Food system transformation is key to achieving food security and environmental sustainability in China

Background

The food system is a driver of climate change Vermeulen et al. (2012), land-use change, and biodiversity loss (Newbold et al., 2015) and an essential factor for realising the Sustainable Development Goals (SDGs), especially 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) (United Nations (UN), 2015). It, especially in the production phase, has placed tremendous pressure on planetary boundaries (PB, the environmental limits within which humanity can safely operate) regarding climate change, ocean acidification, biogeochemical flows (nitrogen and phosphorus), freshwater use, land-use changes, and biodiversity loss (Springmann et al., 2018). One of the global challenges is how to feed an increasing population with less pollution (Griggs et al., 2013).

Food system transformation is increasingly recognised as critical for achieving food security and environmental sustainability (Newbold et al., 2015, Doelman et al., 2022). Food transformation options can be divided into those aimed at either the supply or demand side (Herrero et al., 2016, Smith et al., 2008). Demand-side options aim to change consumer behavior to reduce consumption of emission-intensive food products, such as shifting towards less meat-intensive diets based on the EAT-Lancet diet recommendation (Willett et al., 2019). Supply-side options attempt to improve food production efficiency, which may include improving crop production efficiency through Integrated Soil-crop System Management technology (ISSM) (Chen et al., 2014, Cui et al., 2018) and improving monogastric and ruminant livestock production efficiency up to the levels of developed countries (Du et al., 2018, Bai et al., 2018, Wang et al., 2023).

While the direct environmental benefits of food system transformation are well acknowledged, possible unintended negative environmental spillovers have received less attention. For example, previous studies focused on supply-side options have not adequately accounted for market-mediated responses (i.e., holding costs and prices constant) by assuming that a one percent increase in food production will will directly result in a one percent reduction in land demand under unchanged consumption. However, increased food productivity through higher total factor productivity (TFP) may increase profits of food producers, potentially encouraging expanded food production and leading to greater agricultural land use and associated emissions, a phenomenon also known as “Jevons paradox” or the “rebound effect” (Ceddia et al., 2013, Chaudhary and Hertel, 2024). Gatto et al. (2023) have explored the negative environmental spillovers of a global dietary shift caused by economic spillovers into non-food sectors, but did not consider supply-side options. Thus, previous studies may underestimate the potential environmental benefits of food system transformation by narrowly focusing on specific transformation options or may overestimate the potential of certain transformation options by disregarding market-mediated responses.

Despite the significance of acknowledging the indirect environmental impacts of food system transformation, an integrated environmental-economic modelling framework at the global scale that incorporates both food supply- and demand-side transformation options is still lacking. In this study, we analysed the possible environmental and economic consequences of Chinese food system transformation, considering both food supply- and demand-side transformation options. We take China as an example, as China is among the largest and most populous countries in the world, and its food system exerts enormous impacts on the environment (FAO, 2022), making it a focal point of our study. We aim to address the research question of whether food supply- and demand-side transformation options can help achieve food security and environmental sustainability in China. Seven sustainability impacts were considered on China and its main food and feed trading partners (MTP, including Brazil, the United States, and Canada): food price, food affordability, food availability, agricultural land (cropland and pasture land) use, emissions of greenhouse gases (GHGs), emissions of acidification pollutants, emissions of eutrophication pollutants.

The integrated environmental-economic model and database

We developed a global comparative static AGE model, a modified version of an integrated environmental-economic model (Zhu & Van Ierland, 2004, 2012; Zhu et al., 2006). Our model incorporated two major enhancements, which facilitate analysis of the food system. First, we enhanced the representation of food-related (cereal grains, oilseeds &pulses, vegetables & fruits, roots & tubers, sugar crops, pigs, laying hens, broilers, dairy cows, other cattle, and sheep & goat) sectors and associated non-food (alfalfa, maize silage, other non-food crops, compound feed, nitrogen fertiliser, phosphorous fertiliser, non-food, food processing by-products, food waste, grass, and crop residue) sectors. Second, we further added three main environmental impacts of food systems into the model: emissions of GHGs, acidification pollutants, and eutrophication pollutants.

Scenarios

- **S0 (Baseline):** The economies of China and MTP in 2014.
- **S1 (Feed supply-side option):** Upcycling underutilised low-opportunity-cost-feed in monogastric (food waste and by-products) and ruminant (grass and crop residue) livestock.
- **S2 (Crop supply-side option):** Improving crop production efficiency through ISSM.
- **S3 (Livestock supply-side option):** Improving monogastric and ruminant livestock production efficiency up to the level of USA.
- **S4 (Consumer-side option):** Shifting towards less meat-intensive diets based on the EAT-Lancet diet recommendation.
- **S5 (S1+S2+S3+S4):** Combing feed, crop, and livestock supply-side as well as consumer-side measures.

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