Quantifying the environmental and economic impacts of upcycling food waste and food processing by-products as animal feed in China: a general equilibrium approach

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Workshop

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Motivation: Feeding animals with food waste and food processing by-products

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

Research gap and question

What has been studied for feeding animals with food waste and food processing by-products?

- Environmental benefits of feeding animals with food waste and food processing by-products (e.g. Van Zanten et al., 2018; Van Hal et al., 2019; Fang et al., 2023).

What is missing in studies for feeding animals with food waste and food processing by-products?

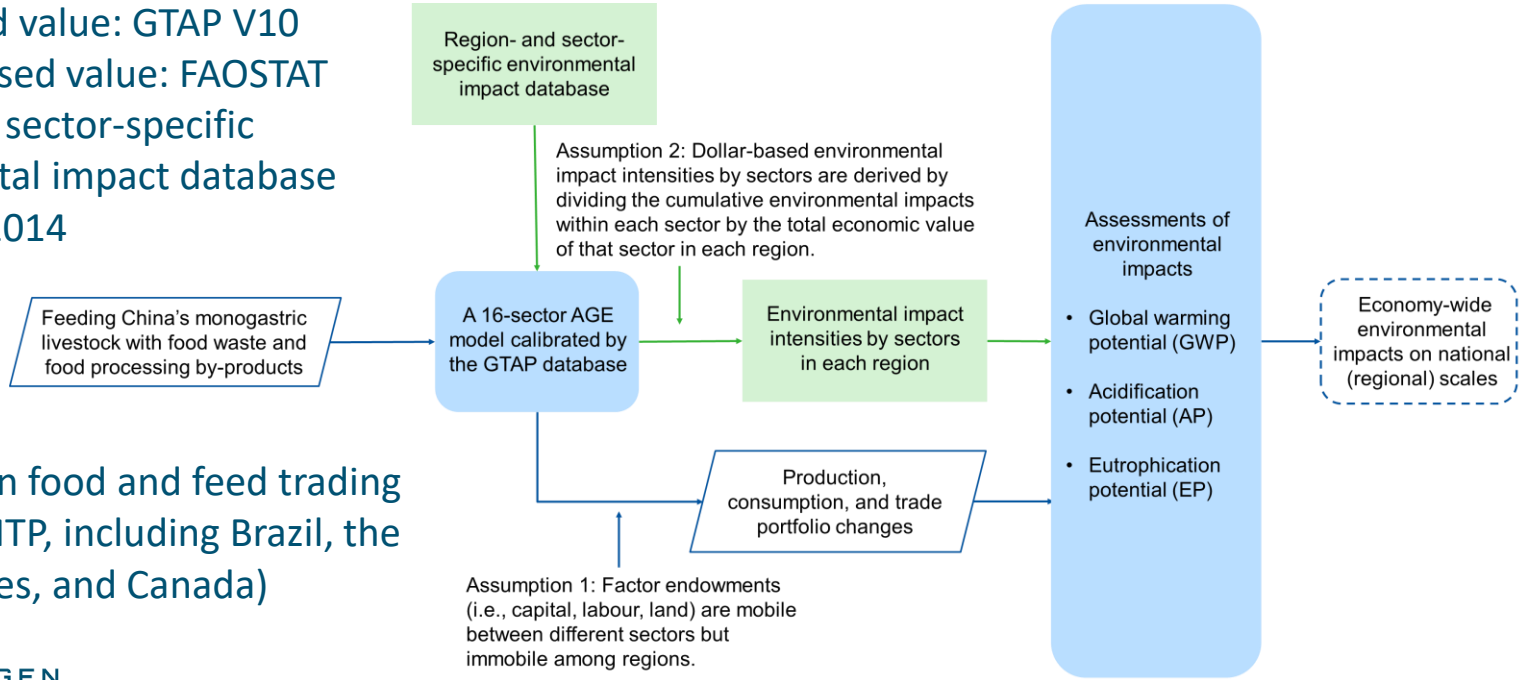
- Indirect effects and spillovers, such as the possible rebound effect of expanded livestock production, its knock-on effects beyond the agricultural sectors, and cross-border impacts on other countries.

What are the environmental and economic impacts of upcycling food waste and food processing by-products as animal feed in China?

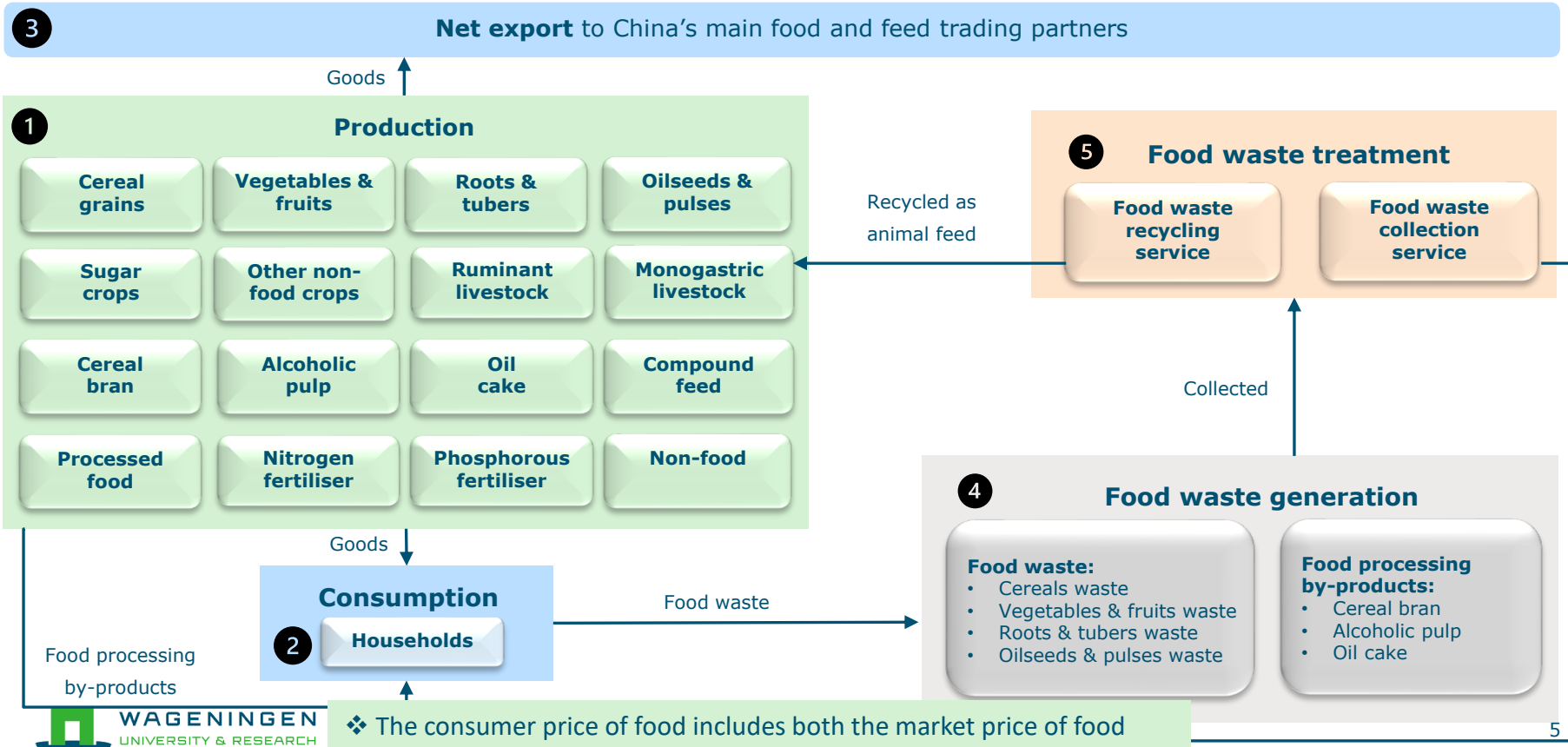
Integrated environmental-economic modelling framework based on applied general equilibrium (AGE) models

- **Database:**
  - ✓ Dollar-based value: GTAP V10
  - ✓ Quantity-based value: FAOSTAT
  - ✓ Region- and sector-specific environmental impact database
- **Base year:** 2014

- **Regions:**
  - ✓ China
  - ✓ China's main food and feed trading partners (MTP, including Brazil, the United States, and Canada)



AGE framework with food waste generation and treatment components



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

The current utilisation of food waste and food processing by-products in China

	Total amount (Tg)	Used as feed (%)	Discarded biomass (%)
Cereals waste	36.09	39%	Landfill (40%) & incineration (21%)
Vegetables & fruits waste	175.01	39%	Landfill (40%) & incineration (21%)
Roots & tubers waste	13.32	39%	Landfill (40%) & incineration (21%)
Oil seeds & pulses waste	1.27	39%	Landfill (40%) & incineration (21%)
Cereal bran	31.05	36%	Landfill (42%) & incineration (22%)
Alcoholic pulp	45.60	16%	Landfill (55%) & incineration (29%)
Oil cake	86.42	72%	Landfill (18%) & incineration (10%)

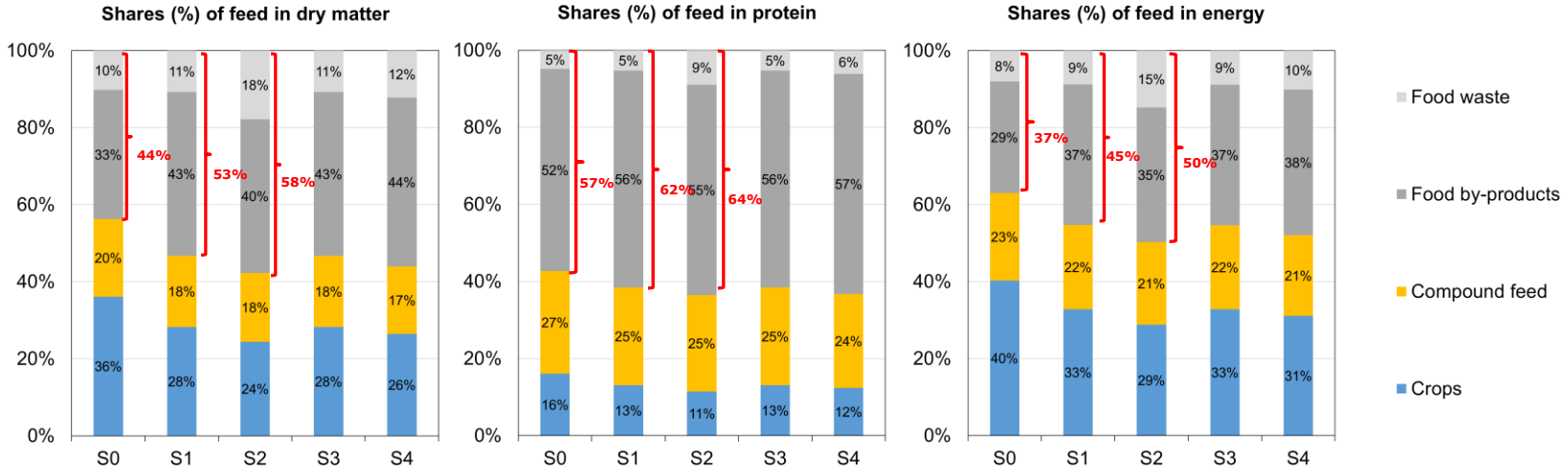
Key assumptions used in the scenarios

- *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".

Upcycling food waste and food processing by-products as feed could replace human-edible feedstuffs per unit of animal output

- **Increased shares of food waste and food processing by-products within total feed use for monogastric livestock production in S1-S2:** from 44% to 53-58% in dry matter, from 57% to 62-64% in protein, and from 37% to 45-50% in energy.

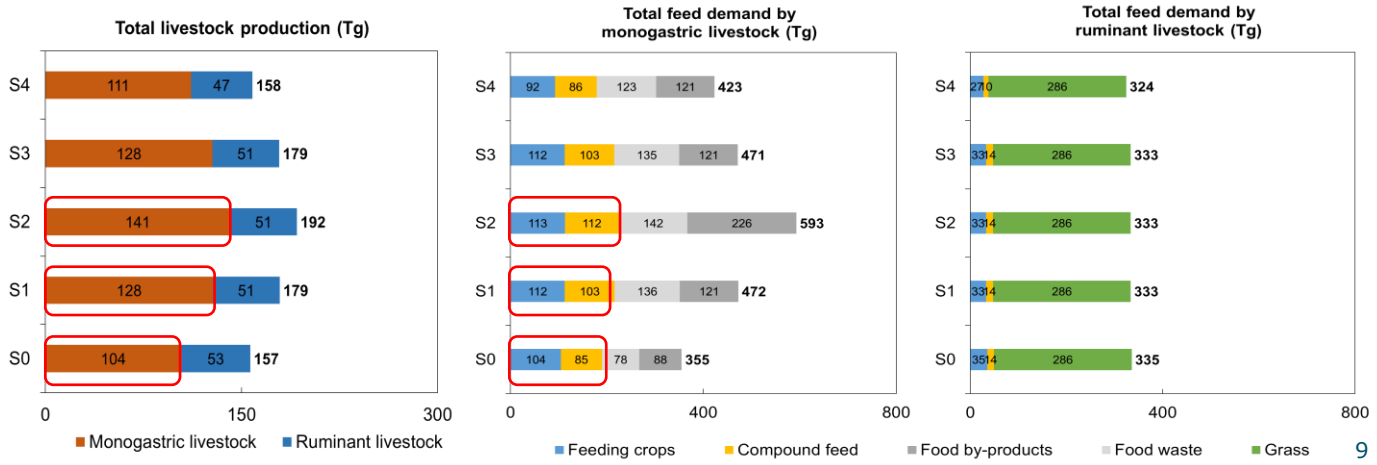


Expanded monogastric livestock production reverses the substitution of human-edible feedstuffs with food waste and food processing by-products

- **Expand monogastric livestock production in S1-S2:** A 23-36% increase in monogastric livestock production and a 3% decrease in ruminant livestock production.
- **Feed demand increase in S1-S2:** A 10-14% surge in total demand for human-edible feed crops as feed for monogastric and ruminant livestock production.

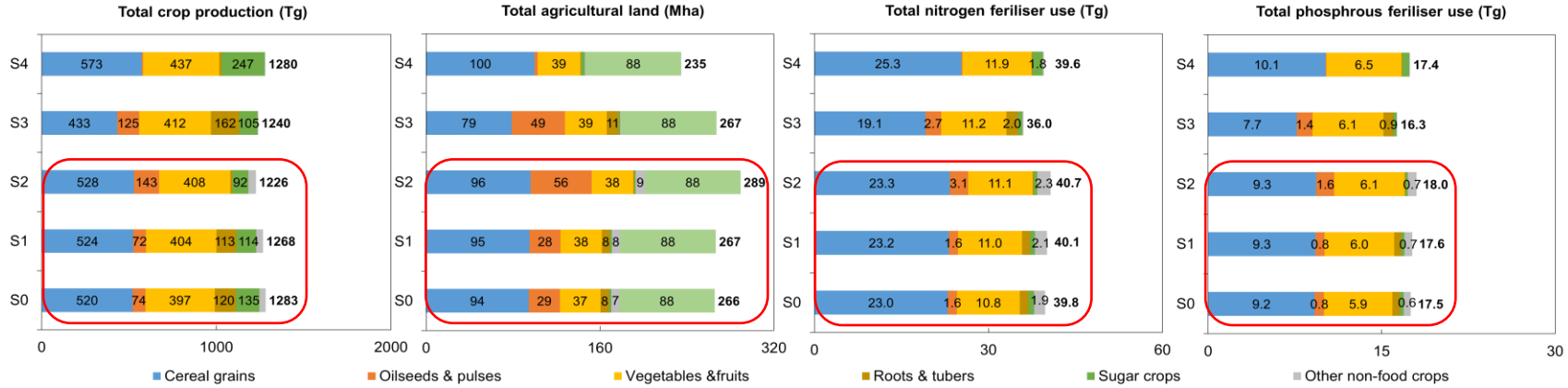
Providing 27-40% more feed protein and 26-39% more feed energy

→A 2.1-3.0% decrease in total feed cost



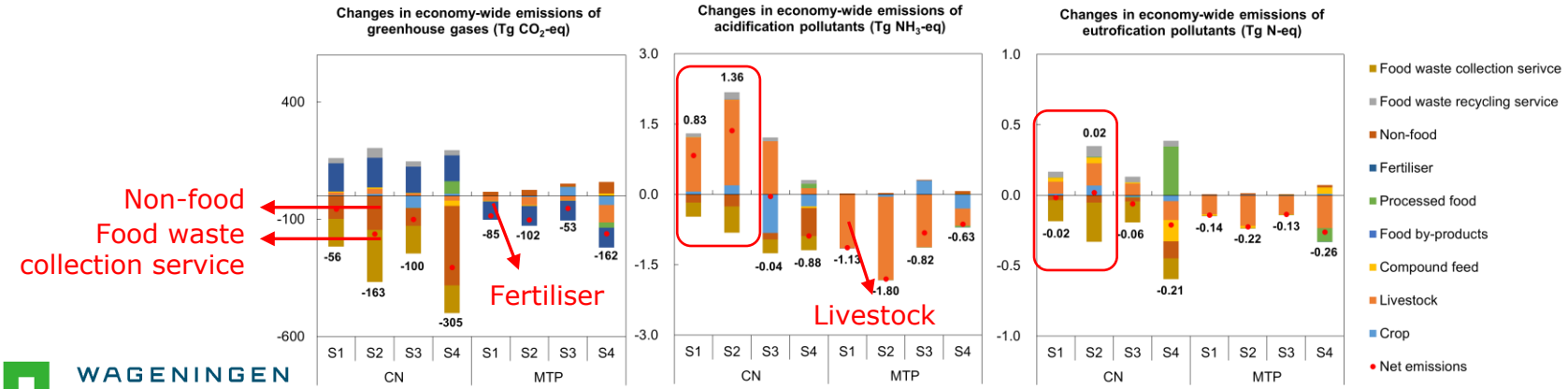
Higher labour cost and reduced labour availability leads to the substitution of labour with other relatively cheaper factor inputs for crop production

- **Reduced crop production and increased crop imports in S1-S2:** Total crop production declines by 1.2-4.4%, with the import share rising from 11% to 15–19%.
- **More cropland and fertiliser use in S1-S2:** Crop cultivated area expands by 0.6-13% with a 0.8-2.3% and 0.8-2.8% increase in total N and P fertiliser use, respectively.



Rebound effects may diminish the environmental benefits of upcycling

- **Diminished environmental benefits in China in S1-S2:** Increased emissions of acidification (2.5-4.0%) and eutrophication (±0.2%) pollutants and decreased GHG emissions (0.5-1.4%).
- **Trading Partners' Environmental Gains in S1-S2:** Reduced emissions of GHG (1.1-1.3%), acidification (8-13%) and eutrophication pollutants (2.5-4.0%).

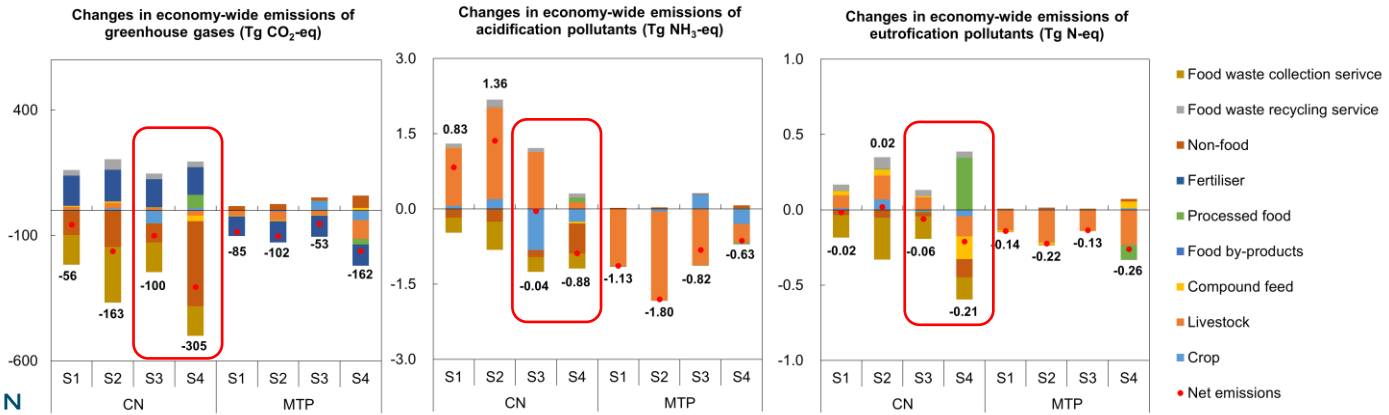


Implementing regional uniform emission taxes on economy-wide emissions could absorb the rebound effects on emissions

- **A modest mitigation target (S3) could absorb the rebound effects:** Emissions of GHG, acidification and eutrophication pollutants do not exceed their baseline (S0) levels
- **An ambitious emission mitigation target (S4) achieved a further emission reduction:** To meet China's and MTP's annual GHG mitigation targets under the Paris Agreement while also addressing China's emission reduction goals for acidification and eutrophication pollutants in line with the "14th Five-Year Plan".

S3: S1+A modest mitigation target

S4: S1+An ambitious mitigation target



But emission taxes may risk global food security

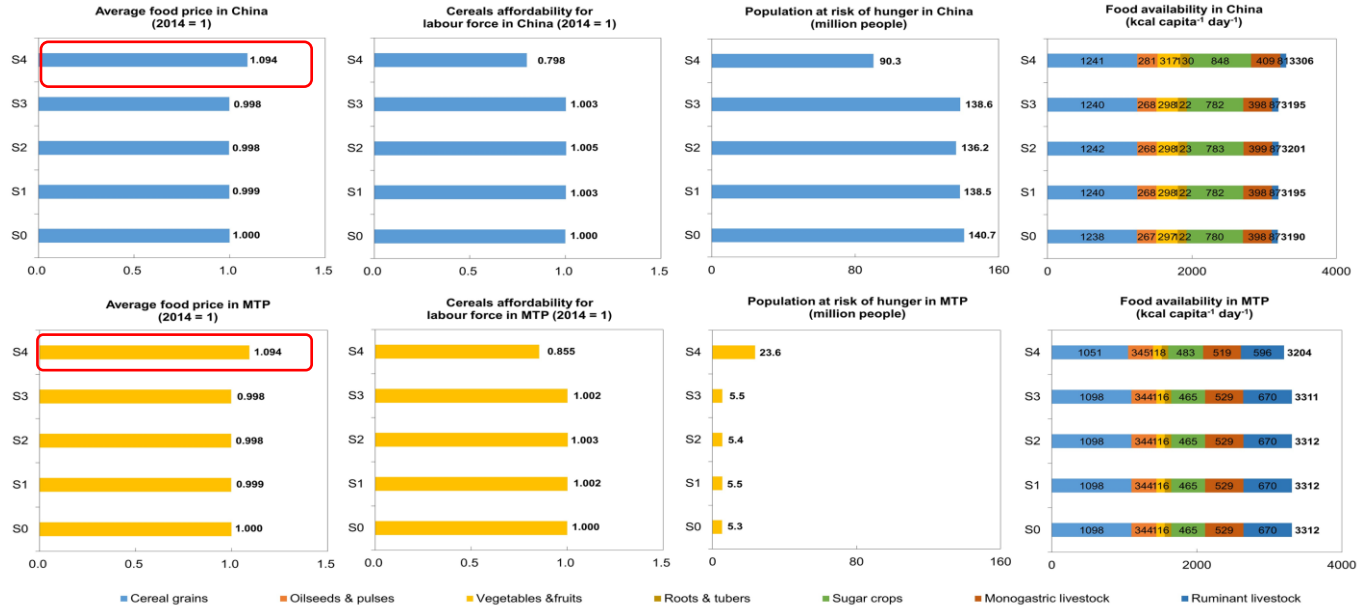
- **A modest emission mitigation target (S3)** could absorb rebound effects while safeguarding global food security.
- **An ambitious emission mitigation target (S4)** could counteract rebound effects but may negatively affect food security indicators, i.e., a 9.4% rise in food prices.

China

S3: S1+A modest mitigation target

S4: S1+An ambitious mitigation target

Trading partners



Conclusions

- **Rebound effects of livestock production expansion:** Upcycling food waste and food processing by-products as feed increased monogastric livestock production by 23-36%.
- **Asymmetric impacts of upcycling food waste and food processing by-products as feed on food security and environment sustainability:** This upcycling enhanced food security but increased Chinese economy-wide emissions of acidification (2.5-4.0%) and eutrophication (0.5-1.4%) pollutants due to expanded monogastric livestock production.
- **Absorbing rebound effects through emission taxes:** Implementing appropriate emission taxes provides an opportunity to absorb the rebound effects on emissions but may negatively affect food security indicators and shift emission-intensive sectors from China to its trading partners, depending on the height of the taxes.

Thank you!

Questions?

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What are monogastric and ruminant livestock?

Monogastric livestock

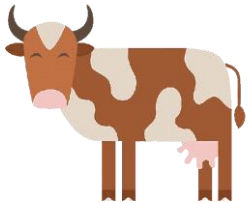
Pigs

Laying hens

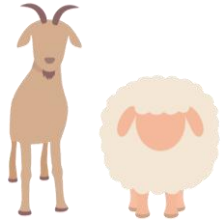
Broilers

Ruminant livestock

Dairy cows

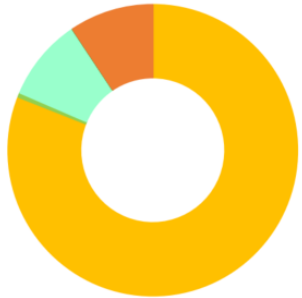


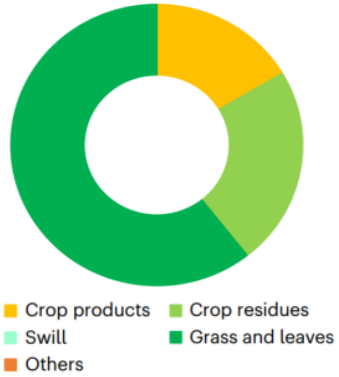
Other cattle



Sheep & goat

Feed ratio





(Cheng et al., 2022, Nature Food)

Prices of food waste recycling service and food waste collection service in China

	Food waste treatment	Price (dollar ton^{-1})	Weighted price (dollar ton^{-1})
Food waste recycling service	Recycling waste as feed	54	54
	Collection	40	
Food waste collection service	Landfill	31	82
	Incineration	64	

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(Bhada-Tata and Hoornweg, 2012; Kaza, et al., 2018; Alsaleh and Aleisa, 2023)

The reasons of the limited use of food waste and food processing by-products as feed in China

- The early stage of industrialization of recycling food waste as feed and the reliance of industrialized livestock production on concentrate feed in China.
- Food processing by-products (e.g., unprocessed oil cakes) contain anti-nutritional factors that hinder animal protein absorption.
- Although fermentation can eliminate these factors and improve digestion and growth performance, its limited adoption in China leads to large quantities of by-products being discarded in landfills and incinerators.

(Bai, Z. et al. , 2018; Wang, Y. et al. , 2023; Mathivanan, R. et al., 2006)

The feasibility of upcycling food waste and food processing by-products as feed in China

- The food waste treatment industry (i.e., food waste collection and recycling service) has seen significant development and expansion in China in recent years.
- The Chinese government recently launched an action plan to reduce reliance on soybean imports, which includes a key initiative to give a trial to feed production from food waste in 20 cities by 2025, ensuring a stable feed supply for monogastric livestock production.
- The geographic proximity of industrial livestock farms to municipal food waste collection plants further facilitates the feasibility of upcycling.

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(Bai, Z. et al. , 2023; Zhou, M.-H., et al. , 2019; MARA, 2023)