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LETTER

Food self-sufficiency targets reshape climate trade-offs and synergies in China's food system

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Abstract

China's prioritization of food self-sufficiency is likely to reconfigure global agricultural trade and associated GHG emissions, yet its climate compatibility remains uncertain. Here, we employ a well-established food system integrated assessment model (GLOBIOM-China) to quantify how self-sufficiency targets alter domestic and trade-embodied GHG emissions through 2060. Our findings indicate that solely increasing food self-sufficiency rate would reduce China's trade embodied GHG emissions by 50% (107 Mt CO_2-eq yr^{-1}), but increase domestic emissions by 7% (55 Mt CO_2-eq yr^{-1}). This results in a net reduction of 52 Mt CO_2-eq yr^{-1} in overall emissions while intensifying domestic land competition. We uncover a market-mediated mitigation feedback that higher soybean self-sufficiency raises domestic feed costs, acting as an implicit constraint that limits the expansion of the high-emitting livestock sector. This upstream intervention delivers emission reduction elasticities comparable to directly targeting ruminant production. However, to prevent such passive mitigation, self-sufficiency must be coupled with production efficiency gains and dietary shifts. This combined pathway reduces overall GHG emissions by 211 (162–259) Mt CO_2-eq yr^{-1} (20%) by 2060, aligning national food security with global climate targets.

1. Introduction

Achieving the Paris Agreement targets hinges on rapidly decarbonizing global food systems, which currently generate approximately 34% (18 Gt CO_2-equivalent) of total anthropogenic greenhouse gas (GHG) emissions (Crippa *et al* 2021). Without aggressive mitigation, emissions from food production and agricultural land-use change alone threaten to overshoot the 1.5 °C climate target (Clark *et al* 2020), underscoring the urgent need for mitigating emissions from the food system. China's food system plays a key role in this context. In 2018, it contributed between 1.5 and 2.4 Gt CO_2-eq annually depending on accounting scope, with agricultural production accounting for 53% of non-CO_2 emissions (Chen *et al* 2022, Hu *et al* 2023, Liu *et al* 2023). Meanwhile, China's food system is undergoing a rapid transition characterized by surging demand for animal-source foods (He *et al* 2018, FAO 2024). Demand for livestock products and associated feed has outpaced domestic supply, resulting in growing reliance on agricultural imports. By 2020, the self-sufficiency rate (SSR) in bovine meat and dairy products was below 70%, while the SSR of soybean stood at mere 15% (FAO 2024). Consequently, a substantial and growing portion of China's overall GHG footprint is now outsourced globally as trade-embodied emissions (Zhao *et al* 2021, Hong *et al* 2022).

Quantifying the trade-offs between food self-sufficiency and GHG emissions help reduce reliance on imports and avoid increases in global emissions. Although enhancing self-sufficiency has become a central policy goal in China (reinforced by the Food Security Law in 2024 and related national strategies), its compatibility with climate mitigation remains

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uncertain. However, most climate mitigation policies focus on domestic emissions (Dubash *et al* 2021), while agricultural supply chains are increasingly globalized. As a result, GHG emissions embedded in traded products are often overlooked, obscuring the true climate impacts of food self-sufficiency strategies. A consumption-based perspective is therefore essential for evaluating how adjustments in domestic production and trade reshape global emissions (Caro 2023).

Besides, there are concerns that climate mitigation measures might limit the potential for enhancing food production (Smith *et al* 2013, Frank *et al* 2017, Fujimori *et al* 2019). Advances in agricultural technologies and management practices offer potential synergies between production and sustainability, it is still unclear whether these measures are sufficient to offset the potential trade-offs between higher food self-sufficiency and GHG mitigation. In particular, few studies have systematically assessed how adjustments in food self-sufficiency reshape domestic emissions, trade embodied emissions, and land-use dynamics within an integrated food system framework.

In this study, we employed the calibrated Global Biosphere Management model (GLOBIOM-China, see table S1 and S2) to examine how alternative food self-sufficiency pathways reshape China's agricultural production, trade, and GHG emissions through 2060. By explicitly distinguishing domestic from trade-embodied emissions, we capture the climate implications of cross-border production shifts. Comparing enhanced self-sufficiency scenarios against a baseline, we quantify production-side trade-offs and synergies between food security and climate mitigation, assessing their interplay with technological gains, dietary shifts, and land constraints.

2. Methods

2.1. Modeling framework

We employed GLOBIOM-China, a spatially explicit global partial equilibrium model (Havlík *et al* 2014, Zhao *et al* 2021), updated to explicitly represent agricultural nutrient cycling and associated emissions, including cropland, pasture and livestock systems (Chang *et al* 2021). The GLOBIOM-China model is benchmarked to the base year 2000 and subsequently calibrated to reproduce observed conditions in 2010. The 2020 simulation serves as an out-of-sample validation step, ensuring consistency with reported production, consumption, and trade statistics. After this validation, the model is used to simulate long term dynamics up to 2060, consistent with China's carbon neutrality target and the associated policy horizon. Exogenous drivers play a pivotal role in shaping the future dynamics of demand and supply across regions, thereby influencing international trade patterns. All key parameters, including yield growth, productivity changes, and demand trajectories, follow SSP-consistent pathways (Fricko *et al* 2017), which inherently shape resource competition, management adjustments, and production costs.

2.2. Food demand and trade

Population and economic growth are main drivers for shaping future food demand, as evidenced by the increasing preference for more GHG-intensive products such as livestock consumption as per capita gross domestic product increases (Valin *et al* 2014). Additionally, food demand is influenced by income elasticity which is derived from USDA, which provides elasticities for 144 countries and regions across eight major food product groups (Muhammad *et al* 2011). Restricted by land availability and agricultural resources (e.g. irrigation and fertilizer inputs), food price fluctuations occur, which implicitly influence consumer choices and consumption patterns. The total food demand is met through a combination of domestic production and imports.

In the model, the interdependent product markets and bilateral trades can be effectively modeled using the Enke–Samuelson–Takayama–Judge spatial equilibrium approach (Takayama and Judge 1971), dynamically respond to relative differences in regional supply and transport costs. The model also enables the generation of new trade flows, even if they did not occur in the base year.

2.3. GHG emissions accounting

In the GLOBIOM-China model, GHG emissions of the food system originated from food production and agricultural land use change were assessed using a bottom-up approach. This approach has a similar system boundary to that used by (Clark *et al* 2020; Xuan *et al* 2023), (i.e. emissions from domestic production excluding post-processing, transportation and retail emissions), ensuring comparability and consistency in assessing the sources and magnitudes of emissions. Our GHG accounting includes emissions from nitrogen fertilizer use (N_2O), rice cultivation (CH_4), aquaculture emissions (CH_4 and N_2O), livestock manure management and application (CH_4 and N_2O), enteric fermentation in ruminant animals (CH_4), and land use change emissions, especially for deforestation emissions, see figure S1 for GHG accounting boundary.

Crop sector emissions are simulated using the EPIC-IIASA biophysical model across 18 crops and four management systems, following the GGCMI phase 1 protocol (Muller *et al* 2019). In this study, EPIC outputs are used to represent baseline crop productivity and management responses. Climate change-induced yield shocks are not included. Livestock emissions integrate feed conversion efficiencies and manure management distributions from the RUMINANT model (Herrero *et al* 2013), calibrated against national statistics. Enteric fermentation (CH_4) and manure management (N_2O) emissions apply IPCC Tier 3 and Tier 2 methodologies, respectively(IPCC 2006) and (Tables S3-S4). Aquaculture emissions are estimated by multiplying projected production volumes of major aquatic products by CH_4 and N_2O emission factors (e.g., with the aquatic emissions contributing approximately 9.0–9.5 kg CO_2e kg^{-1} for freshwater species and marine species, respectively) reported in recent studies (Shen *et al* 2024, Zhang *et al* 2024). All non-CO_2 emissions are converted using IPCC AR6 global warming potentials, using GWP100 values of 27.9 and 273, respectively (IPCC 2021). Finally, land-use change (LUC) emissions, predominantly deforestation driven by cropland and pasture expansion, are endogenously modeled using a land-conversion cost matrix (Frank *et al* 2016). The associated CO_2 emissions are quantified via an IPCC Tier 3 approach integrated with the G4M forest model (Kindermann *et al* 2008).

To investigate trade embodied emissions, we adopt the environmental footprint methods (Würtenberger *et al* 2006, Caro *et al* 2014) to quantify the diverse GHG emission intensities for different agricultural products across various regions. equation (1) calculates the average GHG emission intensity (*EI*) per unit of product for a specific region and year, by dividing total emissions ($GHG_{R,P,S,Y}$) by total production ($PROD_{R,P,S,Y}$) across systems:

$$EI_{R,P,Y} = \frac{\sum_S GHG_{R,P,S,Y}}{\sum_S PROD_{R,P,S,Y}}. \quad (1)$$

Here, *R* represents the different regions; *P* denotes the 24 types of agricultural products, and *S* represents the individual production systems; *Y* indicates the specific year in the future scenario. We then make the assumption that the emission intensity of products for both domestic consumption and export remains the same within a single region. Subsequently, equation (2) estimates the GHG emissions embodied ($IMGHG_{R,P,Y}$) in imports by multiplying imported quantities ($IMQ_{R,P,Y}$) with the corresponding emission intensity ($EI_{R,P,Y}$) of the exporting region.

$$IMGHG_{R,P,Y} = IMQ_{R,P,Y} \times EI_{R,P,Y}. \quad (2)$$

Furthermore, we employ a top-down approach (Curtis *et al* 2018) to quantify trade embodied deforestation emissions. Cropland deforestation emissions are allocated by crop expansion, and pasture-related deforestation by grazing area for ruminants. The detailed description of the virtual trade flow quantification can be found in Zhao *et al* 2021.

2.4. Scenario analysis

We developed a series of scenarios (Table 1) to assess the impacts of food SSR in China and the effects of mitigation options in this study:

(1) Business-as-usual (BAU): An SSP2-based reference pathway incorporating existing national policies, and ⩾95% SSRs for staple grains (rice, maize, wheat).

(2) Self-sufficiency (SeS): Aligned with China's 2024 Food Security Law, this scenario maintains staple security while enforcing progressive 2060 SSR targets: 50% for soybeans, 80% for other crops, 90% for ruminant products, and 95% for pig meat (tables 1 and S5). This pathway establishes the baseline for evaluating SSR-emission sensitivities, see section below.

(3) Mitigation (MiT): Building upon the SeS constraints, this scenario integrates systemic supply and demand side interventions. Supply side improvements include enhanced crop yields via advanced management and breeding (Zhao *et al* 2024), ruminant feed efficiencies improving toward developed region benchmarks (table S6), achieving an overall realistic increase of approximately 21% by 2060. And it also reflects the ambitious nitrogen management interventions adopted in the MiT scenario, including manure recycling and improvements in NUE from 40% to 60% (Zhang *et al* 2015). Demand side levers include halving food loss and waste and shifting toward an SSP1-aligned sustainable diet characterized by reduced animal-sourced food consumption (Doelman *et al* 2018).

We test three groups of sensitivities on the basis of the SeS scenario. In the first group (i.e., sensitivity scenarios SeS 1–6), the import quantities for soybean, other crops, ruminant products, and pig meat are forced to decrease (−30%, −20%, −10%) or increase (+10%, +20%, +30%) by different levels compared to those in the SeS scenario. In addition, given China's high reliance on imports of soybean and ruminant products, we designed two alternative pathways: a feed-focused trade strategy (SeS 7–12) and a livestock-focused strategy (SeS 13–18). These scenarios impose proportional changes in import quantities that decreasing (−30%, −20%, −10%) or increasing (+10%, +20%, +30%) relative to the SeS scenario for soybean and ruminant products, respectively. The analysis was conducted using the results from four periods in the GLOBIOM-China projections (i.e. 2030, 2040, 2050, and 2060), resulting in a sample size of 24 for each group with the six levels (−30% to +30% import quantities) across four

Table 1. Assumptions made for different scenarios for the year 2060 compared to the base year values of 2020.

Drivers	BAU (Business as usual)	SeS (Self-Sufficiency scenario)	SeS 1–18 (Sensitivity test for the SeS scenario)	MiT (Mitigation scenario)
Crop yield	+17% (Zhao *et al* 2021)	Same as BAU	Same as BAU	+30% (Zhao *et al* 2024)
Ruminant feed efficiency	+13% (Zhao *et al* 2021)	Same as BAU	Same as BAU	+21% (Zhao *et al* 2024)
NUE target	Constant ∼ 40% (Chang *et al* 2021)	Same as BAU	Same as BAU	Reach 60% (Zhang *et al* 2015)
Trade assumption	Only three staple crops 95% (Zhao *et al* 2021)	Three staple crops: 95% Soybean: 50% Other crops: 80% Ruminant products: 90% Pig meat: 95%	The import quantities for soybean, other crops, ruminant products, and pig meat are individually forced to decrease or increase by 10%, 20%, 30%) compared to that in the SeS scenario	Three staple crops: 95% Soybean: 50% Other crops: 80% Ruminant products: 90% Pig meat: 95%
Consummer patterns	SSP2 (Zhao *et al* 2021)	Same as BAU	Same as BAU	Calorie intake: -10% from animal source, −5% from crop source; Food loss and waste: −50%

Note: SeS 1–6: the import quantities for soybean, other crops, ruminant products, and pig meat are all forced to decrease (−30%, −20%, −10%) or increase (+10%, +20%, +30%) by different levels compared to that in the SeS scenario; SeS 7–12: the import quantities for soybean are all forced to decrease (−30%, −20%, −10%) or increase (+10%, +20%, +30%) by different levels compared to that in the SeS scenario, respectively; SeS 13–18: the import quantities for ruminant products are all forced to decrease (−30%, −20%, −10%) or increase (+10%, +20%, +30%) by different levels compared to that In the SeS scenario, respectively.

periods. See Supplementary Information for detailed scenario settings and model uncertainties.

3. Results

3.1. Food system overall GHG emissions in China

In the BAU scenario, China's overall food system GHG emissions are projected to be 1047 (760–1334, hereafter, numbers in parentheses indicate 95% confidence interval (CI) of the estimates) Mt CO_2-eq yr^{-1} by 2060, lower than the current emission level of 1194 Mt CO_2-eq yr^{-1} in 2020 (figures 1(a) and (b), also table S7). By 2060, GHG emissions from domestic food production account for 835 (595–1075) Mt CO_2-eq yr^{-1} (80% of the overall emissions). Structurally, domestic crop emissions will decrease over time, while livestock emissions are projected to rise. GHG emissions from ruminant meat production (266 (188–344) Mt CO_2-eq yr^{-1}) represent the largest proportion of domestic food production emissions, followed by rice (141 (99–182) Mt CO_2-eq yr^{-1}), pig & poultry products (107 (75–138) Mt CO_2-eq yr^{-1}), and aquatic products (95 (73–118) Mt CO_2-eq yr^{-1}; figure 1(a)). In terms of gas types, methane dominates domestic emissions across the period (contribute 58% of domestic emissions by 2020, and 64% by 2060) with 44 Mt CO_2-eq yr^{-1} increase from 2020 to 2060 (figures 1(c) and S2). They are primarily derived from ruminant products and rice production. N_2O emissions from fertilizer application are projected to decrease by 39 Mt CO_2-eq yr^{-1} from 2020 (188 Mt CO_2-eq yr^{-1}) to 2060 (149 Mt CO_2-eq yr^{-1}). But the N_2O emissions from the livestock sector are expected to increase by 17 Mt CO_2-eq yr^{-1} from 2020 to 2060. CO_2 emissions due to land use change contribute a small portion of the domestic GHG emissions across 2020–2060 because of the simulated marginal agricultural land expansion. Spatial GHG emissions from crop and livestock sector can be found in figure S3.

Emissions embodied in China's agricultural imports are projected to peak at 290 (248–331) Mt CO_2-eq yr^{-1} in 2020 and decrease by 27% in 2060 (212 (165–259) Mt CO_2-eq yr^{-1}). This reduction is mainly attributed to the decreased LUC emissions associated with agricultural import (figure 1(b)). With technological improvements and slowed growth in food demand, the rate of land use change declines (Alexander *et al* 2017, Dong *et al* 2018). For example, China's annual growth rate of imports is projected to further decrease, particularly for soybeans, which

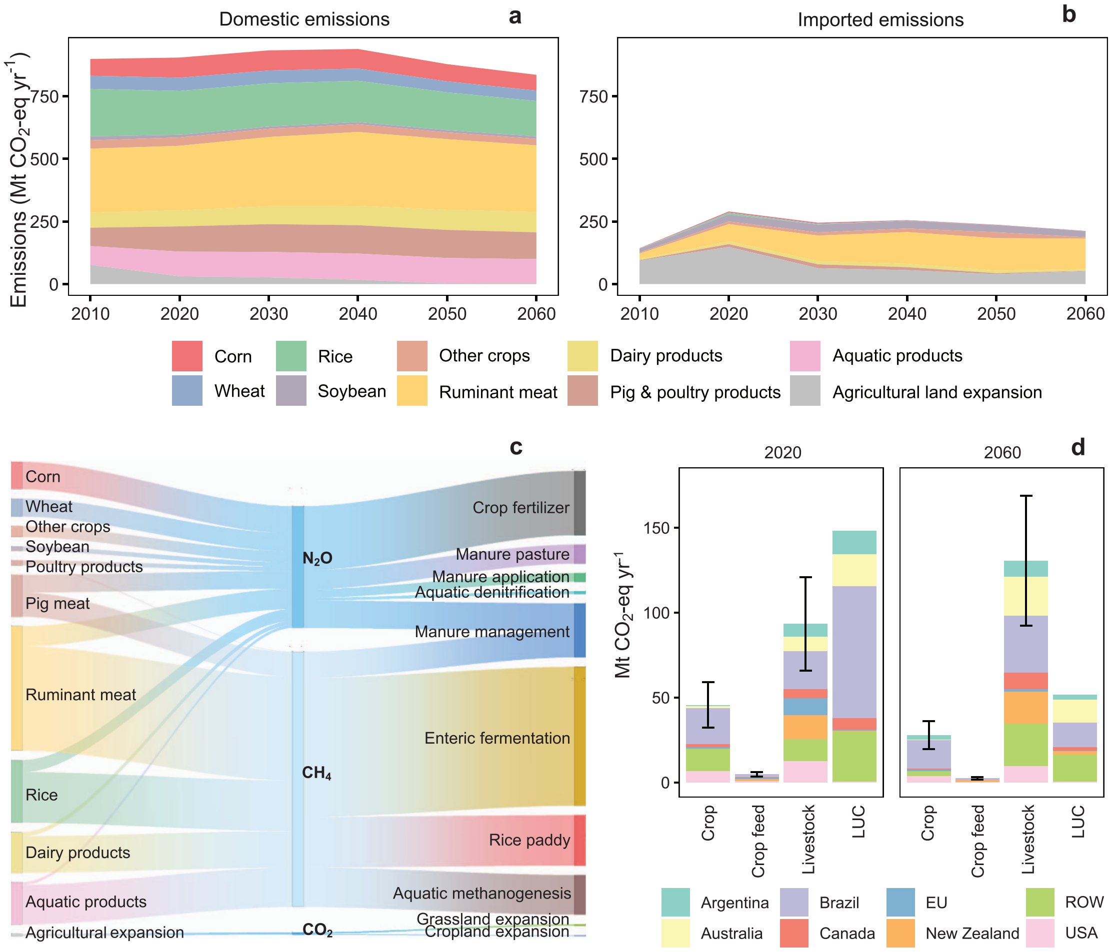

Figure 1. GHG emissions in China's food system. Domestic (a) and virtually imported (b) GHG emissions differentiated by food categories across 2010–2060 under the BAU scenario; (c) Domestic emissions detailed by process and gas type in 2060 under the BAU scenario; (d) Imported emissions from different countries/regions by 2020 and 2060 under the BAU scenario with the error bars show the 95% confidence interval (CI).

declined from 32% in the 2000s to 8.3% in the 2010s (FAO 2024). As Brazil supplies most of China's soybean imports, lower import growth reduces pressure for cropland expansion and associated LUC emissions. Consequently, virtually imported LUC emissions are projected to decrease from 148 Mt CO_2-eq yr^{-1} in 2020 to 52 Mt CO_2-eq yr^{-1} in 2060. Virtual GHG emissions related to crop imports are also projected to decrease from 46 Mt in 2020 to 28 Mt CO_2-eq yr^{-1} in 2060, largely due to the declined rice and corn imports. In contrast, virtually GHG imports of ruminant products are projected to keep increasing and becoming the primary source of imported emissions by 2060. From 2020 to 2060, the share of virtual GHG imports from Australia and New Zealand is projected to increase, largely due to the increasing imports of livestock products and the decreased deforestation in Brazil (figure 1(d)).

3.2. The emission shifts of pursuing high food self-sufficiency

By 2060, overall GHG emissions (domestic and virtually imported) under the SeS scenario are projected to decrease by 52 Mt CO_2-eq yr^{-1} compared to the BAU scenario, reaching 996 (717–1276) Mt CO_2-eq yr^{-1}. Higher self-sufficiency reduces imported emissions by 107 (81–133) Mt CO_2-eq yr^{-1}, but increases domestic emissions by 55 (38–75) Mt CO_2-eq yr^{-1} (i.e. 7% higher than that under the BAU scenario; figure 2(a)). Relative to BAU, emissions associated with ruminant products and agricultural land expansion decline by 52 and 13 Mt CO_2-eq yr^{-1}, respectively. In contrast, soybean related GHG emissions increases by 11 Mt CO_2-eq yr^{-1} because reduced imported emissions are more than offset by higher domestic production emissions. As a result, domestic agricultural prices under the SeS scenario are projected to rise by 10% compared to that under the BAU scenario in 2060 (figure S4(a)). Soybean prices are mostly affected by the elevated SSR, potentially increasing by six folds if soybean SSR reaches ∼50% (figure S4(b)). The prices of ruminant meat are also expected to double compared to those under the BAU scenario. As such prices rise, domestic food and feed protein consumption is expected to decline by 7.3% by 2060 (figure S5). This reduction is primarily driven

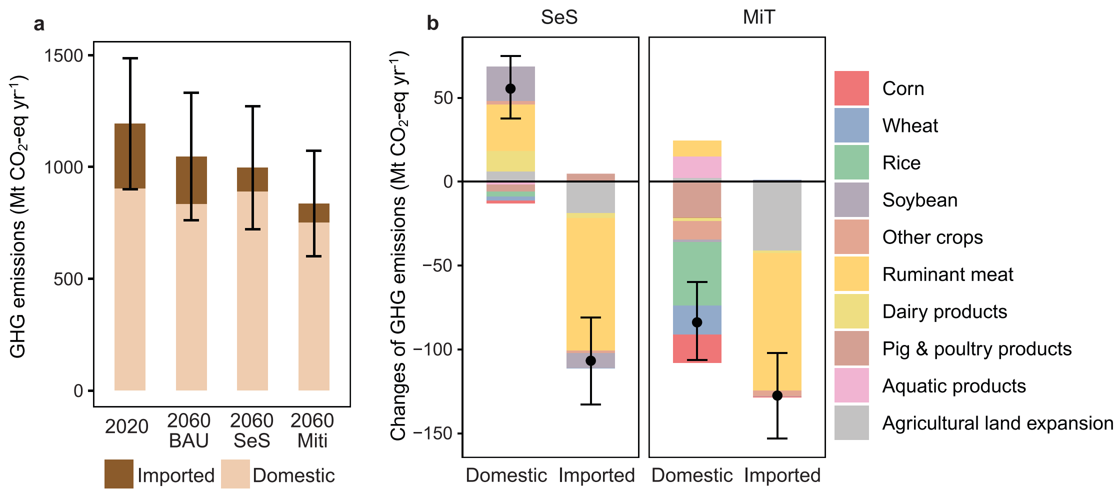

Figure 2. Projected changes in the domestic and trade embodied GHG emissions of China's food system under different scenarios. A, overall (domestic and trade-embodied) GHG emissions; b, changes of GHG emissions between 2020 and 2060 differentiated by food categories. Error bars show the 95% confidence interval.

by competition for cropland among soybean, corn, and wheat under stringent self-sufficiency targets, highlighting the resource constraints associated with pursuing higher domestic production.

The environmental benefits of reduced imports are unevenly distributed across exporting regions. South America, mainly Brazil and Argentina, accounts for 94.4 Mt CO_2-eq yr^{-1} of emission reductions, representing 74% of the global total, mainly through avoided deforestation and lower emissions associated with soybean and beef production (figure S6). Additional reductions occur in Australia and New Zealand due to lower dairy and beef exports. In contrast, emissions embodied in imports from the United States increase by approximately 5.4 Mt CO_2-eq yr^{-1}, reflecting a shift in trade patterns toward U.S. soybean and livestock products. These results indicate that higher self-sufficiency reshapes rather than uniformly reduces global trade-related emissions.

3.3. Market-mediated feedbacks of targeted soybean and livestock self-sufficiency

To systematically unpack the mechanisms through which self-sufficiency targets reshape total emissions, we conducted a regression analysis across a series of sensitivity scenarios (SeS 1–6). The results reveal a steep economic cost associated with forcing food production within domestic biophysical limits. Specifically, we identify a strong positive relationship between agricultural prices and protein SSR, where every 1% increase in food system protein SSR drives a 2.0% (1.3%–2.6%) surge in the agricultural price index (figure 3(**a**)). This profound price shock translates directly into demand destruction. As agricultural prices escalate, total protein consumption is forced to decline (figure 3(b)). Strikingly, each 1% increase in SSR triggers a 0.73% (0.47%–1%) contraction in domestic protein intake (figure 3(c)). It is this suppressed consumer demand that ultimately shrinks the overall GHG emissions (figure 3(d)). Based on the significant relationships observed in figures 3(a)–(d), we ran further regressions between the SSR (both in calorie and protein) and the overall GHG emissions (figures 3(e) and (f)). Rather than resulting from efficiency improvements, the emission reductions under strict self-sufficiency constraints reflect passive mitigation. Specifically, escalating domestic production costs force a reduction in food consumption, which inadvertently drives down overall emissions.

Regarding the soybean and ruminant products, which are highly sensitive to the changes in SSR, we evaluated isolated self-sufficiency targets for soybeans (SeS 7–12) and ruminant products (SeS 13–18; see Methods). No significant relationship ($p > 0.01$) is observed between the changes in crop sector GHG emissions and soybean SSR (figure 4(a)), which can be attributed to the nitrogen-fixing properties of soybeans (less fertilizer demand and associated emissions). However, this upstream feed shift induces a substantial cross-sectoral mitigation effect: a 1% increase in soybean SSR yields a 0.24% (0.11%–0.38%) decrease in livestock sector GHG emissions. This decoupling is driven by economic feedback, as the increased production costs of domestic soybeans elevate feed prices, which consequently limits livestock production scale and suppresses consumption.

Correspondingly, enhancing ruminant self-sufficiency also decreases crop sector GHG emissions (figure 4(c)), although this relationship is moderately correlated ($R = -0.62$) reflecting the sector's lower dependence on feed crops relative to pigs and poultry. Notably, enhancing ruminant SSR effectively reduces

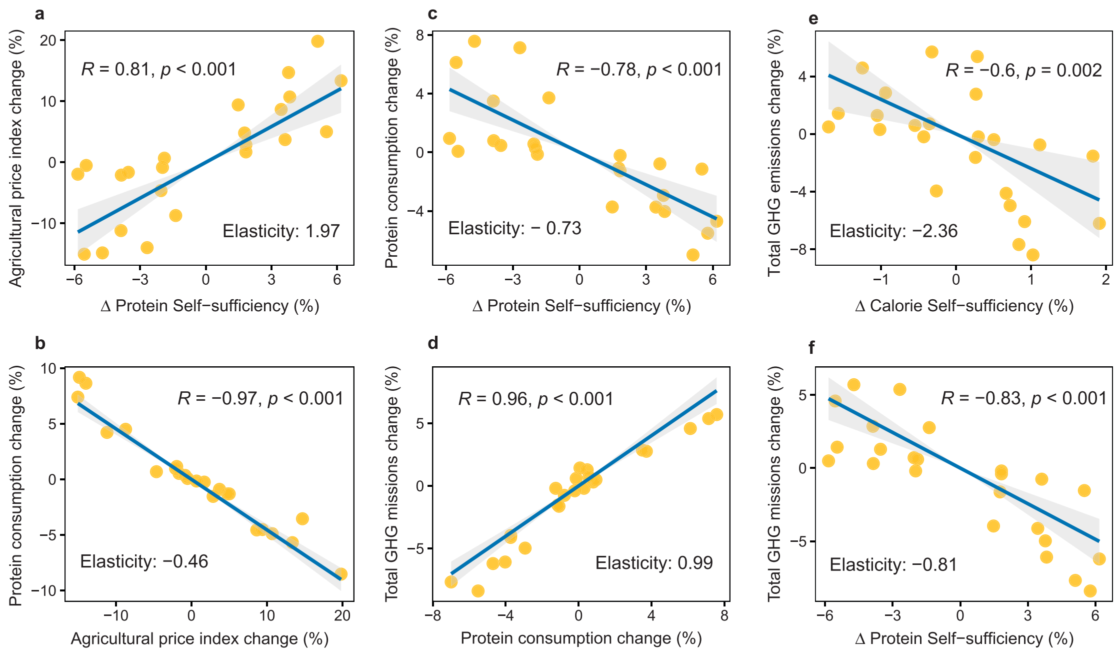

Figure 3. Fitted linear regression between changes in food system self-sufficiency, agricultural prices, food system protein consumption, and total GHG emissions. Predictions are based on an ordinary least squares (OLS) estimation of the linear regression of uncertainty results from SeS scenarios 1–6. (a) shows the change in agricultural price index (price = 1 in 2060 BAU scenario) as a function of change in protein SSR; (b) and (c) illustrate the change in protein consumption change as a function of change in agricultural price index and change in protein SSR, respectively; (d) depicts change in total GHG emissions as a function of change in protein consumption; (e) and (f) present the change in total GHG emissions as a function of change in food system calorie and protein SSR. Dots indicate the results from 2030 to 2060 for different scenarios. The blue lines represent the linear regression fits, and the shaded areas indicate the 95% prediction intervals.

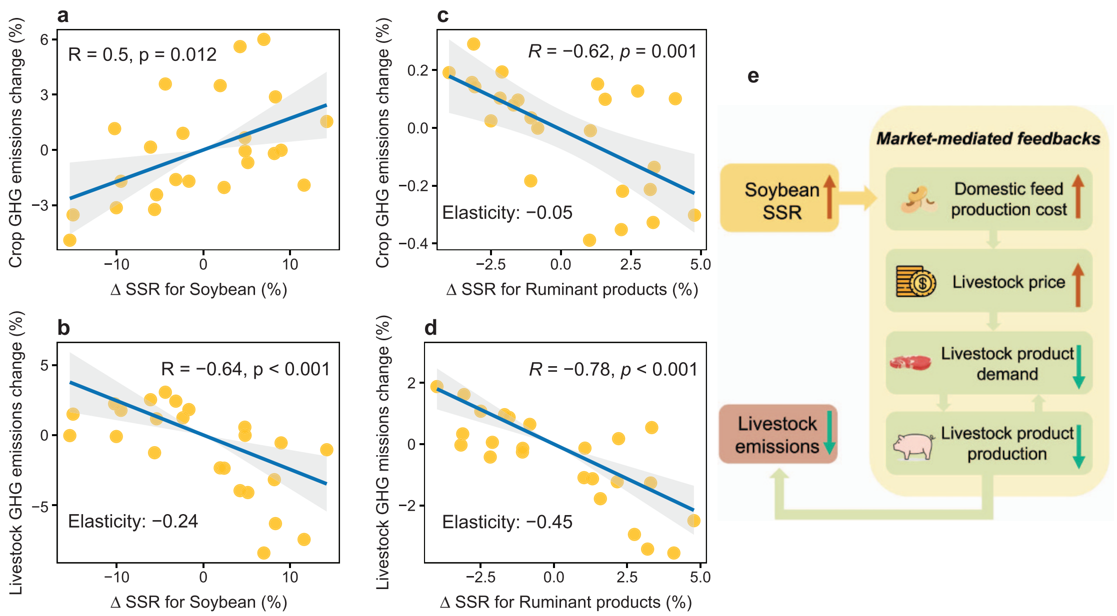

Figure 4. Cross-sectoral climate mitigation feedbacks driven by targeted agricultural self-sufficiency policies. Predictions are based on an ordinary least squares (OLS) estimation of the linear regression of uncertainty results from scenarios SeS 7–12 for soybean (a), (b) and SeS 13–18 for ruminant products (c), (d). The right flowchart shows the market-mediated economic feedback mechanism of livestock GHG emission respond to soybean SSR change (e). GHG emissions here include both domestic and imported emissions. Dots indicate the results from 2030 to 2060 for different scenarios. The blue lines represent the linear regression fits, and the shaded areas indicate the 95% prediction intervals.

total livestock GHG emissions (figure 4(d)) with an elasticity of −0.45. Despite the vast disparity in absolute emission intensities between crop and livestock production, the emission elasticity of soybean SSR (−0.24) operates on a comparable magnitude to that of ruminant SSR (−0.45). These comparable elasticities provide robust evidence that restructuring feed supply chains can serve as a highly effective,

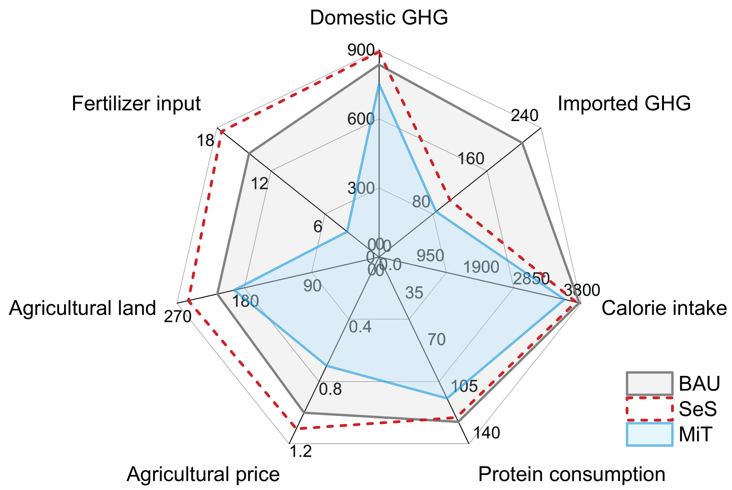

Figure 5. Food system impacts under different scenarios in 2060. The seven dimensions include domestic and imported emissions (Mt CO_2-eq), agricultural land use (Mha), agricultural price index (price = 1 in 2060 BAU scenario), nitrogen input (Mt), total food and feed consumption (Mt protein) and calorie intake (kcal/day/capita).

market-driven pathway for climate mitigation, leading benefits comparable to direct interventions in the livestock sector.

3.4. Mitigation pathways to decouple food security from environmental and welfare trade-off

By adopting mitigation measures that may offer a more sustainable and climate-friendly pathway, overall GHG emissions are projected to be 836 (598–1075) Mt CO_2-eq yr^{-1} by 2060. This corresponds to a 16% reduction (160 Mt CO_2-eq yr^{-1}) compared to the SeS scenario, and a 20% reduction (211 Mt CO_2-eq yr^{-1}) relative to the BAU scenario. Domestic emissions decrease to 751 (536–968) Mt CO_2-eq yr^{-1} and virtual emissions drop to 84 (62–106) Mt CO_2-eq yr^{-1} by 2060. Shifting toward a healthier diet in the MiT scenario increases aquatic product consumption by 10 kcal/day/capita (figure S7), driving an additional 12.7 Mt increase in associated emissions.

Despite these substantial emission reductions, the impact on food intake in China remains minimal relative to the BAU pathway. By 2060 per capita caloric and protein intake decrease by 7.3% and 3.5%, respectively, with livestock protein declining by 7.4% (figure 5 and table S8). In contrast, total protein consumption, including both food and feed sources, drops by 14% compared with the BAU scenario. This reduction largely reflects lower feed requirements for livestock production. Crop-based protein consumption falls by 16%, mainly driven by declines in corn (−23%) and soybean (−16%). The MiT scenario also leads to coordinated changes in land use, input intensity, and market outcomes (see figure S8). Fertilizer input and agricultural land use both decline relative to BAU, consistent with lower production intensity and improved resource use efficiency. By 2060, the agricultural price index is projected to decrease to 0.7 (with BAU normalized to 1). This indicates that mitigation options offer a pathway to lower reliance on imports while achieving a more sustainable balance between emissions and resource use. Decomposition analysis (figure S8) further shows that improved nitrogen management is the dominant contributor to fertilizer reductions, whereas GHG mitigation is achieved through a combination of productivity improvements, dietary shifts, and nitrogen interventions.

4. Discussion and conclusion

A key innovation of this study is quantifying the market-mediated climate feedback linking food self-sufficiency policies and global GHG emissions. Increasing soybean SSR indirectly suppresses livestock emissions by raising feed costs and constraining expansion of emission intensive livestock production (figure 4(b)). Despite the substantially lower emission intensity of soybean compared with ruminant products, improvements in soybean self-sufficiency generate a comparable mitigation elasticity in the livestock sector. These findings highlight the critical role of feed structure (Bai *et al* 2018) and trade dependence as leverage points for reducing overall GHG emissions. In China, food security remains a top priority due to a large population, rising demand for livestock feed, and dependence on a limited number of import suppliers. And countries including Japan, South Korea, and Russia have also adopted self-sufficiency targets in response to geopolitical uncertainty and supply disruptions (Fanzo *et al* 2024). However, pursuing food self-sufficiency alone (as seen in SeS scenario) generates important trade-offs. While reducing trade-embodied emissions, reshoring production increases domestic land competition, fertilizer use, and environmental pressures. Under the SeS scenario, harvested cropland and pasture area expand by 18%, accompanied by a 21% increase in fertilizer use. Furthermore, as our results indicate, the emission reductions achieved solely through high self-sufficiency are largely a passive mitigation driven by escalating food prices that suppress consumer demand.

Reconciling food security with environmental goals requires coupling self-sufficiency target with technological and dietary transitions. Existing policies aimed at increasing soybean SSR remain limited and less effective, largely due to the lower profitability of soybean cultivation (Di *et al* 2023). There is an urgent need to tap into the natural potential for boosting and sustaining soybean production through strategic spatial planning, while ensuring environmental conservation (Li *et al* 2024; Wu *et al* 2020). In addition, ambitious nitrogen management interventions can address other environmental issues related to air, health, and ecosystems (Guo *et al* 2024). Importantly, these supply-side interventions must be complemented by targeted demand-side transitions. While reducing ruminant and red meat consumption is widely recommended to meet global climate targets (Webb *et al* 2020). China's per capita consumption of ruminant products is still below the global average (FAO 2024). Therefore, focusing excessively on reducing ruminant consumption may not be ideal or culturally practical (van Oort *et al* 2024). Instead, we suggest that prioritizing reductions in monogastric product consumption (especially pig meat) offers a feasible solution. Decreasing pork demand reduces both livestock related emissions and the need for imported feed crops. In addition, stringent self-sufficiency requirements reduce per capita red meat consumption by approximately 13%, suggesting important implications for public health. While reducing red meat intake is recommended to lower cardiovascular and cancer risks, recent evidence suggests that Chinese populations may exhibit a higher tolerance for red meat consumption than western populations because of cooking practice (Du *et al* 2020). Therefore, future research direction would be to integrate consumption projections with an assessment of public health benefits or potential nutritional trade-offs.

In conclusion, by explicitly accounting for the dependencies among production, trade, and consumption, our analysis reveals trade-offs and synergies between food self-sufficiency and climate mitigation goals. Increasing self-sufficiency alone reduces trade-embodied emissions but risks greater domestic environmental pressures through land expansion and resource use. Nevertheless, combining self-sufficiency targets with technological improvements, feed efficiency gains, and moderate dietary shifts can transform these trade-offs into synergies. Our study provides a systems perspective for designing food security strategies consistent with China's carbon neutrality goals and offers a transferable framework for other countries facing similar food security and climate challenges.

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Data availability statements

All data that support the findings of this study are included within the article (and any supplementary files).

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Conflict of interest

The authors declare that they have no conflict of interest.

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