nature food

Article

https://doi.org/10.1038/s43016-026-01378-1

Integrated policies could raise China's soybean self-sufficiency and ease global land-use pressure

Received: 24 July 2025

Accepted: 2 June 2026

Published online: 10 July 2026

Check for updates

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Growing demand for animal-sourced foods is intensifying global reliance on soybeans, with China, the largest consumer and a low self-sufficiency rate (SSR) country, driving global largest imports and associated environmental spillover. To improve its SSR, China has implemented policies including rehabilitating salt-affected land, approving genetically modified soybeans and promoting healthy dietary transition. Here we evaluated these interventions using a scenario-based framework benchmarked against a no-policy baseline reconstructed soybean demand. China's SSR declined from full self-sufficiency in 1961 to 17% by 2022 and is projected to decline to 12% by 2050 without intervention. Each 10% implementation of salt-affected land and genetically modified soybeans alone could increase soybean SSR by 1.4% and 1.0%, whereas a 50% healthy dietary implementation alone could raise to 17%. Although individual policies yield modest improvements, their combined implementation could increase SSR to 74% by 2030 and 80% by 2050. This shift could free soybean sufficient to feed 1.89 billion additional people globally while avoiding cropland expansion in tropical frontiers, enabling reforestation and carbon sequestration.

Sustainably coordinating food security and resource use for healthy diets (HDs) is a major global challenge[1,2]. Soybeans are central to this challenge, as the dominant protein-rich feed crop underpinning animal-sourced foods production[3,4]. Although animal-sourced foods provide high-quality protein, overconsumption increases health risks and pressure on soybean supply[5,6].

Globally, soybean production is highly concentrated, with Brazil and the USA contributing 67% of total production and 86% of global exports in 2022, largely serving China and the European Union[7]. This intensification has caused environmental degradation, particularly in Brazil's Amazon and Cerrado[8]. Soybean expansion deforested 2.19 Mha between 2011 and 2016[9], releasing an estimated 74.81 megatonnes of CO_2 equivalent ($MtCO_2e$) of emissions[10,11]. This expansion threatens habitats critical to 971 plant and 372 animal species classified as endangered or vulnerable[12,13]. Despite the Soy Moratorium[14], deforestation persists, highlighting governance constraints.

The increased global consumption of animal-sourced foods has improved protein access, particularly in China[15]. Over six decades, population growth and dietary transformation have increased soybean consumption beyond domestic production capacity[7,15]. By 2022, China

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https://doi.org/10.1038/s43016-026-01378-1

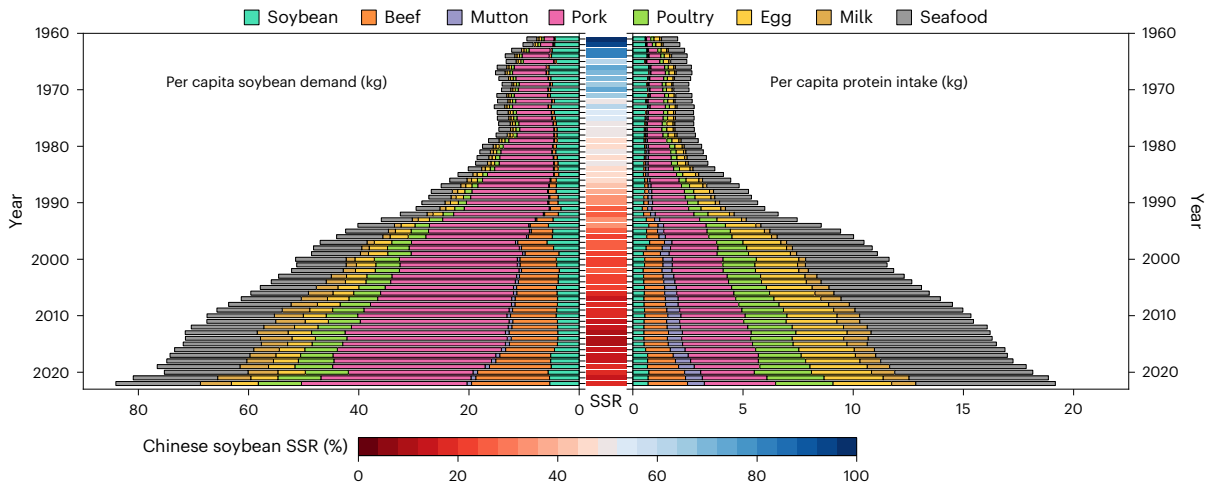

Fig. 1 | Soybean-related dietary transformation in China, 1961–2022. Left: the per capita soybean demand (kg). Middle: a heat map of soybean SSR (%). Right: the per capita protein intake (kg). Soybean-related foods include soybeans, beef, mutton, pork, poultry, egg, milk and seafood.

consumed 31% of global soybean production, yet its self-sufficiency rate (SSR; the ratio of domestic soybean production to total national demand) was only 17%, requiring imports equivalent to 60% of global trade[7]. China's dependence on imports generates global spillovers, shifting land-use pressure to vulnerable ecosystems in producing countries[16]. For example, each tonne of soybean imported by China from Brazil is associated with 0.23 tCO_2e emissions from deforestation[10]. China's market dominance further influences global supply, prices and trade dynamics[17].

Balancing China's soybean SSR improvement with nutrition transition governance and environmental sustainability remains challenging. Existing measures show limited efficacy (Supplementary Note 1 and Supplementary Fig. 1). Despite a declining population, documented shifts in dietary patterns are projected to sustain growth in China's soybean demand and imports in the absence of more effective interventions[18], potentially escalating global supply instability and environmental spillover.

Three key policies can enhance the soybean SSR: first, rehabilitating salt-affected land for soybean cultivation[19,20] (approximately 10.2 Mha of improvable land, primarily comprising lightly and moderately salt-affected soils; Supplementary Note 2), second, adopting genetically modified (GM) soybean varieties (Supplementary Note 3) and, third, promoting dietary transformations aligned with national guidelines (Supplementary Note 4). Here, we address three questions. First, this study examines how China's total soybean demand and SSR will evolve by 2030 and 2050 without policy interventions; second, it investigates how China's SSR trajectories respond to targeted policy interventions; and third, it assesses the extent to which the improved SSR driven by policy interventions contributes to global Sustainable Development Goals (SDGs), especially those closely related to SDGs 2 (Zero Hunger), 13 (Climate Action) and 15 (Life on Land), while acknowledging the interlinkage of all SDGs[21–23].

In this study, we first reconstructed China's soybean demand from 1961 to 2022. We then developed and selected the best-performing model to project China's soybean-based dietary structure, demand and its SSR by 2030 and 2050, in the absence of policy interventions. Next, we evaluated three policies, individually and in combination, across implementation levels to assess their potential to improve SSR. Finally, we quantified global spillover effects by linking changes in China's SSR to progress towards SDGs 2, 13 and 15 and examined key uncertainties and their implications.

Results

Baseline of soybean demand and SSR from past to future

From food to feed. Over six decades, China's dietary transformation increased per capita protein intake 9.6-fold, from 2 kg in 1961 to 19.2 kg in 2022, driven predominantly by animal-sourced foods (Fig. 1). This required an 8.9-fold rise in per capita soybean demand (9.5 to 84.1 kg) and a 19.2-fold surge in protein-driven soybean demand (6.4 to 122.5 Mt), compared with the 3.2-fold growth in domestic production (6.3 to 20.3 Mt).

China's soybean SSR declined from complete self-sufficiency (1961) to 11% (2015), with a marginal recovery of 17% (2022). Population growth and dietary transformation accelerated soybean demand. Direct soybean consumption has remained stable (4–6 kg per capita), yet its protein contribution collapsed from 28% (1961) to 4% (2022), whereas indirect use (animal feed) surged from 54% to 94% of the total soybean demand.

China's evolving animal-sourced food consumption has reshaped soybean demand and protein intake (Fig. 1). Pork remains the dominant driver, increasing from 1.9 to 30 kg per capita (share peaking at 52% in 1990, declining to 36% by 2022), yet contributing 17% of protein intake, highlighting a resource-efficiency paradox: high soybean feed input and low protein output. Beef-related soybean demand rose 65.6-fold (from 0.2 to 14.2 kg per capita), with its share expanding 2% to 17%. Seafood exhibited superior feed-to-protein conversion efficiency: 18% of soybean demand (15.3 kg per capita) delivered 33% of protein intake (6.3 kg per capita) by 2022. Mutton contributed <1% (from 0.03 to 0.85 kg per capita) despite protein intake share (2–4%). Poultry, eggs and milk exhibited intermediate patterns. Since the 1990s, dietary shifts have transitioned China's soybean demand from direct consumption to predominantly feed-intensive livestock utilization.

Projected growth in soybean demand. Bayesian ridge regression projected soybean-related consumption (Extended Data Table 1 and Extended Data Fig. 1). Without policy interventions, dietary transformation raises per capita soybean demand to 96.8 kg by 2030 and 119.9 kg by 2050 (Fig. 2), with protein intake 5555 and 39%. Total soybean demand reaches 140.1 Mt (2030) and 161.0 Mt (2050). Without policy interventions and yield improvement (assuming 2022 yield levels), this trajectory would depress China's soybean SSR to 12% by 2050, jeopardizing domestic supply stability.

Pork remains the dominant driver of soybean demand, accounting for 34% of total demand by 2030 and 2050. Seafood demonstrates superior protein efficiency, contributing 40% (2030) and 37% (2050) of total protein intake despite ranking second in soybean demand. Beef is projected to surpass seafood in soybean demand by 2050, with a 10-Mt increase representing 24% of total demand increase. Milk drives per capita soybean demand of 2.7 (2030) and 4.8 kg (2050). Direct soybean consumption and other animal foods (poultry, eggs and mutton)

https://doi.org/10.1038/s43016-026-01378-1

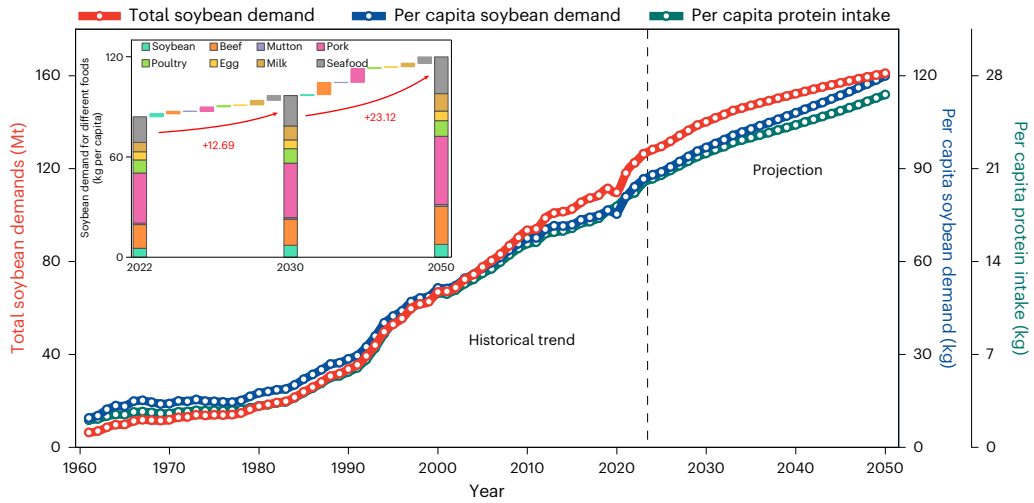

Fig. 2 | Historical (1961–2022) and projected (2023–2050) soybean demand in China. The figure shows per capita soybean demand, per capita protein intake from soybean-related foods and total national soybean demand. Inset, top left: the dietary composition by food category in 2022, 2030 and 2050, including soybeans, beef, mutton, pork, poultry, egg, milk and seafood. The vertical dashed line denotes the boundary between the historical trend (1961–2022) and projected (2023–2050) periods.

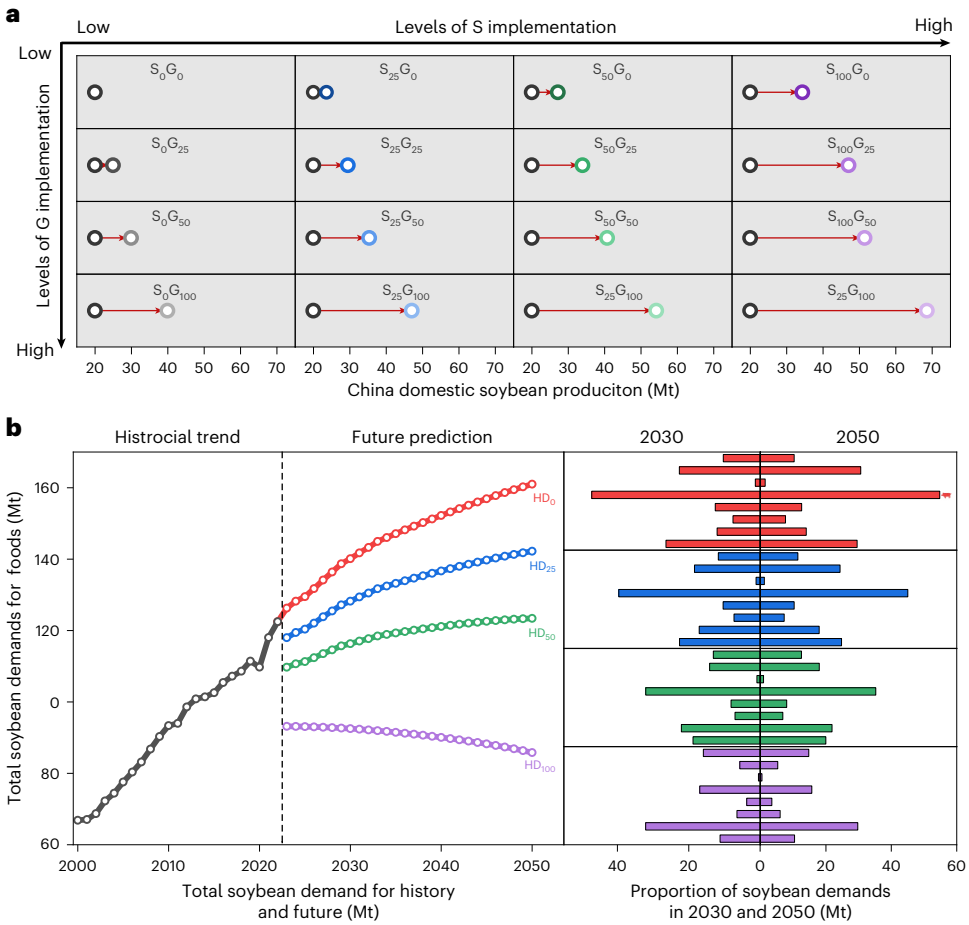

Fig. 3 | Scenario-based soybean production and consumption in China. **a**, Production scenarios include area expansion (S, planting soybean on improved, previously uncultivated, salt-affected arable land), yield improvement (G, adopting GM soybeans) and their combinations. The black circle in each panel indicates baseline production in 2022 without policy interventions; the coloured circles represent projected production under policy implementation. Each policy lever is modelled at four levels of implementation (0%, 25%, 50%, 100%). The horizontal axis (left to right) reflects increasing levels of S implementation; the vertical axis (top to bottom) reflects increasing levels of G implementation. **b**, Consumption scenarios. Left: the historical trend of total soybean demand (2000–2022). Middle: the soybean demand under four implementation levels of an HD (2023–2050): 0% (HD_0, baseline, red), 25% (HD_{25}, blue), 50% (HD_{50}, green) and 100% (HD_{100}, purple). Right: the per capita composition of soybean-related food consumption in 2030 and 2050 under each implementation level.

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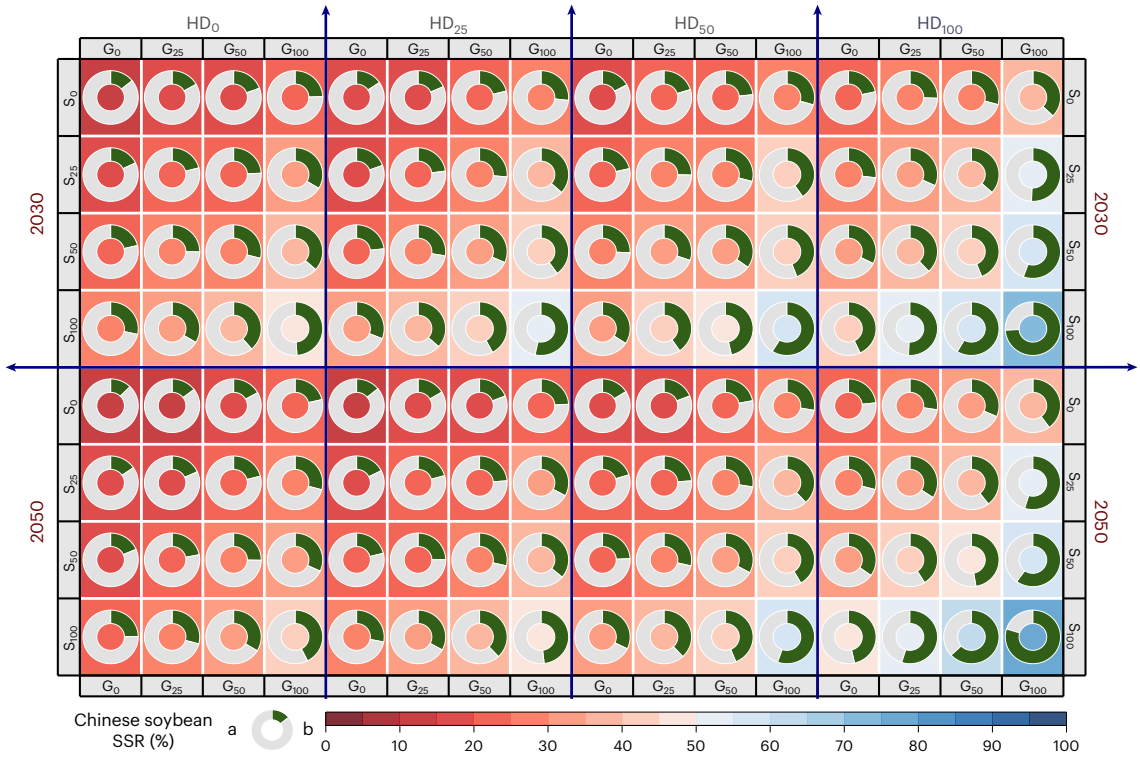

Fig. 4 | Scenario-based soybean SSR in China by 2030 and 2050. Top: projections for 2030. Bottom: projections for 2050. Each tile represents the combined effects of production (S, area expansion on improved salt-affected land; G, yield improvement via GM soybeans) and consumption (HD) interventions at four implementation levels (0%, 25%, 50% and 100%). The value of each tile represents the SSR, marked by both colours, from low (red) to high (blue), and an inner ring chart: the green segment denotes a specific SSR.

see marginal increase, with their collective share declining from 23% (2022) to 20% (2050).

Policy interventions on soybean production, consumption and SSR

Production pathways. We evaluated soybean production increases under policy interventions: area expansion (S) via salt-affected land rehabilitation, yield improvement (G) via GM soybeans and their combination (S + G), across four intensities (0%, 25%, 50% and 100%) (Fig. 3 and Extended Data Fig. 2; full 0–100% at 10% intervals in Supplementary Figs. 2 and 3).

Baseline soybean production (S_0G_0) is 20.0 Mt (2022 level). Area expansion alone elevates domestic soybean production to 25.0 Mt ($S_{25}G_0$), 29.9 Mt ($S_{50}G_0$) and 39.9 Mt ($S_{100}G_0$). Yield improvement alone demonstrates more modest gains, 23.6 Mt (S_0G_{25}), 27.2 Mt (S_0G_{50}) and 34.3 Mt (S0G100). Marginal productivity analysis reveals area expansion delivers 2.0 Mt per 10% implementation intensity, versus a 1.4-Mt increase for yield improvement, highlighting land rehabilitation's immediate scalability. Combined implementation (S + G) generates additive benefits, from 29.4 Mt ($S_{25}G_{25}$) to 68.5 Mt ($S_{100}G_{100}$).

Consumption pathways. We modelled dietary transformation following the Chinese Dietary Guidelines, an HD promoting plant-based protein (especially soybeans), milk and moderate animal-sourced food consumption[24], at four intensities (0%, 25%, 50% and 100%; Fig. 3 and Extended Data Fig. 2).

Baseline (HD_0, 2022 diet) projects soybean demand of 140.1 Mt (2030) and 161.0 Mt (2050) (Fig. 3). Recommended per capita soybean demand is 53 kg, representing 55% (2030) and 44% (2050) of projected demand. Partial adoption (HD_{25}, HD_{50}) slows but does not reverse upward trends: HD_{25} reaches 128.2 Mt (2030) and 142.2 Mt (2050); HD_{50} stabilises at 116.3 Mt (2030) and 123.4 Mt (2050). Full implementation (HD_{100}) reduces demand to 92.5 Mt (2030) and 85.2 Mt (2050), reductions of 47.6 and 75.2 Mt from HD_0.

Demand reductions stem from lower consumption of soybean-intensive foods, offset by increased milk and direct soybean intake. By 2030, HD100 reduces pork (−68%), beef (−24%), poultry (−33%), mutton (−15%), eggs (−15%) and seafood (−57%) relative to HD0, with increases in milk (+166%) and direct soybean (+54%). By 2050, reductions deepen (pork −75%, seafood −65%), whereas milk (+112%) and direct soybean (+43%) remain elevated. Consequently, milk and soybeans account for 53% of HD_{100} soybean demand, addressing the 'high input, low nutrition' paradox.

Combined pathways. Under baseline (S_0G_0 + HD_0), China's soybean SSR remains low: 14% (2030) and 12% (2050), indicating persistent import dependence (Fig. 4). Isolated interventions offer limited improvements. Dietary modification alone raises SSR from 16% (S_0G_0 + HD_{25}) to 22% (S_0G_0 + HD_{100}) by 2030 and from 14% to 23% by 2050, demand growth outpaces these gains. Production-side alone reaches 28% via area expansion ($S_{100}G_0$ + HD_0) and 24% via yield improvement (S0G100 + HD_0) by 2030, both declining three to four percentage points by 2050. Marginal SSR gains per 10% implementation are +0.8% (area expansion) and +0.5% (yield improvement). S + G without dietary transformations achieves 49% SSR (2030) and 43% SSR (2050), no single intervention exceeds 30% and combined production remains below 50%.

Full policy roll-out ($S_{100}G_{100}$ + HD_{100}) boosts China's soybean SSR to 74% (2030) and 80% (2050), cutting imports from 116.3 Mt (2022) to 24 Mt (2030) and 17.3 Mt (2050) (Fig. 4). Among the 64 scenarios, 7 raise SSR above 50% by 2030, and 6 remain effective in 2050.

Spillover effects on global SDGs

Global food security implications. China's soybean policy interventions affect global food security and advance SDG 2 (Zero Hunger)

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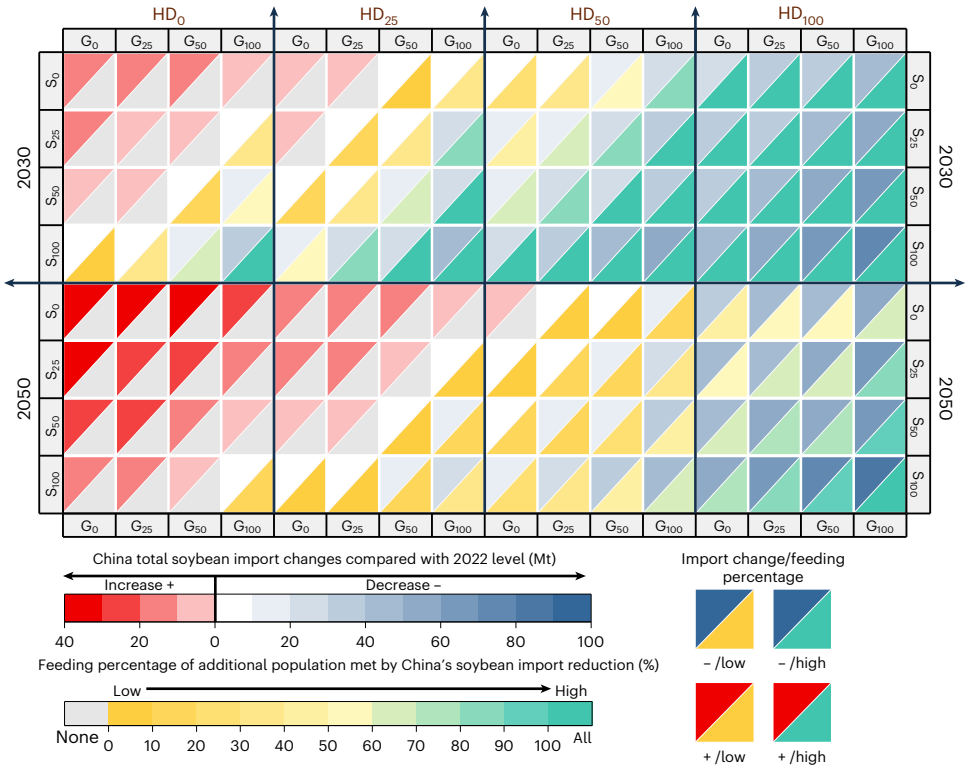

Fig. 5 | Spillover effects of changes in China's soybean imports on global soybean consumption. Top: projections for 2030. Bottom: projections for 2050. Each tile represents the combined effects of production (S, soybean area expansion on improved salt-affected land; G, yield improvement via GM soybeans) and consumption (HD) interventions at four implementation levels (0%, 25%, 50% and 100%). The top left value within each tile indicates the change in China's soybean imports relative to the 2022 baseline. The bottom right value indicates the feeding percentage, that is, the share of the additional global population (since 2022) whose soybean demand could be met by China's import reduction under each scenario.

through demand-supply rebalancing. Reduced import dependency would generate global soybean surpluses to support food-insecure regions[25]. We evaluated feeding potential in food-insecure regions (for example, sub-Saharan Africa)[26].

Without interventions, China's soybean imports reach 111.5 Mt (2030) and 132.4 Mt (2050), approximately 70% and 85% of 2022 global trade volumes (Fig. 5). Full implementation ($S_{100}G_{100}$ + HD_{100}) reduces imports to 78.5 Mt (2030) and 85.2 Mt (2050), availing 33 Mt and 47.2 Mt for potential global redistribution. These surpluses could feed 1.74 billion (2030) and 1.89 billion (2050) people at current global per capita consumption (45 kg). Among 64 policy combinations (Fig. 5), 27 can meet the additional demand of 0.5 billion people by 2030, avoiding 1.1–53.8 Mt of soybean production worldwide. Only full-intensity implementation can meet 2050 demand despite a projected population increase of 1.6 billion, generating an approximately 11.3-Mt surplus while avoiding soybean expansion.

Land-sparing benefits of soybean policy. China's freed soybean production supports SDG 2, directly advances SDG 15 by reducing deforestation and promoting reforestation and aids SDG 13 by preventing carbon emissions (Fig. 6). Soybean area expansion in China is confined to restored low productivity land, reducing pressure on natural ecosystems and limiting land use change-related carbon losses.

Meeting the soybean demand for an additional 0.5 (2030) and 1.6 billion (2050) people would require 42.3 and 112.5 Mt of soybeans, translating 12.6 Mha and 33.6 Mha of cropland expansion at current global yields (3,350 kg ha^{-1} in 2022), probably in Brazil's Amazon and Cerrado biomes[12]. China's policies could avoid 1.1–28.7 Mha of deforestation by 2030 and 1.1–36.9 Mha by 2050, preventing 0.6–16.4 $MtCO_2e$ and 0.6–21 $MtCO_2e$ carbon emissions, respectively (Fig. 6). Thus, China's policies relax the assumed trade-off between Zero Hunger and deforestation.

There are 27 out of 64 policy combinations that could eliminate the need for soybean expansion in the Brazilian Amazon and Cerrado by 2030, unlocking 0.31–16.07 Mha of reforestation opportunities (Fig. 6). Full implementation ($S_{100}G_{100}$ + HD_{100}) could restore an additional 3.4 Mha by 2050, sequestering 1.9 $MtCO_2e$ per year. Liberated land could support habitat restoration and deliver an estimated US$18.9 billion annually in ecosystem service value[27].

Discussion

China's soybean SSR policy exemplifies reconciling domestic food security with global SDGs 2 (Zero Hunger), 13 (Climate Action) and 15 (Life on Land). Improving SSR requires coordinated production–consumption policies. Although land competition constrains expansion, rehabilitating salt-affected lands and adopting GM soybeans could increase supply without compromising cereal production. Yet, production-side interventions alone cannot keep pace with rising demand driven by dietary transformation and population growth, underscoring the consumption-side interventions. Dietary transformation towards healthier pattern can moderate soybean demand, reduce methane emissions and ease supply pressure, especially when combined with production gains. Still, even full dietary transformation (S_0G_0 + HD_{100}) alone raises SSR only to 22% by 2030 and 23% by 2050, reaffirming its limited standalone effect.

Quantitatively, production interventions deliver incremental SSR gains, whereas dietary shifts alone yield moderate improvements. Their combination, however, produces nonlinear benefits. A fully integrated implementation (S100G100 + HD100) substantially improves SSR (74% by 2030 and 80% by 2050) while generating co-benefits for food security, climate mitigation and biodiversity conservation. These

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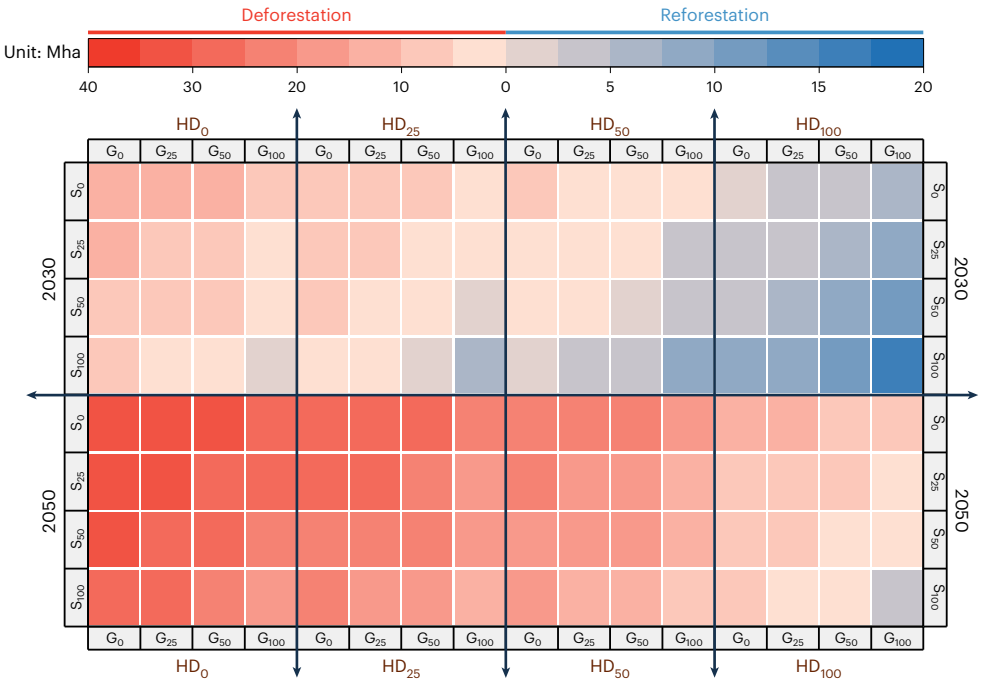

Fig. 6 | Spillover effects of changes in China's soybean imports on forest dynamics. Top: projections for 2030. Bottom: projections for 2050. Each tile represents the combined effect of production (S, area expansion on improved salt-affected land; G, yield improvement via GM soybeans) and consumption (HD) interventions at four implementation levels (0%, 25%, 50% and 100%). Colours indicate projected changes in global forest dynamics, ranging from deforestation (red) to reforestation (blue), reflecting how reduced soybean imports from China alleviate land-use pressure elsewhere, particularly in Brazil's Amazon and Cerrado regions.

findings suggest that policy bundling, rather than isolated interventions, is essential for system transformation. They suggest that food security policies can be redesigned as dual-purpose interventions for domestic resilience and global sustainability. Parallel and phased implementation, combining gradual land rehabilitation, scaled GM adoption and sustained dietary transition, provides a pathway for continuous SSR improvement. Such integration offers a model for aligning national food security with transnational environmental commitments under the Paris Agreement and the post-2020 Global Biodiversity Framework[28,29].

Nevertheless, improved soybean SSR in China involves trade-offs. Expanding soybean cultivation onto rehabilitated land could generate 2.18–8.74 $MtCO_2e$ and consume 9.98 39.92 billion m^3 of water under 25–100% implementation intensities[30], risking soil degradation and threatening biodiversity (for example, Saunders' gull and other endemic species)[13]. China's soybean production is currently more resource-intensive than Brazil and the USA[30], largely owing to lower yields. Integrating high-yielding GM varieties on rehabilitated salt-affected land can narrow this gap and reduce environmental intensity. Soybeans are prioritized on such land because they address China's most severe food security gap while remaining agronomically compatible with light-to-moderate salinity conditions[31,32]. For salt-affected lands in arid and semi-arid regions[19], water availability is an inherent constraint; additional water demand cannot be met through further abstraction from aquifers or rivers. Feasibility depends on substantial gains in agricultural water-use efficiency, expected from 'well-facilitated farmland' investments in irrigation and drainage infrastructure[33], coupled with improved management and varieties. Reclaimed land would thus be supported primarily through more efficient reallocation of existing agricultural water rather than increased withdrawals.

At the global scale, reduced import demand reshapes trade flows and affects exporting economies. In 2022, Brazil's soybean exports to China were worth US$37.3 billion (1.91% of its gross domestic product (GDP))[7]. Beyond these bilateral effects, a higher soybean SSR in China is more likely to induce a gradual realignment of global trade flows than a rupture of existing alliances, reshaping sourcing patterns among major exporters and redirecting part of the surplus towards demand-growing developing economies (Supplementary Figs. 4 and 5). However, market reallocation may not ensure equitable outcomes[34].

Full implementation requires substantial fiscal and institutional commitment. Improved SSR enhances domestic food security resilience to trade tensions (for example, China–US tariffs), supply-side fluctuations (for example, Brazil's Soy Moratorium) and climate anomalies (for example, El Niño events)[14,35–37].

Rehabilitating salt-affected arable land offers opportunities and challenges. Soil improvement costs range from US$1,250–12,500 per hectare (light-to-moderate degradation) to US$31,251 per hectare (severe)[38–41], implying a total investment of US$20.9–104.6 billion for the 10.2-Mha improvable area[20]. This is economically defensible: China's cumulative soybean import expenditure (2000–2024) exceeded US$380 billion[7]. The 10.2 Mha of uncultivated, light-to-moderate salt-affected land spans five major regions (northeast, northwest, central north, north and coastal China), with spatial data being refined by the ongoing Third National Soil Survey[42]. We capture uncertainty via bounded cost range. Rehabilitation costs can be recovered within 1–2 years, considering reduced imports and technological advances[20,27].

Yield improvement via GM soybeans faces high cost (averaging US$115 million and 16.6 years per variety[43]) and sociocultural resistance: only 34% of consumers and 51% of farmers in China accept GM soybeans (Supplementary Note 5). Broader uptake requires transparent labelling, classification and subsidies.

Dietary transformation confronts entrenched dietary preferences since the 1980s. Still, momentum is growing for healthier diets aligned with the Chinese Dietary Guidelines, to improve public health and reduce healthcare expenditure[44]. Drawing on a 30-year US study[45–47], comparable diet-related health gains could save US$161 billion (2030) to US$565 billion (2050) in healthcare costs. Cross-country comparison

shows that convergence towards US or EU-27 diets would worsen China's SSR and environmental burdens (Supplementary Figs. 6 and 7), but cultural lock-in (pork dominance and direct soy food intake) makes such convergence unlikely.

Uncertainty arises primarily from model robustness and key socioeconomic variables. Although projections of food consumption are robust, soybean demand displays wider uncertainty bounds. To address this, we performed 3,000 Monte Carlo simulations across confidence intervals around food consumption estimates, projecting soybean demand to reach 96.8 ± 0.9 Mt by 2030 (coefficient of variation of 1%), indicating high simulation reliability.

Sensitivity analyses revealed that soybean demand in 2030 is most responsive to food production changes (a ±10% change in yields results in a 7% change in soybean demand, that is, elasticity of 0.7), with weaker responses to urbanisation rate (0.03%) and per capita GDP (2%). This highlights the dominant role of domestic food production over socioeconomic drivers. However, China's soybean SSR remained relatively stable, with variations below 1%.

A ±10% population variation by 2030 leads to a ±10% change in total soybean demand, with modest SSR effect: −1.3% (+10% population) and +1.6% (−10% population). A 10% improvement in feed conversion rates would reduce soybean demand by approximately 13.0 Mt and increase SSR by 1.5% by 2030, highlighting feed efficiency gains.

The small inflections around 2020 in Figs. 2 and 3 reflect transient disruptions to global logistics, trade flows and short-term demand. These do not alter the dominant long-term structural trend of a widening domestic production–demand gap but reinforce the strategic rationale for strengthening SSR as a buffer against external uncertainty. Beyond this uncertainty, changes in China's import demand may induce indirect land-use change in exporting countries, where displaced cropland could be repurposed for higher-emission uses, warranting caution in interpreting global mitigation outcomes.

Although centred on China, this soybean policy experiment offers a scalable model for sustainable agricultural transformation in emerging economies facing similar food-environment trade-offs. Simultaneous advances in SDGs 2, 13 and 15 suggest that nationally determined agricultural policies can support planetary goals. Future research should examine institutional and governance innovations required for replication in large developing countries (for example, India) and food-insecure regions (for example, sub-Saharan Africa).

To isolate policy effects, we excluded factors, such as climate change (for example, CO_2 fertilization), agronomic improvement and technological advances[30,48,49]. This conservative approach may underestimate SSR improvement potential, but these omitted factors could amplify gains, generate positive spillover and convert current trade-offs into long-term co-benefits.

Ultimately, China's soybean dilemma encapsulates a broader twenty-first-century challenge: meeting nutritional needs within planetary boundaries. The path forward lies not in prioritizing production or consumption alone but in integrating both to build food systems that are productive, sustainable and equitable.

Methods

Reconstruction of soybean demand

To assess how dietary transformation and domestic production influence China's soybean SSR, we reconstructed annual national soybean demand from 1961 to 2022 using a two-tiered approach: (1) direct consumption of soybean-based foods and (2) indirect utilisation as feed in soy-based systems that produce eight major animal-sourced foods, namely beef, mutton, pork, poultry, egg, milk and seafood. Data on direct consumption were obtained from FAOSTAT[7]. For indirect demand, we first estimated the soybean demand per unit of feed in each soy-based production system (SD_{ui}), calculated from the proportion of soybean meal in feed rations (P_{smi}) and soybean-to-meal processing efficiency (fixed at 0.81)[50] (Supplementary Table 1), where i is each food production system (beef, egg and seafood). The total indirect soybean demand for each product (SD_i) was calculated using product-level consumption (C_i), feed conversion ratios (CR_i) and the corresponding SD_{ui} values as follows:

$$SD_i = C_i \times CR_i \times SD_{ui} = C_i \times CR_i \times P_{smi} \times 0.81.$$

Soy-based protein intake

We quantified protein intake from both direct consumption of soybean-based foods and indirect consumption of animal-sourced foods based on the reconstructed soybean demand. Dietary transformations were assessed using FAOSTAT food consumption data from 1961 to 2022[7] integrated with standardised protein content values (Supplementary Table 1). To ensure temporal consistency, we harmonized the discrepancies between the 1961 and 2013 and 2010–2022 datasets by calibrating them against their overlapping period (2010–2013), which served as a reference baseline.

Soybean consumption modelling

Soybean consumption is primarily influenced by socioeconomic, demographic and production-related factors[51]. We selected representative variables to model the trends in direct and indirect soybean consumption for animal-sourced foods. For direct soybean consumption, we selected eight variables to model its consumption, including soybean cropland area and per capita livestock products, including beef, mutton, pork, poultry, eggs, milk and seafood, and three variables to model their distinct consumption: per capita GDP (economic), urbanization rate (social) and per capita production of different animal-sourced foods. To simulate food consumption trends, we trained and evaluated multiple models, including random forest, Bayesian ridge regression, multiple linear regression, support vector regression, gradient boosting, artificial neural networks and LASSO, against the reconstructed time-series soybean demand across the eight major soy-based food categories. Model performance was assessed, and the best-performing model was selected for future projections. Population and urbanization data for both the historical and projected periods were obtained from FAOSTAT[7], and per capita GDP data were sourced from the World Bank[52]. Historical production data for the eight major soy-based food categories were retrieved from FAOSTAT, whereas projections for 2024–2033 were derived from China Agricultural Outlook[53]. For years beyond 2033, the total production levels were assumed to remain constant at 2033 values.

Scenario for SSR projections

In this analysis, the SSR was defined as the ratio of domestic soybean production to total national demand. To assess the impact of China's production and consumption policies on the SSR in 2030 and 2050, we developed a full-factorial scenario framework comprising three policy levers, each implemented at four intensity levels (0%, 25%, 50% and 100%), resulting in a total of 64 scenarios. The policy levers included: (1) area expansion, involving the rehabilitation of 10.2 Mha of marginal, uncultivated, salt-affected arable lands through soil improvement for soybean production[20,54]; (2) yield improvement, achieved by legalizing GM soybean varieties to raise average yields from 1.95 t ha^{-1} (non-GM) to 3.02 t ha^{-1} (GM)[55,56]; and (3) HD, aligned with national dietary guidelines to moderate animal-source food consumption and improve nutritional balance[24,57].

Spillover scenario for global SDGs

China's soybean policies aimed at increasing domestic SSR may exert transnational effects on global soybean availability and production dynamics. We quantified their potential contributions to several SDGs, including SDG 2 (Zero Hunger), by assessing the capacity to meet population-driven soybean demand based on the 2022 global per capita

baseline, SDG 13 (Climate Action) and SDG 15 (Life on Land) through an analysis of supply–demand dynamics, land use and forest conservation across different policy scenarios.

Specifically, we first estimated the global average per capita demand for food using soybeans under current consumption patterns. On the basis of the reductions in China's soybean imports under different scenarios, we then calculated the number of people whose soybean needs could be met with the saved supply and compared this with the projected global population growth. If the saved volume falls short of future demand, additional soybean production would be required, probably triggering further deforestation in Brazil's Amazon and Cerrado and associated carbon emissions. Conversely, if the saved supply exceeds demand, it would imply no need for further expansion of global soybean cropland, allowing spared land to be reallocated for rainforest restoration or other conservation efforts. Considering the growing meat demand, substantial demographic and economic growth potential in food-insecure regions (for example, sub-Saharan Africa)[38] and sustained global commitments to the SDGs, we estimated the potential feeding capacity on the basis of the premise of full affordability and access.

The R software (4.5.3) is used to analyse all the data in the study.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All data for this work were collected by the authors. The data that support the findings of this study are available within the article and its Supplementary Information. Source data are provided with this paper.

Code availability

No custom code was produced for this study.

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Author contributions

F.L. and J. Sun designed the study and wrote the manuscript. J.P., J. Sardans and J.L. revised the manuscript; Y.Z., Q.H., L.G., T.Z. and S.W. conducted the data collection and model analysis. M.L., P.Y., D.S. and W.W. supervised the study. All authors reviewed and approved the final version.

Funding

J. Sun discloses support for the research and publication of this work from National Natural Science Foundation of China (grant no. 42271276), National Key Research and Development Program of China (grant no. 2023YFD1500200) and Central Public-interest Scientific Institution Basal Research Fund (grant no. Y2025YC75). L.F. discloses support for the research of this work from National Natural Science Foundation of China (grant no. 41801202). Y.Z., Q.H., L.G., T.Z., S.W., J.P., J. Sardans, M.L., P.Y., D.S., J.L. and W.W. declare no relevant funding.

Competing interests

The authors declare no competing interests.

Additional information

Extended data is available for this paper at https://doi.org/10.1038/s43016-026-01378-1.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43016-026-01378-1.

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Peer review information *Nature Food* thanks the anonymous reviewer(s) for their contribution to the peer review of this work.

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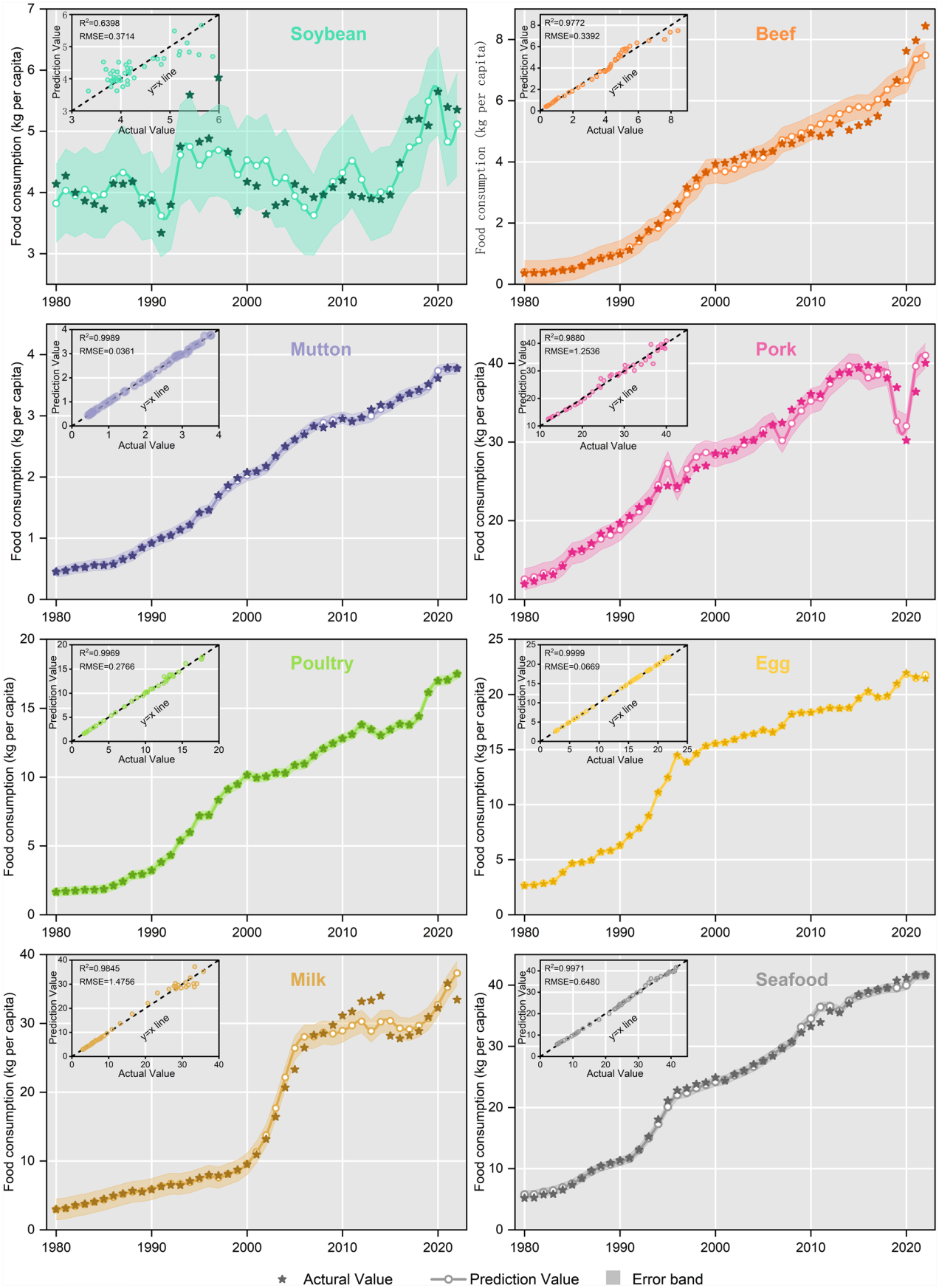
https://doi.org/10.1038/s43016-026-01378-1

Extended Data Table 1 | Performance metrics (R^2 and RMSE) of simulation models reconstructing soybean demand in China, 1961-2022

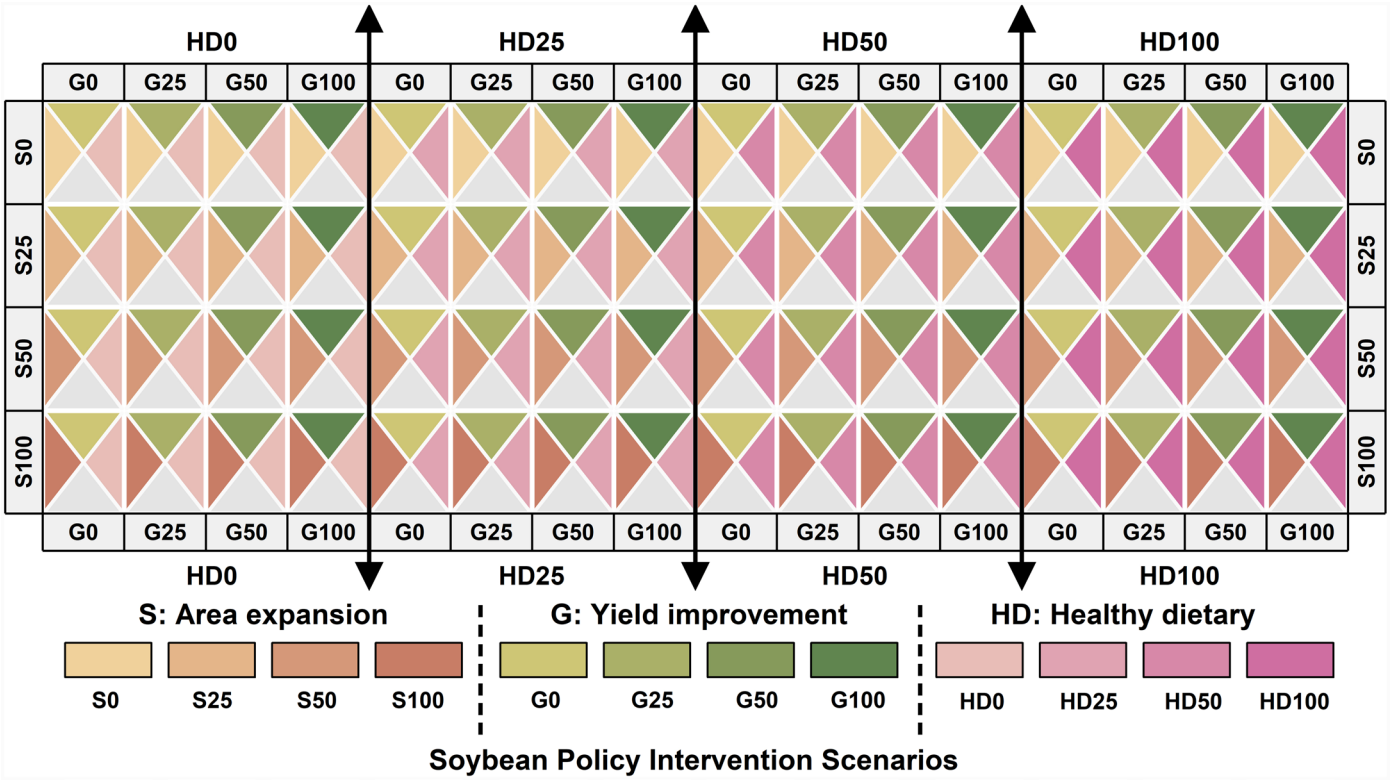
Models	Metric	Soybean	Beef	Mutton	Pork	Poultry	Egg	Milk	Seafood
Random Forest	R^2	0.83	0.99	1.00	1.00	0.99	1.00	0.98	1.00
	RMSE	0.28	0.51	0.06	8.11	1.17	6.19	10.03	9.27
Bayesian Ridge Regression	R^2	0.64	0.98	1.00	0.99	1.00	1.00	0.99	1.00
	RMSE	0.37	0.34	0.04	1.25	0.28	0.07	1.48	0.65
Multiple Linear Regression	R^2	0.51	0.98	1.00	1.00	1.00	1.00	0.96	1.00
	RMSE	0.17	0.11	0.00	0.49	0.03	0.02	6.55	0.17
Support Vector Regression	R^2	0.38	0.76	0.87	0.46	0.55	0.24	0.62	0.33
	RMSE	0.21	1.49	0.16	48.23	12.50	31.07	55.66	97.90
Gradient Boosting Regression	R^2	0.82	0.99	1.00	1.00	0.99	1.00	0.98	1.00
	RMSE	0.06	0.04	0.00	0.38	0.17	0.11	2.34	0.26
Artificial Neural Network	R^2	-652.94	-41.68	-171.78	1.00	-14.65	-4.33	0.96	1.00
	RMSE	223.95	268.13	222.27	0.49	430.94	219.10	5.50	0.14
LASSO Regression	R^2	0.26	0.88	0.69	1.00	1.00	1.00	0.96	1.00
	RMSE	0.25	0.75	0.40	0.35	0.15	0.11	5.45	0.24

https://doi.org/10.1038/s43016-026-01378-1



Extended Data Fig. 1 | Fitting result of the Bayesian ridge regression model for soybean-related food consumption. Food categories include soybeans, beef, mutton, pork, poultry, egg, milk, and seafood. Model performance metrics (R^2, RMSE, and Q-Q plot) are shown in the upper-left inset.

https://doi.org/10.1038/s43016-026-01378-1



Extended Data Fig. 2 | Scenario framework for simulating policy intervention, individually and in combination, across four implementation intensities (0%, 25%, 50%, 100%). The scenarios include: area expansion (S, rehabilitating salt-affected land for soybean cultivation following soil improvement), yield improvement (G, adopting genetically modified soybean varieties), and healthy dietary (HD, aligning national diets with dietary guidelines to moderate animal-sourced food intake). To illustrate these inventions, under the S25G0 scenario, 25% of salt-affected land was rehabilitated and cultivated with soybeans on top of the 2022 baseline area, whereas no GM soybeans were adopted, representing a case of area expansion alone. S0G25 represents a case of yield improvement alone, where 25% of the cultivated soybeans are GM varieties with no additional land expansion. H25 indicates 25% of the soybean-based dietary composition was aligned with the recommended structure of the HD, whereas the remaining 75% retained the current (i.e. 2022) dietary structure. The other intensities represent proportional shifts in area expansion, yield improvement, dietary composition, or their combinations.

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Last updated by author(s): Apr 29, 2026

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Study description	This study evaluates the impacts of three recently introduced soybean-related policies in China—rehabilitating salt-affected land, approving genetically modified soybeans, and promoting healthy dietary change—on the soybean self-sufficiency ratio (SSR). Using scenario simulations for 2030 and 2050, we quantified the individual and combined effects of these policies under four implementation levels each, representing land expansion, yield improvement, and demand reduction pathways. Results indicate that China's SSR could increase to 74% by 2030 and 80% by 2050. The soybeans no longer imported would be sufficient to meet the soybean needs of 1.89 billion additional people globally by 2050, with surplus remaining. The policy-driven shift could also prevent cropland expansion in key tropical soybean frontiers, exemplified by the Brazilian Amazon, thereby enabling reforestation and carbon sequestration.
Research sample	We divided foods into two parts, including (1) direct consumption of soybean-based foods and (2) indirect utilisation as feed in soy-based systems that produce eight major animal-sourced foods, namely beef, mutton, pork, poultry, egg, milk, and seafood.
Sampling strategy	No sampling strategy involved. The study is based on nationally aggregated statistics and scenario simulations rather than different samplings
Data collection	Data were collected manually from FAOSTAT, World Bank, China Agricultural Outlook, as well as published books and papers listed in the references
Timing and spatial scale	Timing: 1961-2050. Spatial coverage: China, Brazil, and rest of the world.
Data exclusions	All data are included.
Reproducibility	All analyses are based on publicly available data from international organizations, on-line databases, peer-reviewed paper, and published books. The study is fully reproducible given access to these datasets, and the methodological work-flow has been described in detail in the Methods. Key results were cross-validated by sensitivity analyses to ensure robustness.
Randomization	No randomization involved. The study is based on nationally aggregated statistics and scenario simulations rather than individual-level experimental units.
Blinding	No blinding.

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Methods

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Plants

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