Towards sustainable food systems in China: transformation options and their connections to the food-land-climate nexus

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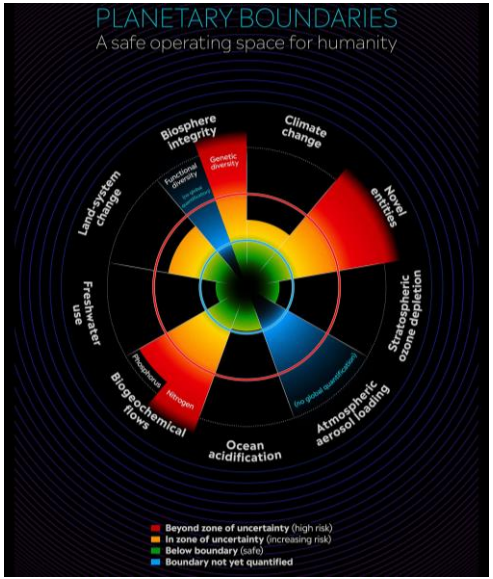
Food system transformation is critical for respecting PBs and achieving SDGs

Planetary boundaries (PBs)



Sustainable Development Goals (SDGs)

(Richardson et al., 2023; UN, 2015; Doelman et al., 2022)

Problem statement

- Food, land, and climate have, in the past, often been treated as individual and disconnected sectors (Johnson et al., 2019).
- Pathways and measures to achieve one or more specific PBs/SDGs may cause trade-offs or unexpected changes for other PBs/SDGs and/or for other sectors/regions in our society.
- It remains unclear how solutions to one PB/SDG affect other PBs/SDGs in the food-land-climate nexus.

Gaps in studies on food system transformation

What has been studied for food system transformation?

- Environmental benefits of food system transformation (e.g. Newbold et al., 2015, Doelman et al., 2022).

What is missing in studies on food system transformation?

- Rebound effect of food system transformation, its knock-on effects beyond the agricultural sectors, and cross-border impacts on other countries

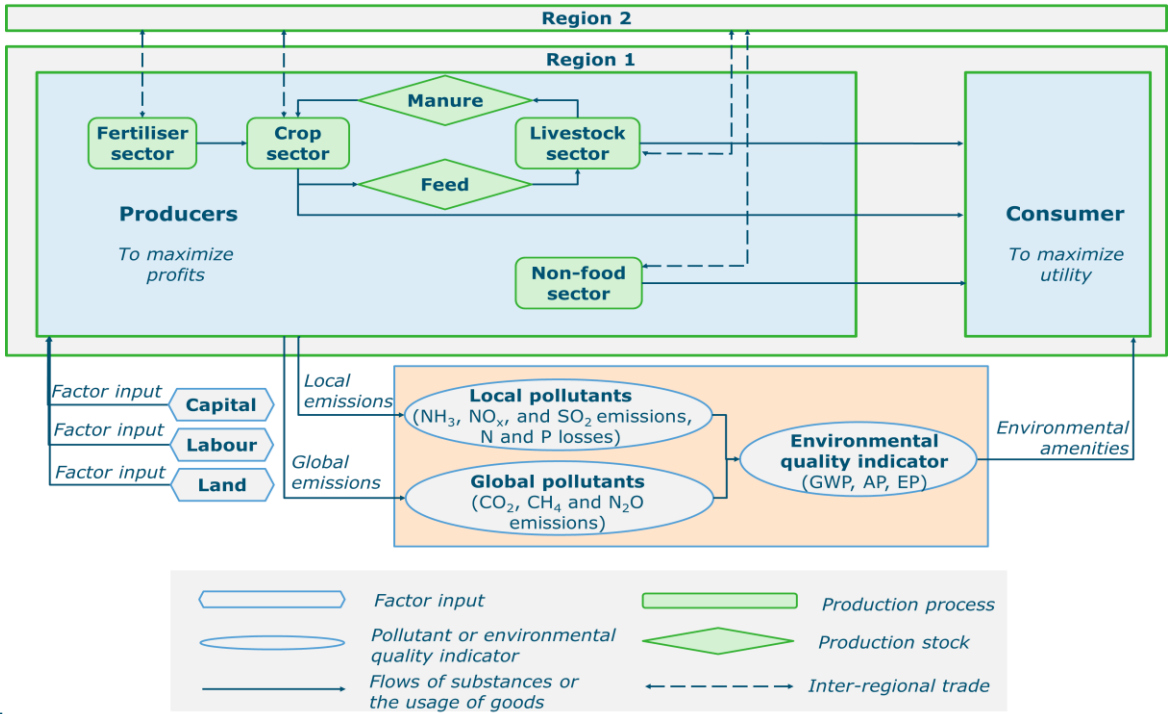
- Economy-wide emissions of greenhouse gases (GHGs, in CO_2-eq), acidification pollutants (in NH_3-eq), and eutrophication pollutants (in N-eq)

- Food security (i.e., average food price, food affordability, population at risk of hunger, and food availability)

Central research questions

- What are the environmental and economic impacts of food transformation options?
- How will these options cause trade-offs and synergies in the food-land-water-climate nexus?

An integrated environmental-economic framework based on applied general equilibrium (AGE) models



(Long et al., 2024, Sustainable Production and Consumption)

Economic and environmental database

- **Database:**

1) GTAP version 10 database (2014 as the base year)

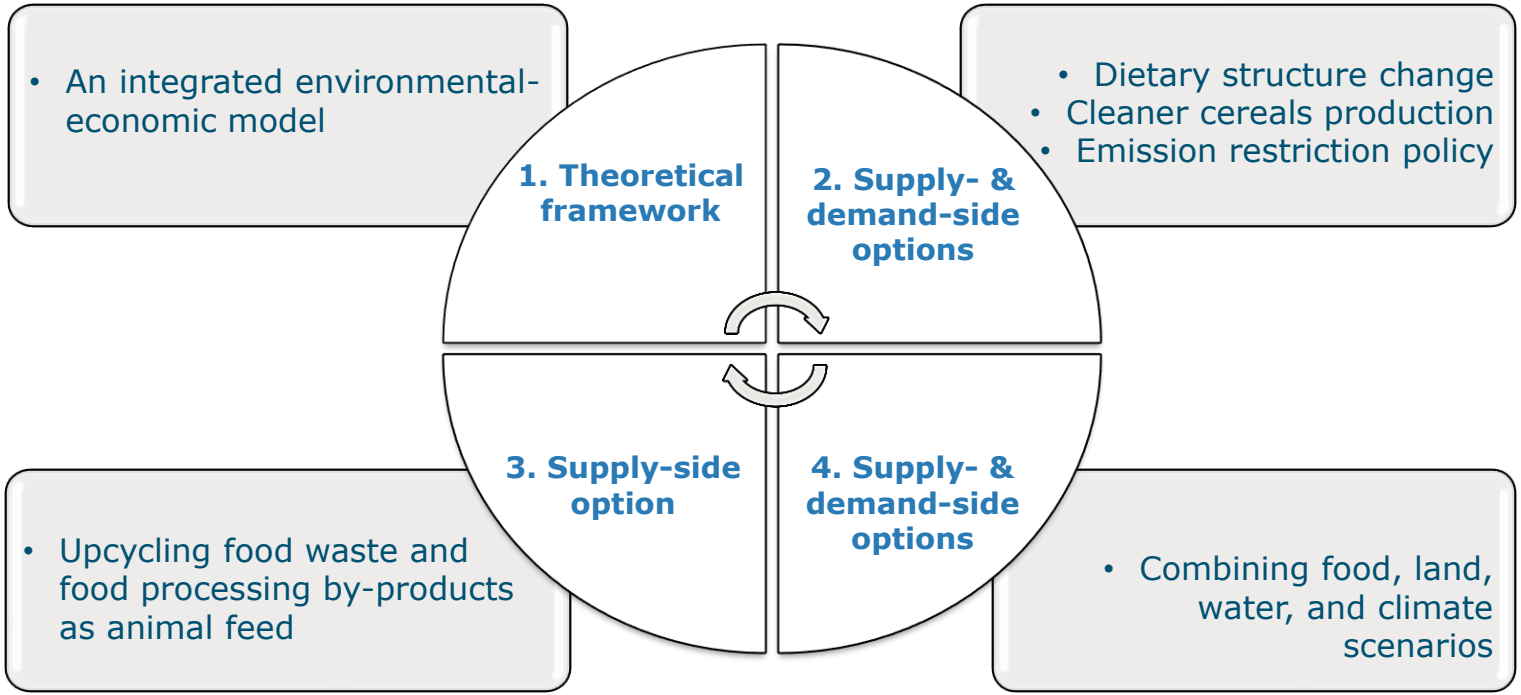
2) Region- and sector-specific environmental impact database

GTAP V10 database:
65 sectors (agriculture, industries, and services), 141 regions

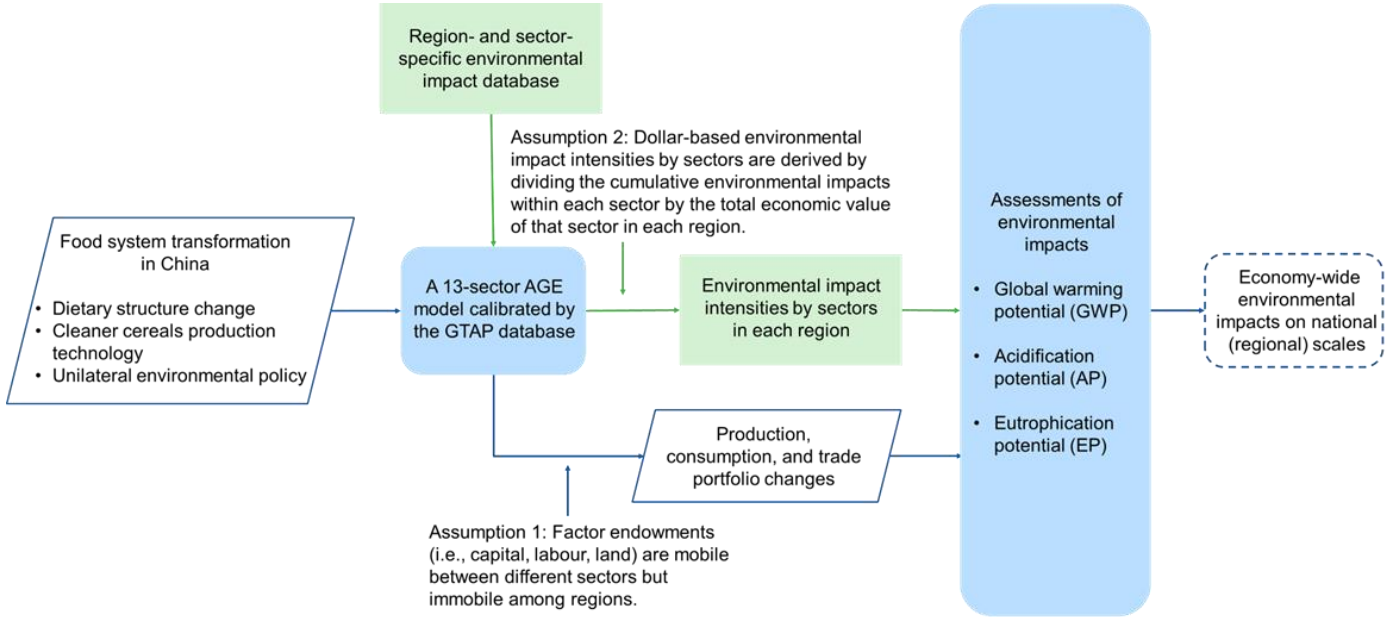
- **Regions:** China and its main food and feed trading partners (MTP, including Brazil, the United States, and Canada)
- **Sectors:** Detailed agricultural sectors and aggregated non-agricultural sector

(Hertel, T.W., 1997; https://www.gtap.agecon.purdue.edu/)

PhD research outline



Paper 1: Exploring sustainable food system transformation options in China: An integrated environmental-economic modelling approach based on the applied general equilibrium framework



(Long et al., 2024, Sustainable Production and Consumption)

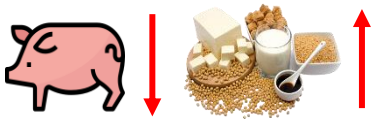
Scenarios of paper 1

Baseline (S0) → **Scenario 1 (S1)**

- **Differences in environmental concerns**

Scenario 2 (S2)

- **A partial shift from pork to soy-based food**

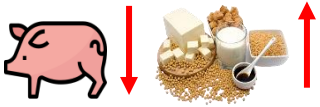


Scenario 3 (S3)

- **Cleaner cereals production technology**

Scenario 4 (S4)

- **Combination of dietary shift and cleaner cereals production**



Scenario 5 (S5)

- **Emission restriction policy**

3% reduction

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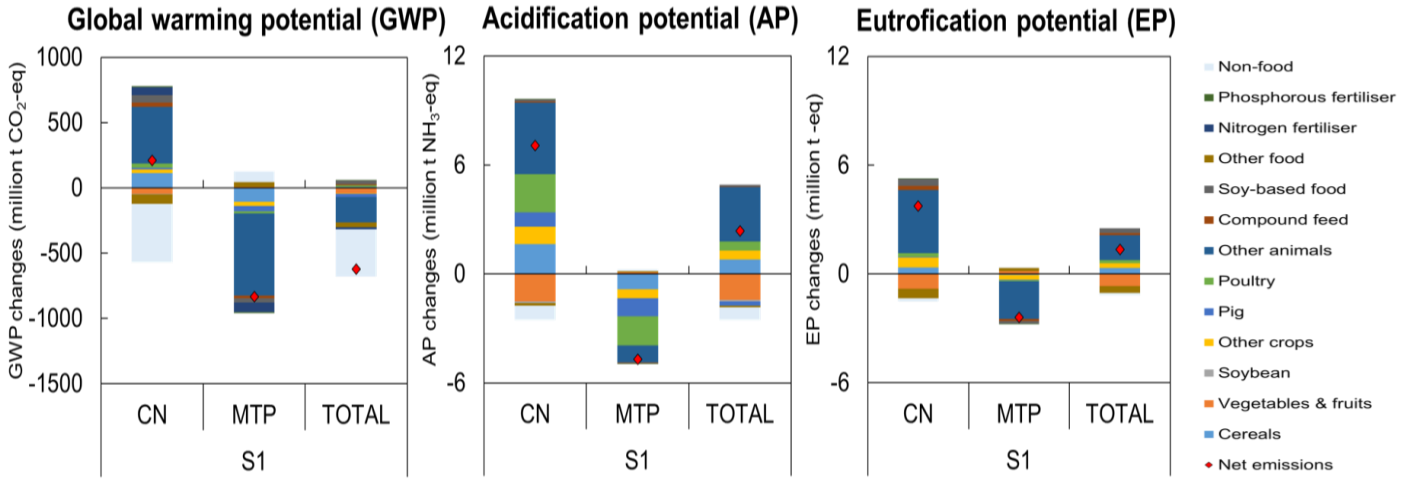
(Long et al., 2024, Sustainable Production and Consumption)

Differences in environmental concerns of consumers led to cross-border pollution spillover effects through international trade

Emissions will leak from trading partners with higher environmental concerns to China, causing negative environmental spillover effects.



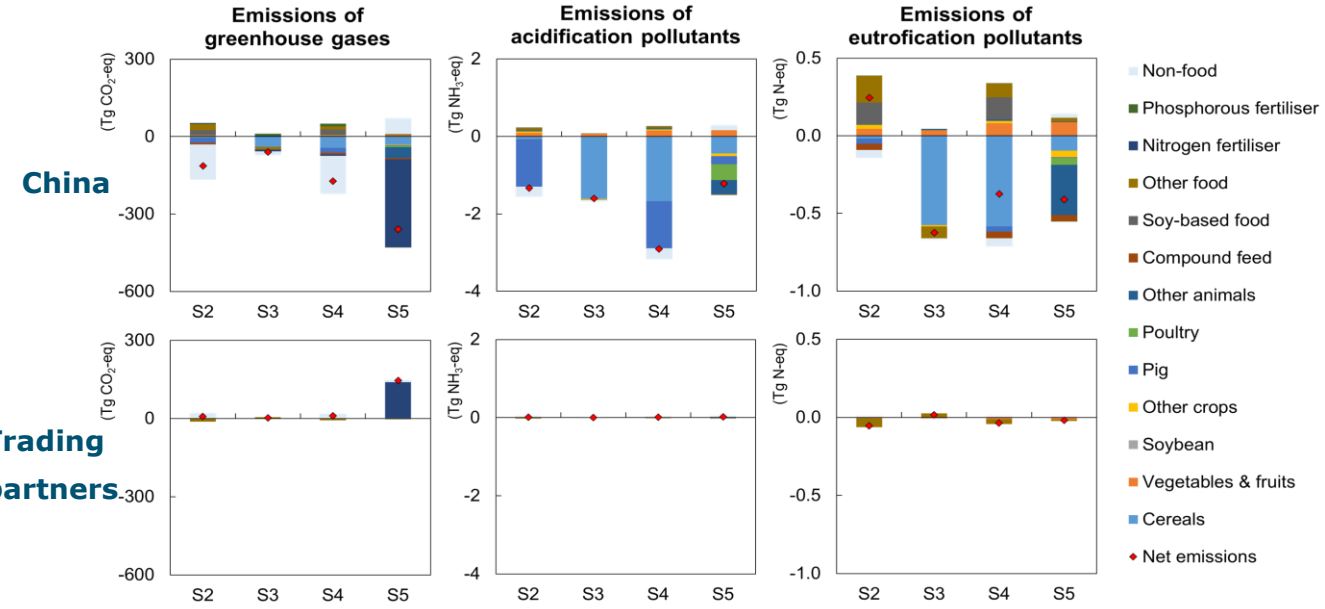
(Long et al., 2024, Sustainable Production and Consumption)

Policy implications

- **Indirect environmental impacts** are crucial to consider when analysing the economy-wide consequences of food system transformations, as these indirect impacts may inadvertently affect other regions and/or economic sectors that were not initially targeted.

- S1: Differences in environmental concerns of consumers

- S2: Dietary structure change
- S3: Cleaner cereals production technology
- S4: Combination of dietary structure change and cleaner cereals production technology
- S5: Emission restriction policy



(Long et al., 2024, Sustainable Production and Consumption)

Paper 2: Rebound effects may undermine benefits of food waste and food processing by-products as animal feed in China

Global food waste disposed in landfills and incinerators exacerbates greenhouse gas (GHG) emissions.

- Global food waste has risen from 1.3 to 1.6-2.5 billion tons in recent years, with a significant portion disposed in landfills or incinerators, exacerbating GHG emissions and associated climate change (Wang, Y. et al., 2024; Gustavsson et al., 2011).

Environmental benefits of feeding animals with food waste and food processing by-products

- Feeding animals with food waste and food processing by-products can mitigate land-related pressures, alleviate the food-feed competition, and reduce emissions from food systems and improper food waste disposal (Van Zanten et al., 2018; Van Hal et al., 2019; Fang et al., 2023).

Contribution to Sustainable Development Goals (SDGs)

- It may contribute to achieving the Sustainable Development Goals (SDGs), including SDG 2 (zero hunger), SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), SDG 13 (climate action), and SDG 15 (life on land) (UN, 2025).

Rebound effect and strategies to absorb rebound effects not covered in previous studies

- **Rebound effect:** Lower feed costs may expand livestock production and diminish these environmental benefits.
- **Strategies to absorb rebound effects:** Strategies to absorb these negative rebound effects have not yet been explored.

Why China?

46% of global pork production

34% of global egg production

13% of global poultry meat production

27% of food produced is lost or wasted

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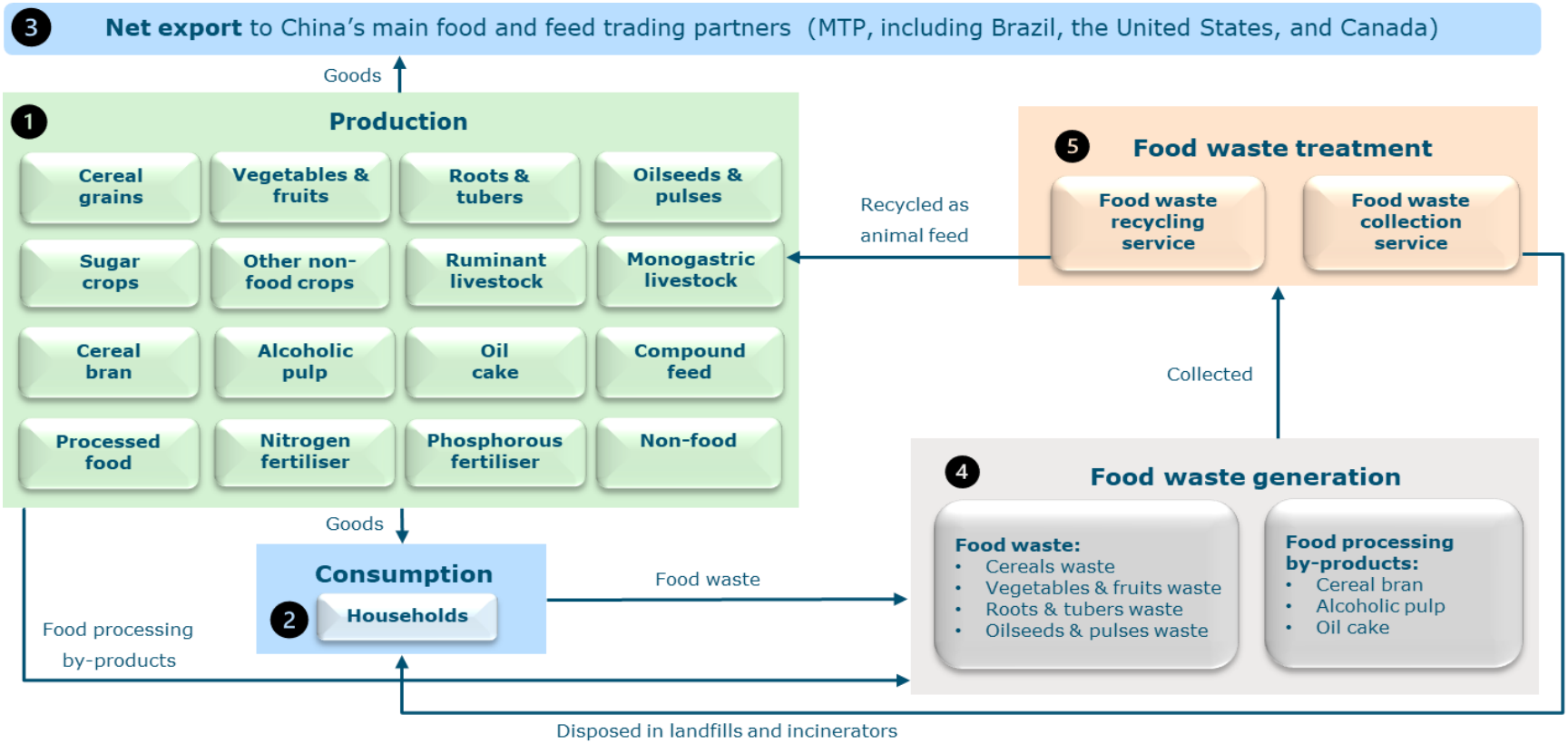
Applied general equilibrium models with food waste



❖ The consumer price of food includes both the market price of food and the cost of collecting food waste and food processing by-products.

(Long et al., 2025, Major revision at Nature Food)

Scenarios of paper 2

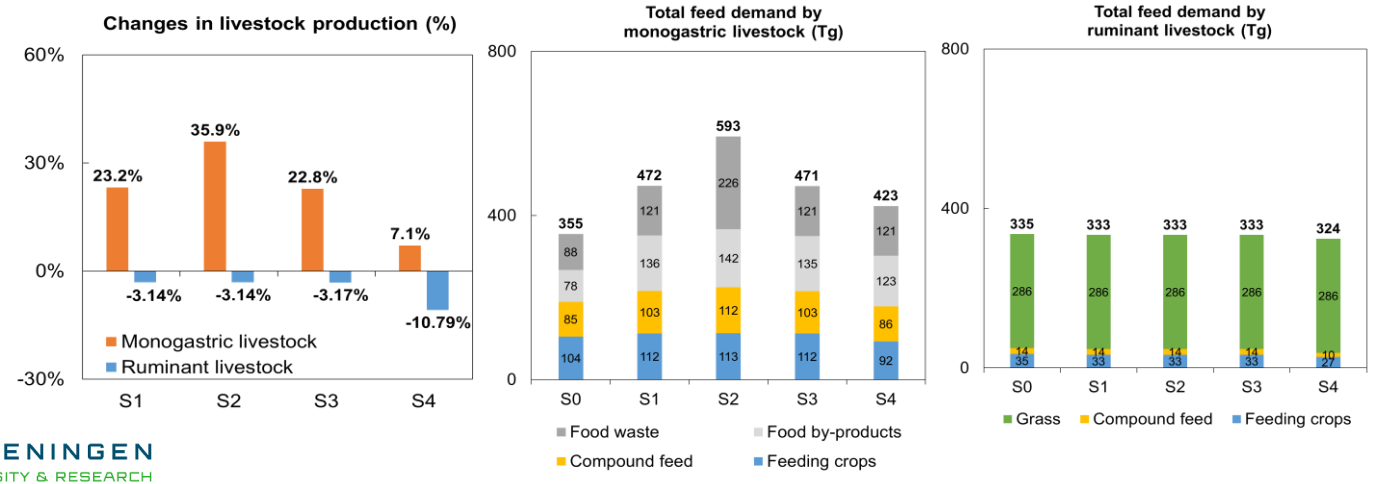
➢ *The protein and energy feed supplies per unit of animal output* are kept constant in all scenarios.

Scenarios	Used as animal feed in its total supply	Emission mitigation target
S0: Baseline	**Food waste: 39%** **By-products: 51%**	No
S1: Partial use of food waste and food processing by-products as feed	**Food waste: 54%** **By-products: 100%**	No → Cross-provincial transportation of food waste is not allowed
S2: Full use of food waste and food processing by-products as feed	**Food waste: 100%** **By-products: 100%**	No → Cross-provincial transportation of food waste is allowed
S3: S1 + A modest emission mitigation target	**Food waste: 54%** **By-products: 100%**	Implementing regional uniform emission taxes across all sectors to ensure that economy-wide emissions of GHGs, acidification pollutants, and eutrophication pollutants in both China and its main food and feed trading partners (MTP) do not exceed their baseline (S0) levels.
S4: S1 + An ambitious emission mitigation target	**Food waste: 54%** **By-products: 100%**	Implementing regional uniform emission taxes across all sectors to meet China's and MTP's annual economy-wide GHG mitigation targets under the Intended Nationally Determined Contributions (INDC) of the Paris Agreement, while also addressing China's emission reduction goals for economy-wide emissions of acidification and eutrophication pollutants in line with the "14th Five-Year Plan".

(Long et al., 2025, Major revision at Nature Food)

Expanded monogastric livestock production reverses the substitution of human-edible feed crops per animal output

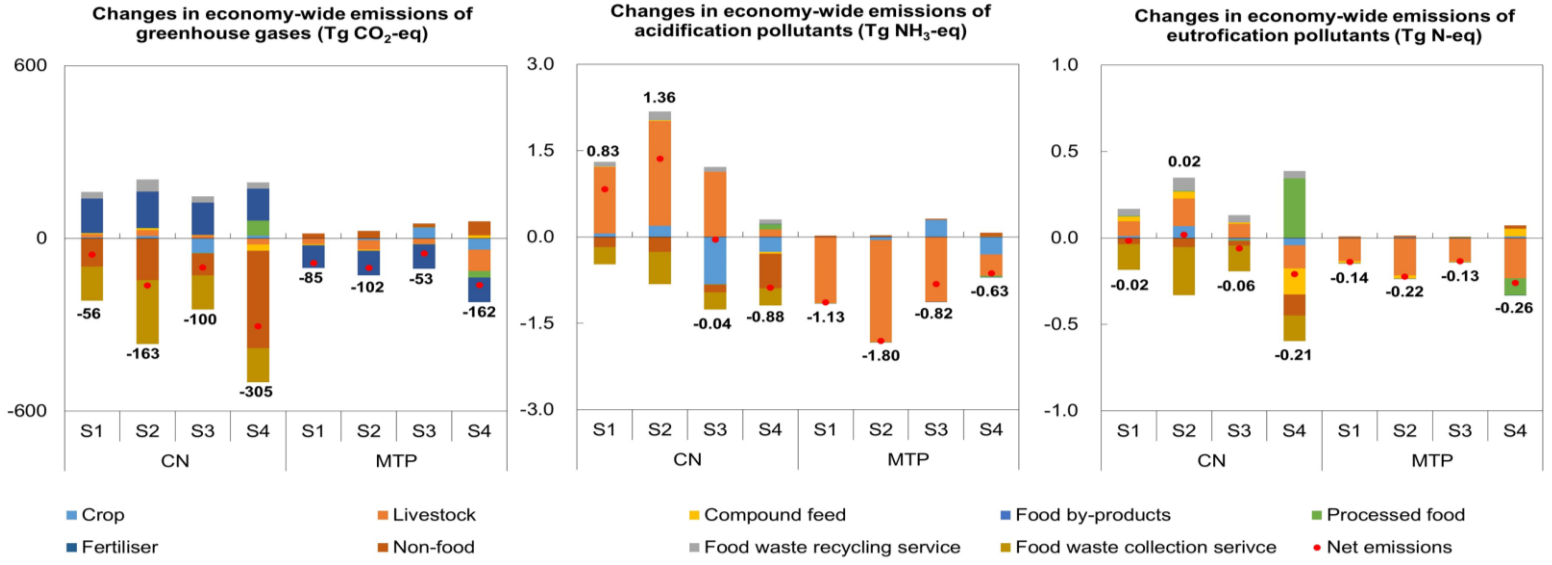
- **Expand Livestock production:** Upcycling food waste and food processing by-products as feed reduces feed costs and drives a 25-36% rise in monogastric livestock production.
- **Feed Demand Increase:** This expansion causes a 17-34% surge in total demand for human-edible feed crops as feed for livestock production.



(Long et al., 2025, Major revision at Nature Food)

Emission taxes could address rebound effects on emissions

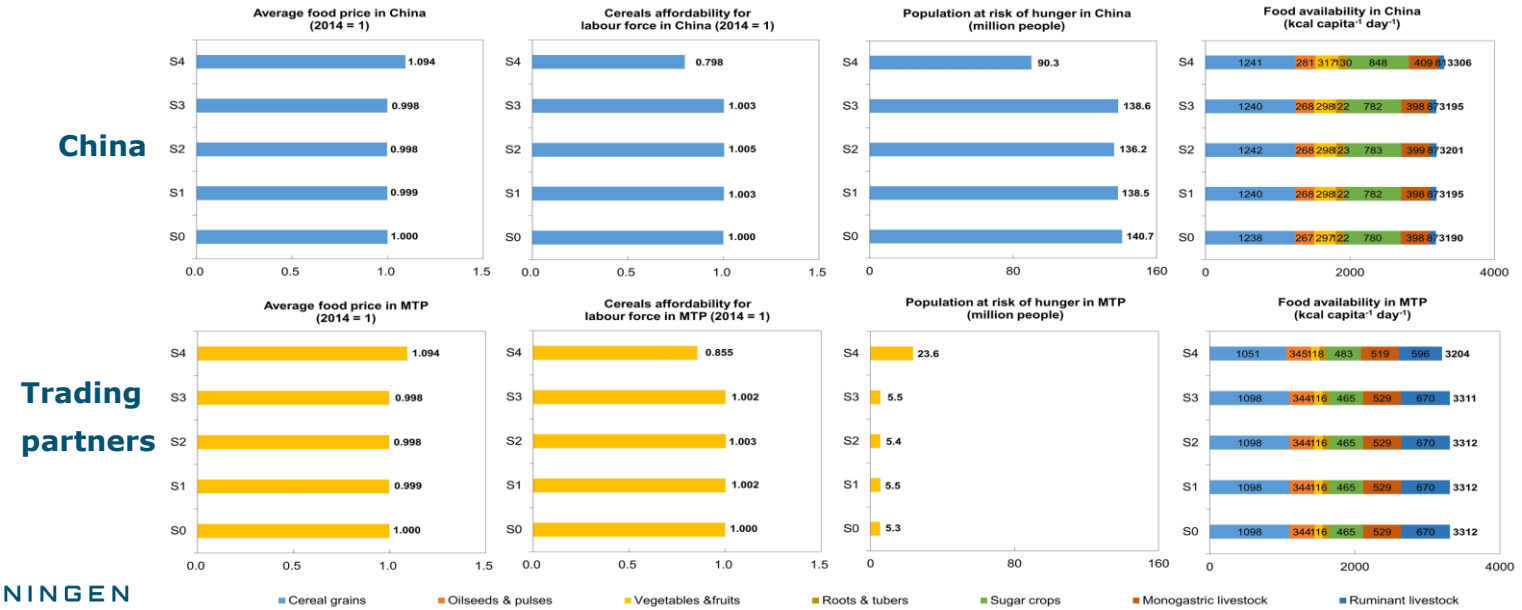
- **Implementing regional uniform emission taxes on economy-wide emissions to achieve emission mitigation targets (S3-4)** could counteract the rebound effects of expanded monogastric livestock production and improve global environmental sustainability.



(Long et al., 2025, Major revision at Nature Food)

But emission taxes may risk global food security

- **An ambitious emission mitigation target (S4)** could counteract rebound effects but risk a 9.4% rise in food prices, threatening global food security.
- Conversely, **a modest emission mitigation target (S3)** provides an opportunity to address rebound effects while safeguarding global food security.



(Long et al., 2025, Major revision at Nature Food)

Paper 4: Unintended trade-offs between food security and environmental sustainability: Impacts of China's dietary shift and afforestation under a stringent climate mitigation policy

Scenarios	Descriptions
S1: Food scenario	**A dietary shift towards less animal-based diet** closing one-third of the gap between current food consumption and **EAT-Lancet diet recommendation for China** in line with SDG 2.1 (safe, nutritious and sufficient food), SDG target 2.2 (end all forms of malnutrition), and SDG 2.c.1 (food price anomalies).
S2: Land scenario	**An afforestation policy** based on China's National Forest Management Plan (2016–2050) in line with SDG 15.1.1 (forest area as a proportion of total land area) and SDG 15.2 (increase afforestation and reforestation). → ***To expand forest land in China by 20% (42 Mha) by 2050***
S3: Climate scenario	**A global uniform carbon tax** aligned with the 2°C climate stabilisation target set by the Paris Agreement in line with SDG 13.2.2 (total greenhouse gas emissions). → ***To reduce net total GHG emissions in China and its trading partners by 25% by 2030***
S4: Combined scenario	Combining food, land, and climate scenarios.

(Long et al., 2025, Unpublished)

Trade-offs and synergies in the food-land-climate nexus

Scenarios	SDG 2 (zero hunger)	SDG 15 (Life on land)	SDG 13 (climate action)
S1: Food scenario	Average food price: -0.06%	• Afforestation in China: +6 Mha • Deforestation in trading partners: -30 Mha	• China's GHG emissions: -2.4% • Global GHG emissions: +4.2%
S2: Land scenario	Average food price: +0.006%	• Afforestation in China: +42 Mha • Deforestation in trading partners: -7Mha	• China's GHG emissions: -5.9% • Global GHG emission: -1.0%
S3: Climate scenario	Average food price: +138%	• Afforestation in China: +4 Mha • Afforestation in trading partners: +33 Mha	• China's GHG emissions: -29% • Global GHG emission: -25%
S4: Combined scenario	Average food price: +205%	• Afforestation in China: +51 Mha • Afforestation in trading partners: -5 Mha	• China's GHG emissions: -42% • Global GHG emission: -25%

S1: A dietary shift in China

S2: A unilateral afforestation in China

S3: A global uniform carbon tax

S4: S1+S2+S3

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(Long et al., 2025, Unpublished)