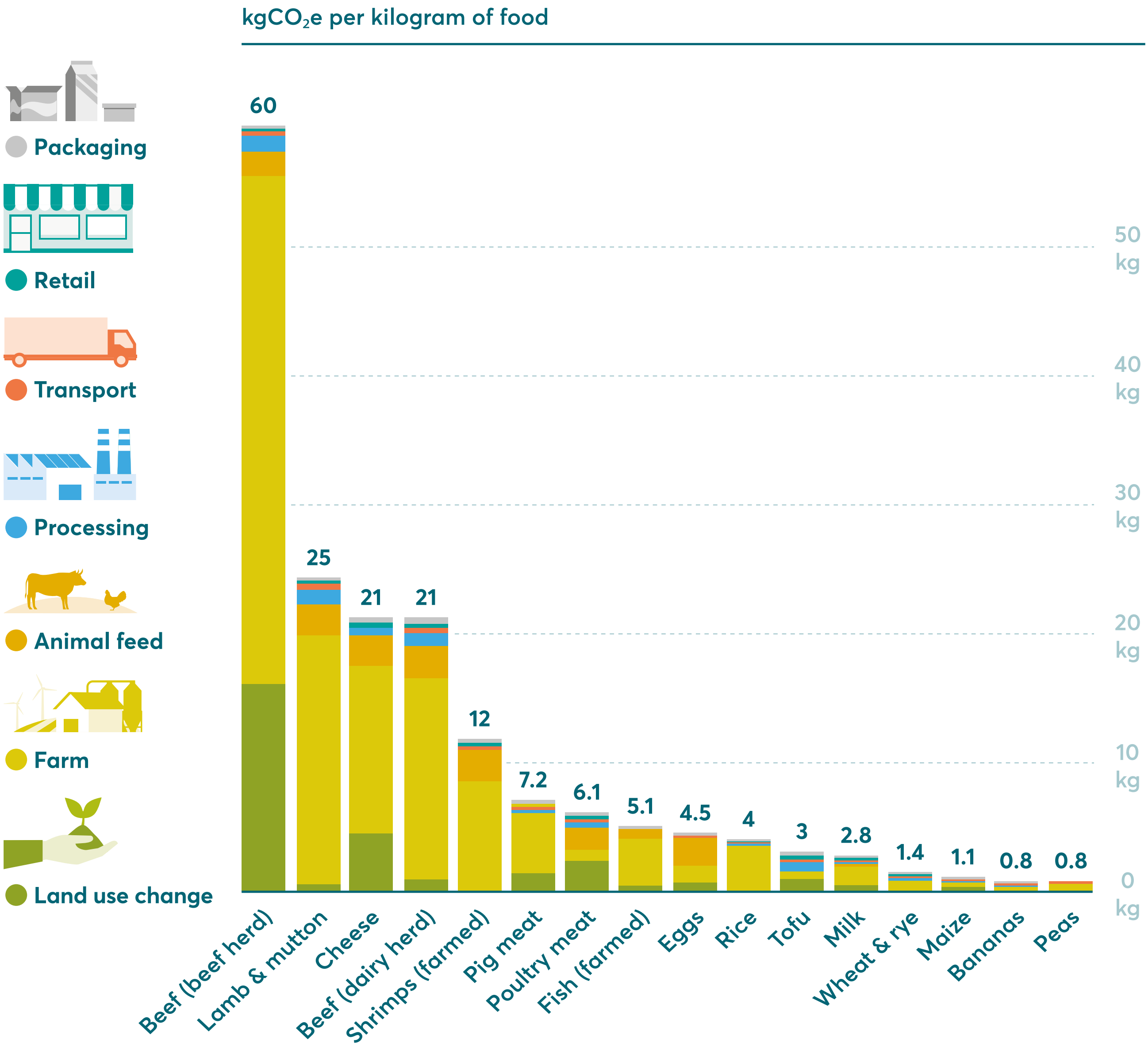
Reducing GHG emissions and increasing carbon removals in food and land use systems are critical for China's carbon neutrality ambition. But such supply-oriented measures can only go so far and need to be complemented by demand-oriented measures. Food demand in terms of quantity and quality is the key driver of GHG emissions from food and land use systems. Managing dietary shifts and tackling excess and wasteful food consumption are therefore critical for China's carbon neutrality ambition. This includes tackling food loss and waste (FLW) and unhealthy diets.

Globally, FLW generates 4.4 $GtCO_2e$ annually, or about 8% of total anthropogenic GHG emissions (EC, JRC/PBL, 2012). This means that the contribution of food waste emissions to global warming is nearly equivalent to 87% of global road transport emissions (IPCC, 2014). In China, FLW is becoming a major sustainability challenge. A recent study found that 27% of food produced for human consumption in the country (349±4Mt) is lost or wasted annually; 45% of this is associated with post-harvest handling and storage and 13% with out-of-home consumption activities (Xue et al., 2021). At the same time, China is facing shrinking arable land for growing food, largely driven by land degradation – about 40% of its soil is already moderately or severely degraded (Patton, 2014). This means China must address FLW to increase food security and reduce pressure on nature through agricultural expansion (CCICED SPS, 2021). The Chinese Government has already made agricultural production and food security a top priority in recent years. With increasingly limited resources, an agricultural policy approach focused on reducing waste and more efficient use of food is necessary to restrain growing GHG emissions (Hawkins et al., 2017).

Substantial changes in dietary patterns have occurred in China over the past decades, with increased consumption of animal-sourced foods; refined grains; and highly processed, high-sugar, and high-fat foods. For example, pork consumption per capita has quadrupled since 1971 and beef consumption has expanded fivefold (He, et al., 2018), generating multiple environmental and health consequences.
First, animal-based diets are associated with higher GHG emissions (Figure 3). In China, CH_4 and N_2O emissions from the agricultural sectors increased by 24% between 1996 and 2010 (Li, et al., 2015.); the

water footprint tripled from 1961 to 2003 (Liu, et al., 2008); and agricultural land use increased by 50% between 1961 and 2014 (FAOSTAT, 2015). Rising demand for livestock products is projected to require between 3 and 12 million hectares (MHa) of additional pastureland in China between 2020 and 2050, resulting in –2% to +16% in agricultural GHG emissions depending on the scenario (Zhao et al., 2021).

Figure 3. Global GHG emissions from food across the supply chain



Source: Poore and Nemecek (2018)

Secondly, dietary shifts can aggravate nutritional and health issues, especially those linked to overweight and obesity. Recent national survey data suggest that more than half of Chinese adults are now overweight or obese, with obesity rates likely to increase further (Pan, et al., 2021) leading also to greater rates of diabetes. On the other hand, increasing plant-based food intake is associated with a reduced risk of diabetes. A recent study examined 37,985 participants from the Henan rural areas and found that diets higher in plant foods and lower in animal foods were associated with a 4% lower risk of type 2 diabetes (Yang, et al., 2021). Another study has shown that replacing red meat with soy could avoid 57,000 premature deaths annually related to small particulate matter (PM2.5), with the adoption of the Chinese Dietary Guideline (CDG) and EAT-Lancet diets even preventing over one million $PM_{2.5}$-related premature deaths annually (Guo et al., 2022).

Clearly, reducing the overall amount of animal-based food consumption and shifting towards healthy dietary patterns could potentially generate important environmental and health co-benefits in China. But experts also flag potential trade-offs related to dietary shifts: for instance, replacing red meat with soy may be associated with increased water use and GHGs (Guo et al., 2022). Hence, the adoption of a holistic approach to managing food and land use systems could help enable larger health-environment co-benefits.

3. China's food and land use policy landscape and carbon neutrality

Since the announcement of the 2060 carbon neutrality goal, various Chinese ministries have started to explore decarbonization pathways in their sectors. By April 2021, the National Energy Administration, Ministry of Housing and Urban and Rural Development and Ministry of Ecology and Environment had issued several documents and guidelines on how energy, housing and construction, transportation, financing and other relevant departments should incorporate the carbon neutrality target into their development processes. However, the role of food and land use systems in climate mitigation has not yet received as much attention as these sectors from Chinese policymakers in recent years.

This is perhaps partially because of the complexity and dearth of scientific evidence on the topic, and partially because food and land use related GHG emissions are often attributed to agricultural activities alone. While the Ministry of Agriculture and Rural Affairs (MARA) has started to develop China's first action plan (in early 2021) to guide the agricultural sector to achieve carbon neutrality (MARA, 2021), there is no systemic approach to assessing the GHG emissions from the entire food and land use system. While some discussions have been held on food, agriculture and carbon neutrality, no detailed plans have been made. The root causes of the current situation lie in the system barriers at institutional level and the lack of policy coherence between different ministries involved in food production and the management of food distribution and consumption.

3.1 Institutional barriers

China lacks a single institution that can take the lead in coordinating emission mitigation work within the agricultural sector, and more broadly in the entire food and land use system. Despite the presence of several cross-sectoral co-ordination mechanisms on agriculture, climate change, and carbon neutrality, GHG mitigation in the agricultural sector has been largely overlooked in the past. To bridge this gap, the Agriculture and Rural Carbon Peaking and Carbon Neutrality Research Institute was established under the Chinese Academy of Agriculture Science (CAAS) on 29 September 2021. The new institute, composed of 24 teams, will explore GHG emission reduction and removal potential in planting and breeding techniques, soil carbon, renewable energy, etc.; develop strategic, forward-looking, systemic and innovative research; and facilitate domestic and international collaboration (CAAS, 2021). This will hopefully lead to broader collaborations between agriculture and other sectors in the food and land use system.

China also lacks a holistic system that treats food and land use systems as a part of the governance structure connecting food production, distribution, and consumption. For instance, MARA manages all issues related to agricultural land and farmers' welfare, but not food consumption or diets. Consequently, food security and production are given more attention than consumption. At the same time, environment and climate change impacts of food and land use systems are not adequately handled, since the Ministry of Ecology and Environment (MEE) – which took charge of both issues between 2018-2021 (Box 2) – lacks capacity on agriculture and food issues. One potential long-term solution to fill these institutional gaps would be to expand MARA's remit to include food and diet related issues, similar to the UK's Department for Environment, Food & Rural Affairs. This would allow China to develop more holistic policies and plans that tackle GHG emission reductions right through from food production to distribution and consumption. To make this happen, an effective first step would be to bring MARA and the State Administration for Market Regulation (SAMR) together to develop a coordinated decarbonization roadmap for food supply and market development.

To achieve its ambitious carbon neutrality target, China's most powerful agency, the National Development and Reform Commission (NDRC), has regained its power over climate policies since early 2021 (Box 2). However, this agency is also responsible for energy and industrial policies (Bloomberg News, 2021), leading to institutional bias towards energy and industry and the underrepresentation of MARA and food and land use systems as a whole. Consequently, although many research institutions in China have begun to shift their focus towards carbon neutrality strategies, and numerous research reports have been published, most of the work is focused on energy, industry, and the environment (such as air and water pollution control, and ecology). Carbon neutrality pathways for food and land use systems are still to be developed.

Box 2. The shifting mandates of NDRC and MEE

The National Development and Reform Commission (NDRC) had overseen China's climate policies until 2018, when the government transferred its climate change department and related responsibilities to the organization now known as the Ministry of Ecology and Environment (MEE), which is less powerful than NDRC.

Since President Xi's announcement of the carbon neutrality goal, some functionalities of the climate change department have been transferred back to NDRC. NDRC is believed to be better placed than MEE to induce the type of structural change needed to achieve the 2060 goal, as it sets energy and industrial policies including approving power projects and deciding on subsidies. Under the new arrangement, NDRC will take the lead in charting the broad plan for cutting emissions, as well as roadmaps for cleaning up carbon-intensive sectors such as power generation and metals production. Meanwhile, MEE will oversee the carbon market, emissions reporting, and international cooperation.

In addition, current research on transforming China's food systems primarily focuses on food security. Despite China's success in reducing the total undernourished population to less than 2.5% by 2020 (FAO, et al., 2021), hunger still prevails among the poor (Si and Scott, 2019). Understanding the synergies and trade-offs between these two policy goals – food security and carbon neutrality in food and land use systems – is therefore extremely important for proposed food system transformations in China. This will require relevant research institutes to break down silos and institutional barriers to foster multidisciplinary collaboration which can spark more innovation in research and affect policy implementation at the local level.

The final institutional issue is the lack of bottom-up mechanisms to engage the private sector effectively, especially the small and medium-sized enterprises (SMEs) along the food value chains. To date few companies in China have made solid commitments and actions on carbon neutrality. This is partly because the top-down approach imposed by the Chinese Government has excluded the small agricultural and food companies that collectively could play a significant role in reducing GHG emissions. These SMEs have very limited capacity to invest in their own climate and sustainability strategies. Hence, government policy and fiscal support to these SMEs will be essential – not only to help remove the institutional barriers to their participation in the sustainable transition, but also to accelerate innovations within these companies to significantly cut emissions and increase profit margins.

3.2. Policy barriers

In the absence of a holistic approach, agricultural policies in China will not be able to adequately address GHG emissions from the whole food and land use system. The supply side of the food and land use system has dominated China's agricultural policies, which primarily focus on agricultural productivity and food quality and safety. GHG emissions on the supply side can be addressed together with other policies that deal with food production efficiency or chemical inputs that negatively affect food quality. However, China lacks effective governance and coherent policies on the consumption side to address the drivers of food production expansion and intensification that could undermine the carbon neutrality goal if not managed properly, such as food loss and waste and unhealthy dietary patterns. Although the new Anti-Food Waste Law has entered into force and a new National Plan for Food and Nutrition Development has also been developed, their primary goals are not to achieve carbon neutrality. The climate mitigation potential of dietary shifts, and reducing food waste in households, hotels, and restaurants, is still not well captured in current climate policies. Therefore, a priority action for researchers in China is to promote demand-side policy research to address food security, food loss and waste, healthy diets and carbon neutrality in a more coherent way.

Second, there is also a lack of specific policies and national plans to address non-CO_2 GHG emissions in the food and land use system. Most of the GHG emissions from agricultural production in China consist of CH_4 (from livestock and rice production) and N_2O (from intensive use of nitrogen fertilizer to boost crop productivity and concentrate feed to intensify livestock production) (FAOSTAT, 2022). In 2012, although crop farming and animal husbandry only contributed 7.9% of all China's GHG emissions, they contributed over 50% of total non-CO_2 emissions (MEE, 2020). The Chinese Government has shown it intends to strengthen control over non-CO_2 emissions, beginning with gradually phasing out HFCs (hydrofluorocarbons) ahead of the 2029 deadline set for developing countries to reduce or eliminate HFCs (Eco.gov., 2021). HFCs are super greenhouse gases, manufactured for use in refrigeration, air conditioning, foam blowing, aerosols, fire protection and solvents. Stronger policy control over HFCs will have direct impacts on many sectors involved in food supply, from post-harvest storage to food distribution and retail.

A third gap is the lack of an entry point to integrate a food and land use system approach into the current climate policy system. China has adopted a '1+N' climate policy system (Carbon Brief, 2021), in which '1' refers to the overarching plan for all sectors and 'N' refers to the specific sectoral plans, such as energy, manufacturing, construction, etc. Recently, the Ministry of Agriculture has issued an "Agricultural emission reduction and sequestration plan" as one 'N' of the '1+N' overarching plan, which may offer a new opportunity for developing an integrated climate policy to reduce emissions from food and land use systems.

Finally, evolving international trade relations and policies for agricultural commodities will directly affect China's domestic food production and related GHG emissions. China's food demand is projected to keep growing in the coming decades, increasing its reliance further on food and feed imports (OECD, 2019). However, trade interruptions during the recent China-US trade war, and new Chinese policies for imported soft commodities since the COVID-19 pandemic in 2020-21 (OECD, 2021), have increased pressure for domestic food production in China and will likely push the country to grow more soybeans for livestock feed. On the other hand, in its recently revised NDC submitted to the UNFCCC at COP26, China included a clear target for increasing its forest stock, effectively limiting agricultural expansion in the future (UNFCCC, 2021). As such, total production gains will have to be achieved by further intensifying agricultural production, including increasing input use efficiency in already high-input farming systems and managing associated GHG emissions.

Therefore, as Chinese researchers adapt and roll out solutions to satisfy China's current and future food demand, it is important to prioritize low-carbon solutions (e.g. transition to renewable energy, increase input use efficiency and reduce fertilizer inputs, etc.) and explore alternative options that can increase agricultural carbon sinks. Farming practices such as agroforestry, silvopasture, no-till, crop diversification, rotational grazing, etc. are often referred to as regenerative agricultural practices. If implemented well, they can help regenerate soil health, increase soil carbon content, and protect farm biodiversity, but their important role has not yet attracted sufficient attention (GAFF, 2021).

4. Way forward: Towards a systemic approach to reducing emissions from China's food and land use systems

This paper has explored the role for China's food and land use systems in achieving its carbon neutrality ambition. It calls for more to be done to understand the associated sources of GHG emissions, as well as to identify supply- and demand-oriented mitigation measures and associated co-benefits. The paper has also explored China's food and land use policy landscape and identified several institutional and policy barriers to achieving carbon neutrality. There is thus still a lot to be done, in both the research and policy domains, to systemically address GHG emissions from China's food and land use systems. A priority is to provide science-based evidence for the potential of a holistic food and land use system approach to addressing climate mitigation needs. Further investment in research in this area could help Chinese national and local governments to develop better informed policies. It would also accelerate the adoption of an integrated food and land use approach in China as an important strategy to reduce emissions from agriculture and offset carbon emissions from other sectors.

To assist and facilitate the transition from the current agriculture-focused approach to a holistic food and land use system approach, and based on our analysis and associated workshops, we conclude here with specific actions for various stakeholders, including policymakers, researchers, and NGOs. Together, these recommendations will help create the enabling environment for all stakeholders, including the private and public sectors, to deliver emission reductions targets at the system level.

4.1. Actions for Chinese policymakers

Climate policies in China have historically been led by two government agencies: NDRC, which focuses on economic development; and MEE, whose remit is environmental improvement (Box 2). Although these departments may consult each other during policy-making processes, there is often a lack of clear intragovernmental collaboration and policy coherence when developing climate strategies and policy actions across different ministries. China is not alone in this problem, which is a common issue in almost all countries around the world, especially Southeast Asian countries such as Indonesia, Malaysia, and Thailand. Sometimes there can even be potential conflicts of interest between several important institutional players (e.g. MEE and NDRC) that can influence climate policies and strategies.

Therefore, China can:

- Ensure alignment of policy goals across different sectors.
- Improve collaboration among different government agencies, for instance by bringing MARA and SAMR together to develop a coordinated decarbonization roadmap for food supply and market development.
- Develop policies to ensure that the pursuit of carbon neutrality targets does not overshadow equally important goals such as food security, nutrition, human health, soil health, water quality and availability, rural livelihoods, etc. This requires systemic thinking to consider all possible solutions and their impacts, including potential trade-offs both within and between different sectors.
- Identify common goals among different ministries and deepen analyses on the synergies and trade-offs between different agricultural policy goals. These policy goals may include carbon neutrality, food security, addressing soil degradation, reducing soil and water pollution, curbing water use for irrigation, farm biodiversity improvement, building farms' climate resilience, etc.
- Adopt a holistic approach, such as FOLU's 10 critical transitions (FOLU, 2019), to systemically address GHG emissions in the entire food and land use system, and promote sustainable food system transitions in all their various facets.
- Promote nature-based solutions (e.g. agroforestry and other regenerative agricultural practices) in agriculture and forestry sectors as cost-effective approaches to increasing carbon sinks. These are essential for carbon neutrality as they can neutralize or offset emissions and other sources of non-point source pollution from the agriculture sector, as well as the energy sector and other industries.
- Develop pathways towards carbon peaking and neutrality at subnational levels and identify options to mitigate the trade-offs between different sectors and regions.

4.2. Actions for research institutes

There is a dearth of research and peer-reviewed evidence in China that quantifies the total emission reduction potential of food and land use systems. Additionally, carbon emissions and emissions reduction in food and land use systems often involve complex ecological processes, making them more difficult to model than processes associated with the energy sector, and carbon capture and sequestration technologies. The Chinese Government and research institutes can increase investment in climate research that tackles GHG emissions from food and land use systems, explores the mitigation potential of different systems, and develops systemic approaches for moving forward. Knowledge exchange and international collaboration should be promoted to learn from other countries that are more advanced in agriculture GHG emission research.

In particular, more research is needed on:

- Methods to better account for GHG emissions and sinks in the AFOLU sector, explore the best options for emission mitigation in the agriculture sector, and analyze when carbon peaking can be achieved for food and land use systems.

- Decarbonization pathways for the agricultural and food sectors along value chains and estimating the costs associated with proposed food system transitions.
- Methods to address food demand-side drivers of emissions and investigate low-carbon and healthy diet options for Chinese citizens.
- Equity impacts of food system transitions towards a low emission future. Changes in agriculture and food policies to reduce GHG emissions may have unequal impacts across different income and gender groups and in rural and urban areas. It is therefore strongly recommended that ex-ante research of the potential socioeconomic impacts is conducted before any policy implementation.
- The impacts of trade policy changes for international soft commodities on China's domestic land use and related emissions from food and land use systems.

4.3. Actions for NGOs

Although NGOs in China are subject to strict laws, they can still play an important role in developing engagement and communication strategies that will support the implementation of food and land use policies and system transition towards the carbon neutrality goal.

For instance, NGOs can:

- Support relevant government campaigns, such as the "clean plate" against food waste.
- Emphasize the importance of nature-based solutions[5] (such as agroforestry, regenerative agricultural practices) in agriculture and forestry and the need to prioritize other objectives alongside climate neutrality, such as rural livelihoods, soil health, human health and nutrition, biodiversity conservation, etc.
- Organize dialogues between research institutes and help break down the disciplinary silos that exist in climate research between different sectors.
- Support and engage with research institutes to better communicate research findings to the public and raise awareness.
- Help connect China with other countries to prioritize GHG mitigation in global agriculture and food systems.
- Support consumer engagement and farmer capacity building.

5 Nature-based solutions in agriculture seek to improve the ecosystem functions of environments and landscapes affected by agricultural practices and land degradation, while enhancing livelihoods and other social and cultural functions (Miralles-Wilhelm, 2021).

Annex 1: Estimated GHG contributions by China's food and land use systems

(Background data for Figure 2 in the text)

Emissions / removals	Activity	By subcategory	Emissions in 2015 (000' ton)
GHG emissions generated in China's food and land use systems	Agricultural production	Crop residues	**33,261.0**
		Rice cultivation	**152,668.1**
		Burning - crop residues	**6,860.8**
		Enteric fermentation	**191,551.9**
		Manure management	**65,906.8**
		Manure left on pasture	**54,272.8**
		Manure applied to soils	**28,766.4**
		Synthetic fertilizers	**170,763.1**
		Drained organic soils	**2,248.7**
		On-farm energy use	**131,113.3**
		Savanna fires	**251.2**
	Land Use change	Land conversion	**2.4**
	Pre-production	Fertilizers manufacturing	**166,749.5**
		On-farm electricity use	**88,799.6**
	Post-production & consumption	Food processing	**8,547.8**
		Food packaging	**103,896.0**
		Food retail	**19,525.8**
		Food household consumption	**397,275.0**
		Food transport	**43,166.9**
	Waste	Food systems waste disposal	**210,203.0**
GHG removals via forest in China	Forest	Forest carbon sequestration (excl. emissions from forest fires)	**-711,273.9**

Source: FAOSTAT, 2022

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