Quantifying the environmental and economic impacts of feeding China's monogastric livestock with food waste: a general equilibrium approach

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Motivation: Feeding animals with food waste

1.3 billion tonnes of global food waste drive greenhouse gas (GHG) emissions

- Around 1.3 billion tonnes of food waste are produced in the world, which are mainly disposed in landfills and incinerators, and are a significant source of greenhouse gas (GHG) emissions (Gustavsson et al., 2011).

Environmental benefits of feeding animals with food waste

- Feeding animals with food waste can possibly reduce GHG emissions, mitigate land pressures, and alleviate food-feed competition (Van Zanten et al., 2018; Van Hal et al., 2019; Fang et al., 2023).

Contribution to Sustainable Development Goals (SDGs)

- It may to achieving 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).

Indirect and spillover effects not covered in previous studies

- **Rebound effect:** Lower feed costs may expand livestock production and increase emissions.
- **Broader Impact:** Knock-on effects on other commodities may alter expected environmental benefits.
- **Economic impact:** Ignoring income effects may bias conclusions on food affordability.

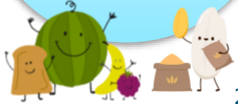
Why China?

46% of global pork production

34% of global egg production

13% of global poultry meat production

30% of food produced is wasted



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Motivation | Method and data | Results | Conclusions

Research questions

What has been studied for feeding animals with food waste?

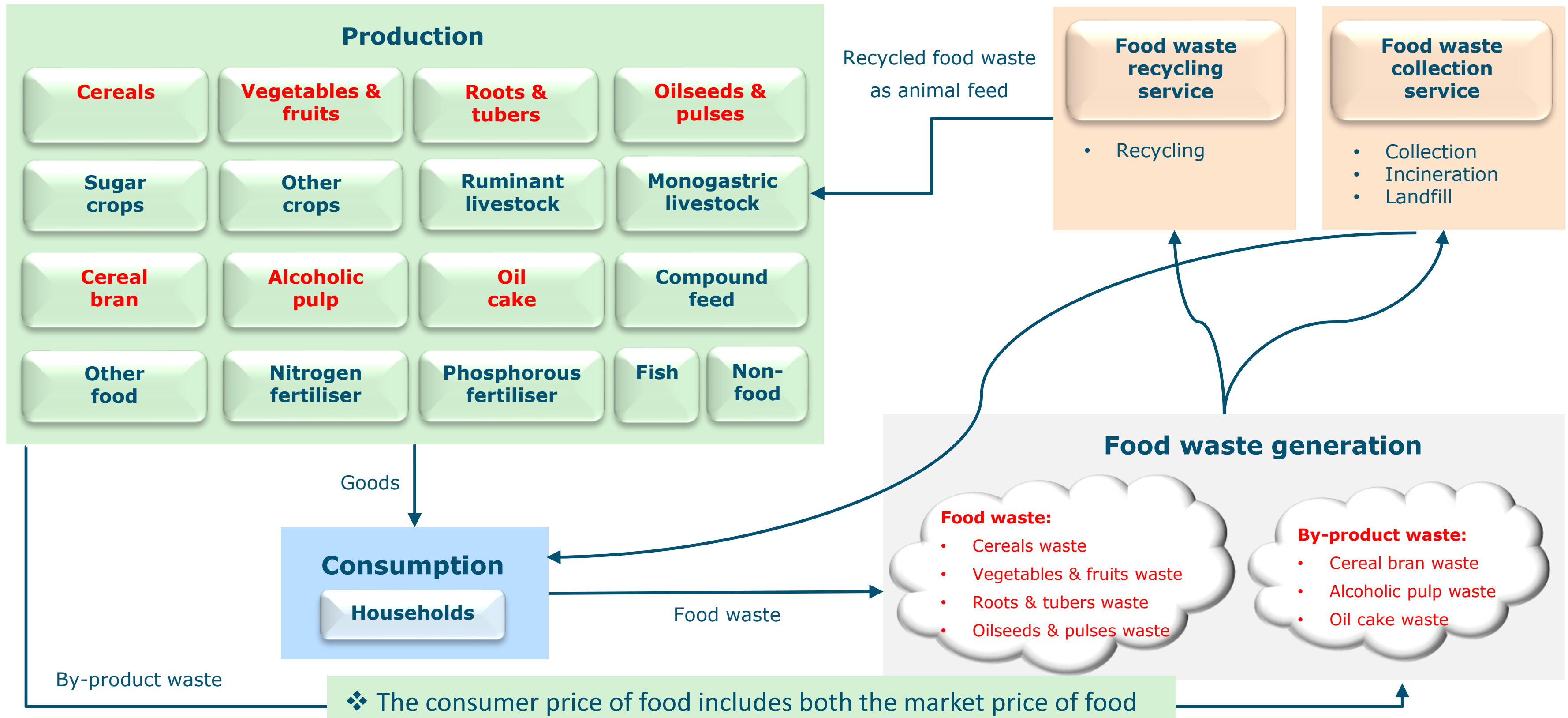
- Environmental benefits of feeding animals with food waste (e.g. Van Zanten et al., 2018; Van Hal et al., 2019; Fang et al., 2023).

What is missing in studies for feeding animals with food waste?

- Impact on livestock production, food supply, and other sectors
- Economy-wide emissions of GHGs, acidification, and eutrophication pollutants
- Food security (i.e., food availability and affordability)

What are the environmental and economic impacts of upcycling food waste in China's monogastric livestock production?

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 by the municipality.

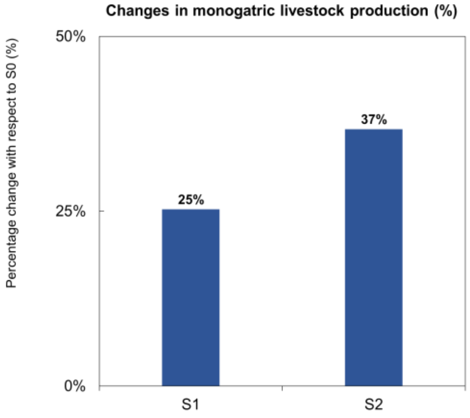
The current food waste utilisation in China

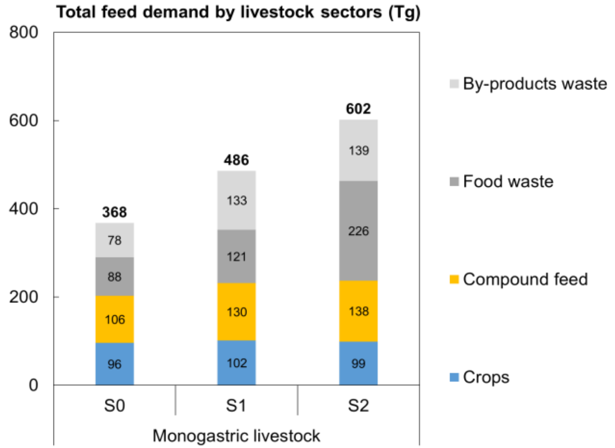
	Total amount (Tg)	Used as feed (%)	Unused biomass (%)
Cereals waste	36.09	39%	Landfill (40%) & incineration (21%)
Vegetables & fruits waste	175.01	39%	Landfill (40%) & incineration (21%)
Roots & tubers waste	13.32	39%	Landfill (40%) & incineration (21%)
Oil seeds & pulses waste	1.27	39%	Landfill (40%) & incineration (21%)
Cereal bran	31.34	36%	Landfill (42%) & incineration (22%)
Alcoholic pulp	42.34	16%	Landfill (55%) & incineration (29%)
Oil cake	84.66	72%	Landfill (18%) & incineration (10%)

Expanded monogastric livestock production will reverse the substitution of human-edible feed crops for per animal output

- **Expand Livestock production:** Upcycling food waste as feed reduced feed costs and increased profits, driving a 25-37% rise in monogastric livestock production.
- **Feed Demand Increase:** This expansion caused a 9.5-9.9% surge in total demand for human-edible feed crops as feed.

Providing 18-28% more feed protein and 22-69% more feed energy

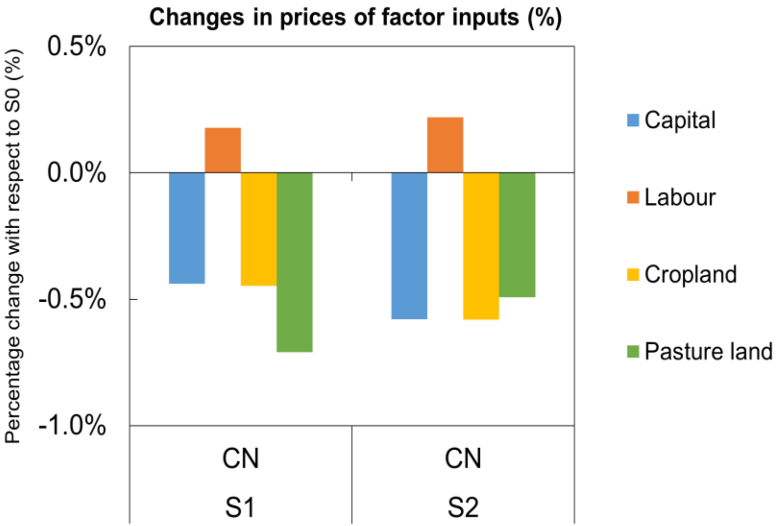




S1: Allowing partial use of food waste as feed
S2: Allowing full use of food waste as feed

Expanded monogastric livestock production will lead to the substitution of labour with other relatively cheaper factor inputs

- **Wage Boost:** Expanded livestock production raised the average wage across the Chinese economy by 0.18-0.22%.
- **Labour Substitution:** Producers may substitute labour with other relatively cheaper factor inputs (i.e., capital, cropland, and pastureland).



S1: Allowing partial use of food waste as feed
S2: Allowing full use of food waste as feed

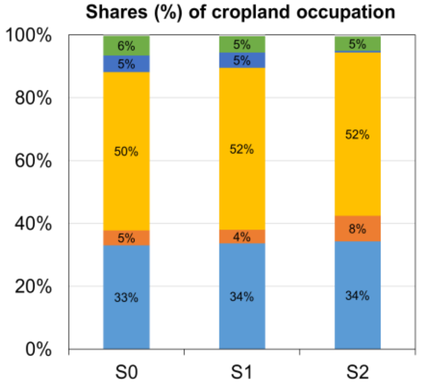
The substitution of labour with other factor inputs has varying impacts on different types of crop production

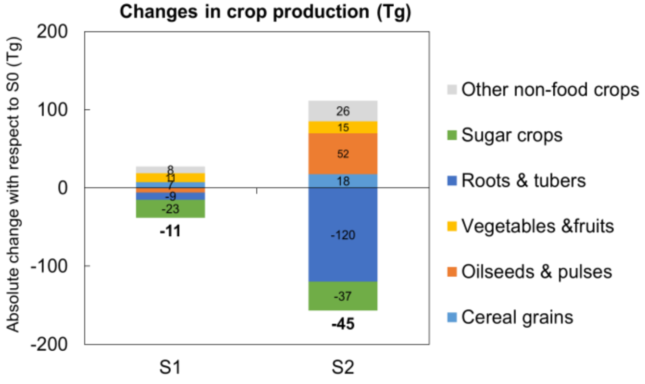
- **Crop Priority Shift:** Crop producers will reduce the production of labour-intensive crops, such as roots & tubers (7-90%) and sugar crops (17-27%).
- **Cropland Reallocation:** Saved cropland will be used for increasing the production of cereal grains (1-3%), vegetables & fruits (2-3%), and other non-food crops (34-105%).
- **Oilseeds & Pulses Production:** Oilseeds & pulses production will decrease by 8% with partial food waste use as feed, but increase by 71% with full use.

→ to choose the cheapest combination of inputs

S1: Allowing partial use of food waste as feed

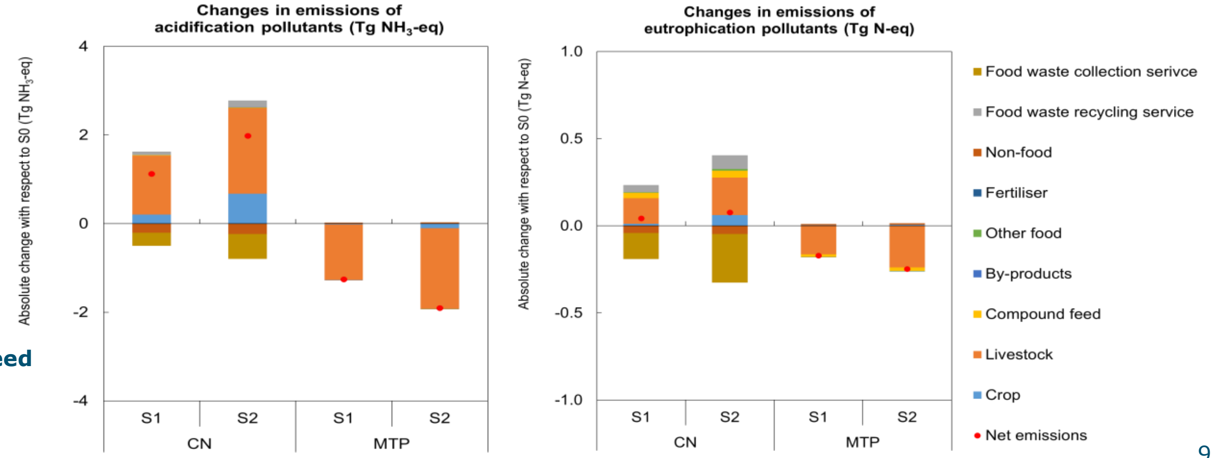
S2: Allowing full use of food waste as feed





Negative environmental spillovers in emissions of acidification and eutrophication pollutants in China

- **Environmental spillovers in China:** Expanded monogastric livestock production increased economy-wide emissions of acidification (3-6%) and eutrophication (0.5-0.8%) pollutants.
- **Trading Partners' Environmental Gains:** China's main food and feed trading partners (MTP, e.g., Brazil, US, Canada) saw reduced economy-wide emissions of acidification (9-14%) and eutrophication pollutants (3-4%) by saving domestic livestock production.



S1: Allowing partial use of food waste as feed

S2: Allowing full use of food waste as feed

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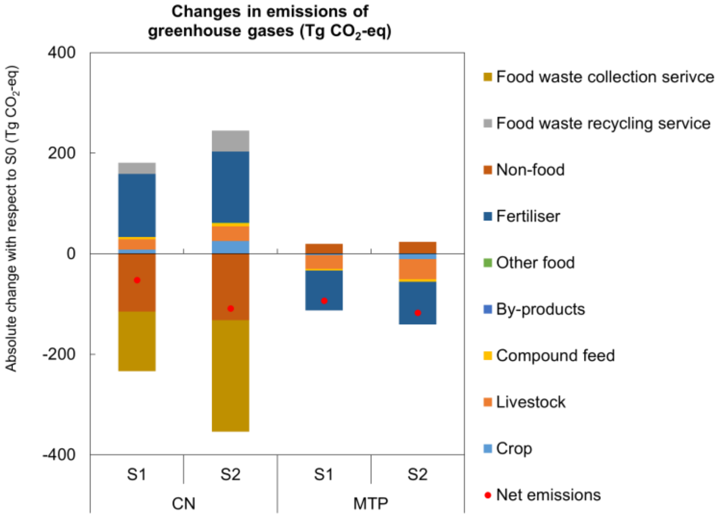
Greenhouse gases (GHG) emissions reduction in China

- **GHGs Reduction in China:** Economy-wide GHG emissions decreased by 0.5-0.9%, primarily due to less food waste in landfills and incinerators, and contracted non-food production.
- **Trading Partners' Environmental Gains:** MTP reduced economy-wide GHG emissions (1.2-1.5%) by saving domestic production of livestock and fertiliser.



S1: Allowing partial use of food waste as feed

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The asymmetric impacts on food security and environment sustainability

Better food security

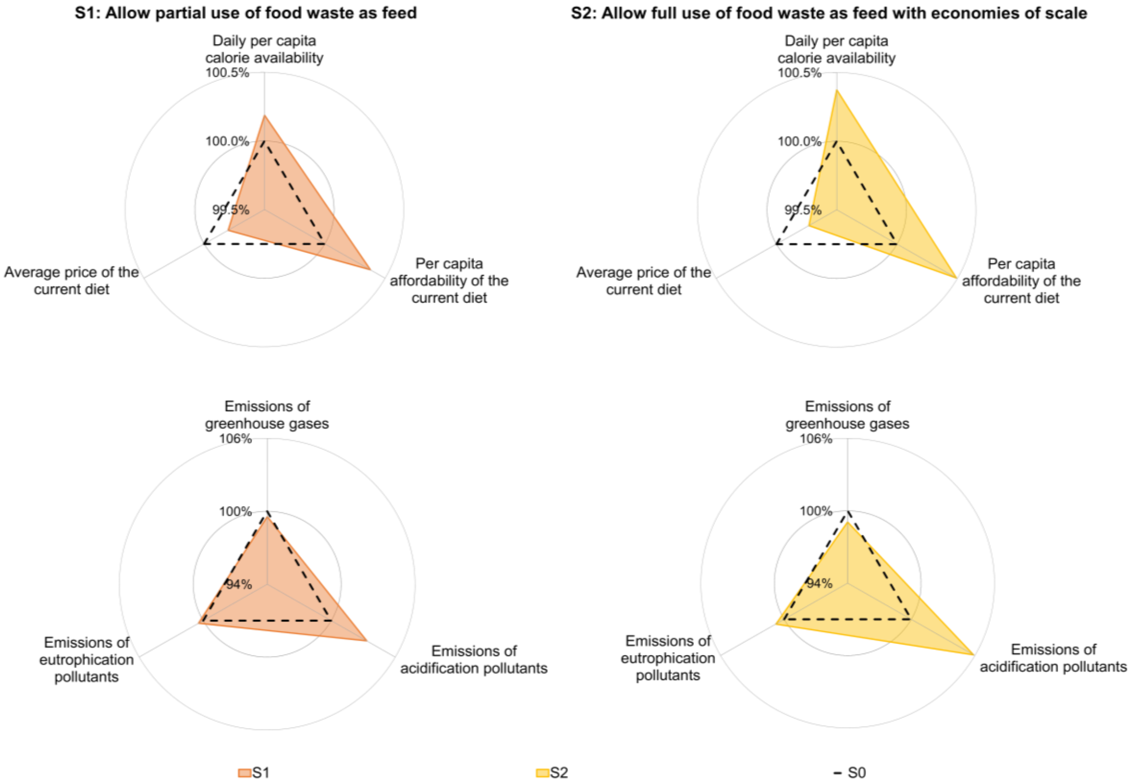
- Improved food availability (0.19-0.37%)
- Improved food affordability (0.38–0.49%)
- Reduced food price (0.20-0.27%)

Worse environment sustainability

- Decreased GHG emissions (0.5-0.9%)
- Increased emissions of acidification (3-6%) and eutrophication (0.5-0.8%) pollutants

S1: Allowing partial use of food waste as feed

S2: Allowing full use of food waste as feed



Conclusions

- **Impact on Livestock Production and Wage:** Upcycling 54-100% of food waste as feed increased monogastric livestock production by 25-37% and the average wage across the Chinese economy by 0.18-0.22%.
- **Negative Environmental Spillovers:** Increased Chinese economy-wide emissions of acidification (3-6%) and eutrophication (0.5-0.8%) pollutants due to expanded monogastric livestock production.
- **GHGs Reduction:** Synergy effects from less food waste in landfills and incinerators, alongside contracted non-food production, decreased Chinese economy-wide GHG emissions by 0.5-0.9%.
- **Asymmetric Impacts on Food Security and Environment Sustainability:** Feeding food waste strategies increased food availability (6-12 kcal $capita^{-1}$ day^{-1}) and affordability (0.38-0.49%) in China but slightly reduced food availability (0.5-1.0 kcal $capita^{-1}$ day^{-1}) and increased affordability (0.18-0.22%) in its trading partners.

Thank you!

Questions?

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Key assumptions used in the scenarios

➤ We will maintain the same *protein and energy intake for per unit of animal output* in all scenarios.

Scenarios [a]	Food waste as animal feed in its total supply	Detailed explanation
S0: Baseline	**Food waste: 39%** **By-products: 51%**	
→ Cross-provincial transportation of food waste is not allowed **S1: Allowing partial use of food waste as feed**	**Food waste: 54%** **By-products: 100%**	• Expanding the "food waste recycling service" sector to achieve this goal.
→ Cross-provincial transportation of food waste is allowed **S2: Allowing full use of food waste as feed with economies of scale**	**Food waste: 100%** **By-products: 100%**	• Expanding the "food waste recycling service" sector to achieve this goal. • A 1% increase in recycling waste will give a 0.078% increase in the costs of recycling waste (Cialani and Mortazavi, 2020).

What are monogastric and ruminant livestock?

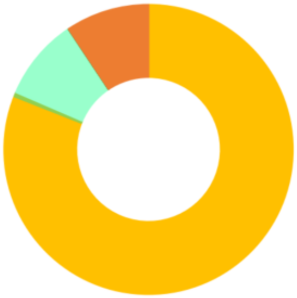
Feed ratio

Monogastric livestock

Pigs

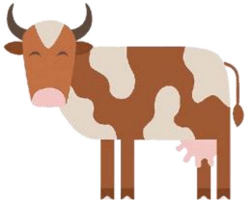
Laying hens

Broilers

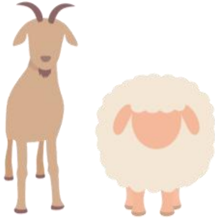


Ruminant livestock

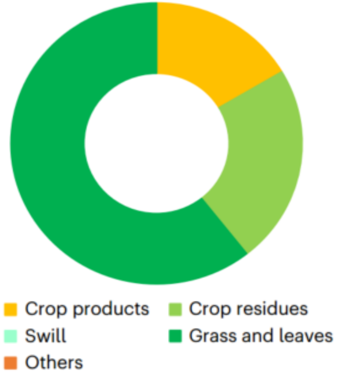
Dairy cows



Other cattle



Sheep & goat



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(Cheng et al., 2022, Nature Food)