# Multi-Model Assessment Reveals Context-Specific Regional Priorities in Food System Transformation

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## Abstract

Transforming food systems toward sustainability requires interventions across both supply and demand sides. Growing evidence demonstrates that bundling measures manages trade-offs and unforeseen consequences that emerge when implementing these interventions together. However, implementation feasibility and effectiveness depend critically on regional context. Using an ensemble of ten global economic models, we decompose the contributions of four food systems transformation measures: increased agricultural productivity, reduced food loss and waste, dietary shifts toward EAT-Lancet recommendations, and ambitious climate mitigation policies, across thirteen world regions. We find that this style of food system transformation sees the agricultural sector contract and reorient globally, but that the mechanisms driving this contraction differ across regions and cluster into two broad archetypes: a cost-led contraction, where mitigation policies and, to a lesser extent, dietary shifts raise production costs, as in South and Southeast Asia and Sub-Saharan Africa; and a demand-led contraction in livestock-intensive regions such as South America, where dietary shifts depress both production and producer prices. The dominant transformation measure and the severity of associated trade-offs differ systematically across these archetypes, demonstrating that while comprehensive bundling is necessary everywhere, regional priorities must vary.

## Introduction

Transforming food systems toward sustainability requires interventions across both supply and demand sides. Growing evidence demonstrates that bundling measures, such as increased agricultural productivity, reduced food loss and waste, dietary shifts, and climate mitigation policies, manages trade-offs and unforeseen consequences that can emerge when implementing measures in isolation. However, implementation feasibility and effectiveness depend critically on regional context.

For example, Sub-Saharan Africa and parts of Asia face high undernourishment and low productivity, where making healthy diets affordable while building productive capacity is paramount, while regions with high animal-sourced food consumption and elevated overweight rates, such as parts of South America, North America, and Oceania, must shift dietary preferences while managing disruption in livestock-intensive sectors. These structural differences mean that the same bundle of interventions can generate different and potentially inequitable distributions of costs and benefits across regions, raising important questions for policy design and international coordination.

We used an ensemble of ten global economic models to decompose how each of the four transformation measures contributes to regional outcomes. Our model ensemble includes both computable general equilibrium models (AIM, ENVISAGE, FARM, MAGNET) and partial equilibrium agricultural sector models (CAPRI, GCAM, GLOBIOM, IMAGE, IMPACT, MAgPIE). All models implement scenarios following the SSP2 middle-of-the-road shared socioeconomic pathway. Models apply harmonized input data for population and GDP trajectories, climate impacts on crops, livestock, and agricultural labor productivity, and diet specifications for both current consumption patterns and the flexitarian EAT-Lancet diet by food group and region. We study thirteen regions spanning the global diversity of food systems and development levels: Australia and New Zealand (ANZ), Brazil (BRA), Canada (CAN), China (CHN), Eastern Europe and Central Asia (ECC), Europe (EUR), India (IND), Middle East and North Africa (MEN), Other Asia (OAS), Other South America (OSA), Southeast Asia (SEA), Sub-Saharan Africa (SSA), and USA.

To understand how these measures interact, we analyze them both independently and as a bundle (see Table 1 for scenario component descriptions). We run two sets of scenarios. The first adds each transformation component individually to a business-as-usual baseline (BAU): BAU_PROD includes increased productivity to BAU, BAU_WAST includes the reduction of food loss and waste, BAU_DIET shifts dietary preferences to align with the EAT-Lancet recommendations, and BAU_MITI includes climate mitigation and land use policies. Comparing these single-measure scenarios to BAU quantifies the individual effect of each component. The second set systematically removes components from an EAT-Lancet food system transformation with ambitious climate change mitigation (ELM): ELM_PROD excludes productivity improvements, ELM_WAST excludes waste reduction, ELM_DIET excludes dietary shifts, and ELM_MITI excludes mitigation policies. Comparing ELM to these leave-one-out scenarios quantifies the total effect of each measure within the bundled context. This reveals whether measures operate independently (where individual and total effects are similar) or whether their effectiveness is substantially modified by the presence of other interventions, with critical implications for whether selective prioritization is viable or whether comprehensive bundling is essential. Unless otherwise noted, we present the total effect of the drivers in this study and use only the driver short-hand without the baseline suffix (eg. total effect of dietary shifts is referred to as DIET; Table 1)

By decomposing both the individual and total effects of each measure in the ELM bundle across thirteen diverse regions, this study reveals how the relative importance of each transformation lever shifts with regional context, demonstrating that effective policy design cannot rely on globally uniform strategies.

# Results

Under the ELM scenario, agricultural production declines relative to BAU 2050 across all regions, but the direction of producer price change diverges. Figure 1 shows the relationship between the change in producer prices and the change in production for each model, region, and scenario driver. The quadrants in the figure represent possible trajectories for the agriculture sector in a particular region: the upper-left (falling production alongside rising prices) reflects a cost-driven contraction where supply constraints outpace demand reductions; the lower-left (falling production and falling prices) reflects a demand-led contraction where dietary shifts reduce the market for agricultural output; the lower-right (falling prices and increased production) captures efficiency improvements where productivity gains expand production at lower cost; and the upper-right (both production and prices rise) reflects demand outpacing supply. We observe that the multi-model median for ELM (open circle) across the regions lies either on the cost-driven (upper-left) or demand-led (lower-left) quadrants.

Whether a region's transformation is demand-led or cost-driven depends on its structural context: how rapidly its population and food demand are growing under SSP2, how far its current consumption patterns deviate from the EAT-Lancet diet, and whether its agricultural sector specializes in commodities that face particular pressure under this style of transformation (i.e. animal-sourced foods, sugar). Under SSP2, global population reaches 9.6 billion by 2050 (23% increase from 2020) with GDP growing 127% globally (Table S1). This growth is concentrated in lower-middle income regions where population and income are expanding rapidly, while high-income regions face near-static demographic trajectories. These diverging baselines shape both the scale of the demand shock that ELM imposes and the structural capacity of each food system to absorb it.

Regions in South and Southeast Asia (IND, OAS, and SEA) and Sub-Saharan Africa (SSA) are characterized by substantial population and income growth under SSP2 that increases food demand in 2050 compared to 2020. These regions begin the projection period with food systems already under supply-side stress: low agricultural land per capita in the case of IND, OAS and SEA, large populations with growing caloric needs, and significant dependence on staple and livestock systems with high emissions intensity. Under the ELM scenario, climate mitigation policies impose substantial cost increases on these supply-constrained systems, driving production down while pushing prices upward. This places them in a cost-led contraction in which supply constraints outpace demand reductions.

IND, OAS, and SEA face the largest median producer price increases under ELM: IND (+44%), OAS (+23%), SEA (+18%). Decomposition of agricultural producer prices reveals that mitigation policies (MITI) are the dominant driver of this outcome. MITI systematically increases producer prices across all regions, with particularly large effects in IND (+14 pp), OAS (+26 pp), and SEA (+16 pp). Land-use constraints and emissions pricing push producer prices up even as production falls, maintaining these regions firmly in the upper-left of the production-price space.

For India, DIET increases producer prices (median +24 pp), because baseline meat consumption is already relatively low. Dietary shifts in IND therefore primarily involve increased demand for vegetables, fruits, and nuts rather than reduced livestock consumption, driving up prices for these protective foods and suggesting that healthy diets may become more expensive than BAU by 2050.

Productivity improvements (PROD) consistently reduce the cost of production across all regions (median −3 to −8 pp; Figure 2 with high model agreement), and are especially critical in regions experiencing overall price increases. In IND, OAS, and SEA, PROD offsets a portion of the cost increases imposed by MITI (IND: −6 pp, OAS: −7 pp, SEA: and −7 pp). PROD also raises production in these regions, making it doubly important as both a cost-reducing and output-expanding measure for increasing food availability. Bundling MITI within the broader ELM food systems transformation dampens the price impact of mitigation for IND and OAS relative to MITI in isolation.

Food expenditure rises substantially across this group (OAS: +32%, IND: +21%, SEA: +10%) compounding existing affordability challenges. The DIET driver increases food expenditure for OAS (+10 pp), IND (+12 pp), and SEA (+6 pp).

Large rice sectors in these regions are also particularly vulnerable under ambitious mitigation, as rice production represents a significant share of agricultural GHG emissions, but is also a sector that will be substantially impacted by climate change. IND, OAS, and SEA see the highest decreases in fertilizer use, driven largely by MITI. Agricultural employment is variable across models, but DIET consistently drives an increase in employment across IND, OAS, and SEA, reflecting the labor-intensity of the horticulture and mixed-cropping systems that expand under dietary transition.

SSA occupies a distinctive position within the cost-led group. Under BAU 2050, SSA is projected to nearly double its population to 2 billion while GDP grows by almost four times its 2020 level (Table S1). Food demand increases substantially as a result: agricultural production rises, median multi-model projections show increases in both crop yields and harvested area, agricultural employment increases, and non-$CO_2$ emissions from agriculture approximately double while land use increases by around 10%. SSA thus enters the transformation scenario from a high-growth baseline, with a food system already scaling to meet rapidly expanding domestic demand.

Under ELM, producer prices increase in SSA (median +12 %), placing it alongside IND, OAS, and SEA. The decomposition shows that PROD lowers agricultural producer prices while MITI increases them, consistent with the broader cost-led pattern. Food expenditure falls overall under ELM for SSA, with DIET driving this reduction and MITI partially offsetting it. SSA is the only region where agricultural employment increases in BAU and increases further under ELM, with DIET as the principal employment driver. The combination of growing food demand, dietary transition toward more diverse foods, and labor-intensive agricultural systems means SSA's employment increases under transformation, unlike the contraction experienced in regions discussed below.

A contrasting pattern characterizes regions where demand collapse, rather than supply-side cost pressure, drives the agricultural contraction. In these regions, livestock production represents a large share of agricultural output or exports. Moreover, the gap between current consumption patterns and EAT-Lancet targets for animal-sourced foods is large, and the dietary transition pulls both production and prices downward, placing them in the lower-left quadrant of Figure 1. DIET is the dominant driver, and the decomposition consistently shows falling producer prices alongside falling production.

The clearest examples of this demand-led dynamic are Brazil and Other South and Central America (BRA and OSA), where the dietary shift away from animal-sourced foods represents a large demand withdrawal from livestock-intensive agricultural systems. In these regions, MITI reinforces DIET through land-use constraints on extensive livestock systems and carbon pricing, amplifying the production contraction. DIET lowers producer prices substantially in regions with high livestock consumption (BRA: −14 pp, OSA: -9 pp). As a result of this contraction, BRA and OSA are projected to avoid substantial GHG emissions (BRA: -51%, OSA: -59%) and agricultural land expansion (BRA: -40%, OSA: -28%) compared to BAU.

## Conclusion

The results presented here reveal that an EAT-Lancet style food system transformation with ambitious mitigation will affect regions heterogeneously, with outcomes diverging between cost-driven and demand-led contraction of the agricultural sector. Across all regions, agricultural production falls relative to BAU, but the mechanisms, distributional consequences, and trade-offs differ fundamentally depending on a region's demographic trajectory, current dietary patterns, and agricultural specialization and the relative importance of each measure within the transformation bundle shifts accordingly.

In regions experiencing cost-driven contraction, for example IND, OAS, SEA, and SSA, the increased production costs imposed by mitigation and dietary transition need to be dampened to avoid further increase in food expenditure. Productivity improvements represent the most consistent policy lever across contexts, reducing producer prices and expanding output in every region. Their buffering role is especially critical where mitigation otherwise risks deepening affordability stress.

In regions where the agricultural sector contracts due to demand shifts, for example BRA and OSA, the manner in which dietary transition is implemented will shape how and how smoothly the sector reorients. Where demand collapse is rapid or concentrated in particular commodities, support mechanisms should be in place to help affected sectors transition without severe disruption.

Together, these findings underscore that a globally uniform transformation strategy risks misallocating both the costs and benefits of food system change, and that effective policy design must be calibrated to regional structural realities.

# Display Items

**Table 1: Scenario assumptions and overview of model implementation**

| | Description |
|---|---|
| Business as usual (BAU) | BAU scenario based on the middle-of-the-road shared socioeconomic pathway, following recent economic, technological, and dietary trends. There are no additional climate mitigation and land-use policies other than national policies that are already implemented. |
| Increased productivity (PROD) | Agricultural productivity increases consistent with the shared socioeconomic pathway of taking the greener road (SSP1), which represents a more sustainable and optimistic world with greater investments in agricultural research and technology compared with the BAU scenario. Models applied exogenous improvements to crop yields and livestock feed conversion efficiency following SSP1 assumptions. Several models also incorporated endogenous mechanisms where productivity improvements respond to economic incentives such as reduced interest rates, particularly in low- and middle-income regions |
| Reduced food loss and waste (WAST) | Reducing food loss and waste consistent with Sustainable Development Goal 12.3 on halving per-capita food waste and reducing losses along the supply chain. Models applied exogenous reductions to loss and waste shares across different stages of the food supply chain (production, processing, retail, and consumption) and food groups, targeting a 50% reduction in these shares by 2050 |
| Diet shift (DIET) | Shifting diets towards healthier consumption patterns consistent with the EAT-Lancet healthy reference diet. Models implemented dietary shifts towards the EAT–Lancet healthy reference diet, primarily through exogenous shocks to shift demand curves or adjusting elasticity parameters that modify consumption patterns to align with recommended intake levels by food group and region by 2050. The models allowed for endogenous price and market responses to these demand shifts, with some incorporating region-specific adjustments to account for local food preferences and economic constraints. |
| Mitigation policies (MITI) | Climate mitigation and land-use policies aligned with achieving a 1·5°C target by 2100. Models achieved this through carbon pricing mechanisms that put a cost on greenhouse gas emissions, with carbon prices increasing over time. This incentivised shifts towards less emission-intensive production methods, adoption of mitigation technologies, limited land expansion, incentivised land-based carbon sequestration such as reforestation and afforestation, and increased demand for bioenergy crops. Several models also incorporated land-use policies such as forest protection |
| Combined scenario (EAT–Lancet food system transformation with mitigation; ELM) | A scenario that combines PROD, WAST, DIET, and MITI |

**Table 2: Participating Models**

| MODEL | FULL NAME | INSTITUTIONS | TYPE |
|---|---|---|---|
| AIM | Asia-Pacific Integrated Model | National Institute for Environmental Studies & Kyoto University | CGE |
| CAPRI | Common Agricultural Policy Regionalised Impact Model | European Commission Joint Research Centre | PE |
| ENVISAGE | Environmental Impact and Sustainability Applied General Equilibrium Model | Purdue University | CGE |
| FARM | Future Agricultural Resources Model | U.S. Department of Agriculture | CGE |
| GCAM | Global Change Analysis Model | Pacific Northwest National Laboratory, Joint Global Change Research Institute (PNNL, JGCRI) | PE |
| GLOBIOM | Global Biosphere Management Model | International Institute for Applied Systems Analysis (IIASA) | PE |
| IMAGE | Integrated Model to Assess the Global Environment | Netherlands Environmental Assessment Agency (PBL) | PE/IAM |
| IMPACT | International Model for Policy Analysis of Agricultural Commodities and Trade | International Food Policy Research Institute (IFPRI) | PE |
| MAGNET | Modular Applied General Equilibrium Tool | Wageningen University | CGE |
| MAGPIE | Model of Agricultural Production and its Impact on the Environment | Potsdam Institute for Climate Impact Research (PIK) | PE |

**Figure 1: Real producer price versus Agriculture Production (% change from BAU 2050)**

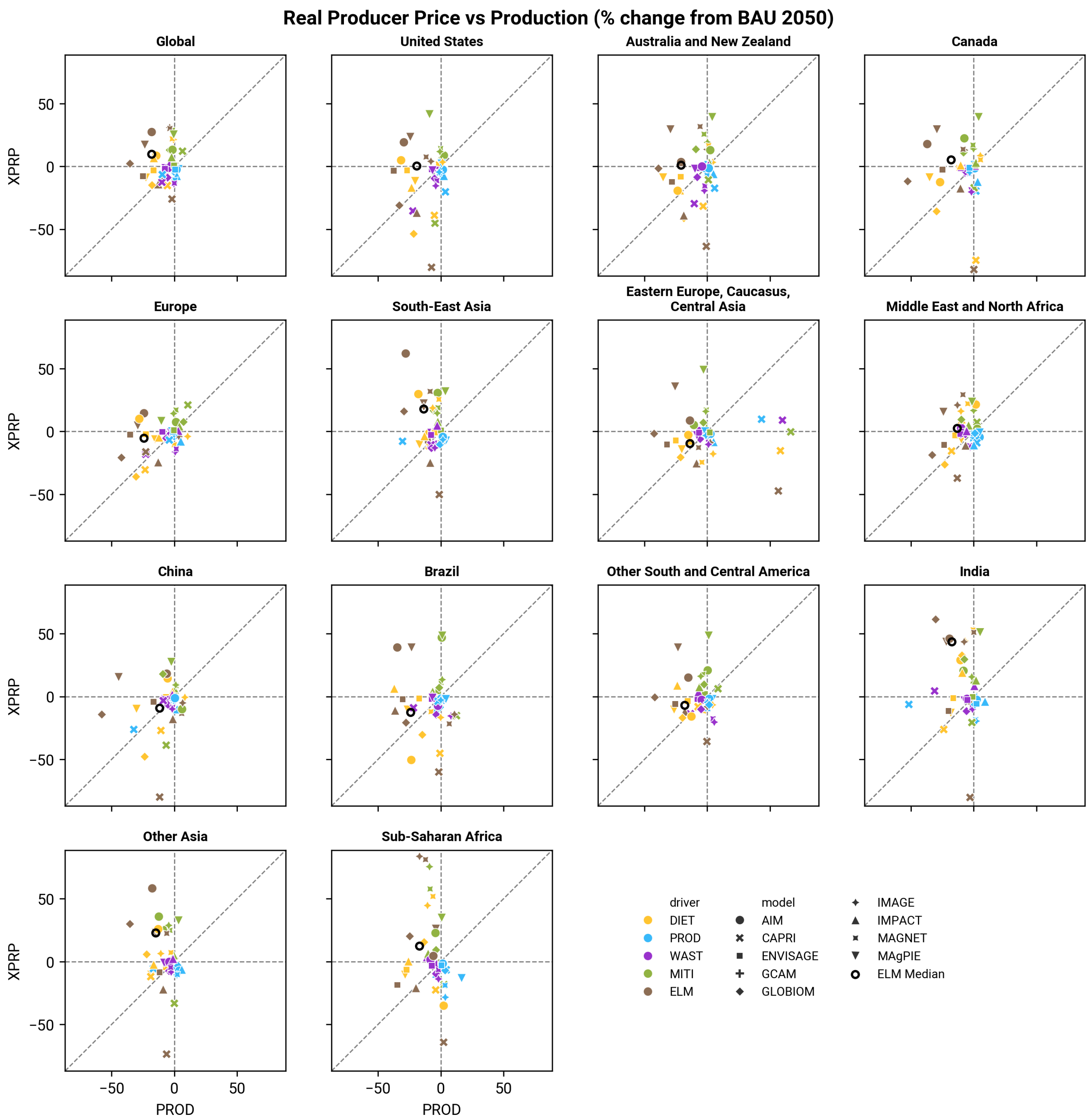


**Figure 2: Food system impacts across scenarios and drivers (% change from BAU):** first column of each panel shows % change in BAU 2050 from BAU 2020. The second column shows % change in ELM 2050 from BAU 2050. The next four columns show the total effect of the drivers DIET, MITI, PROD and WAST in percentage points (pp).

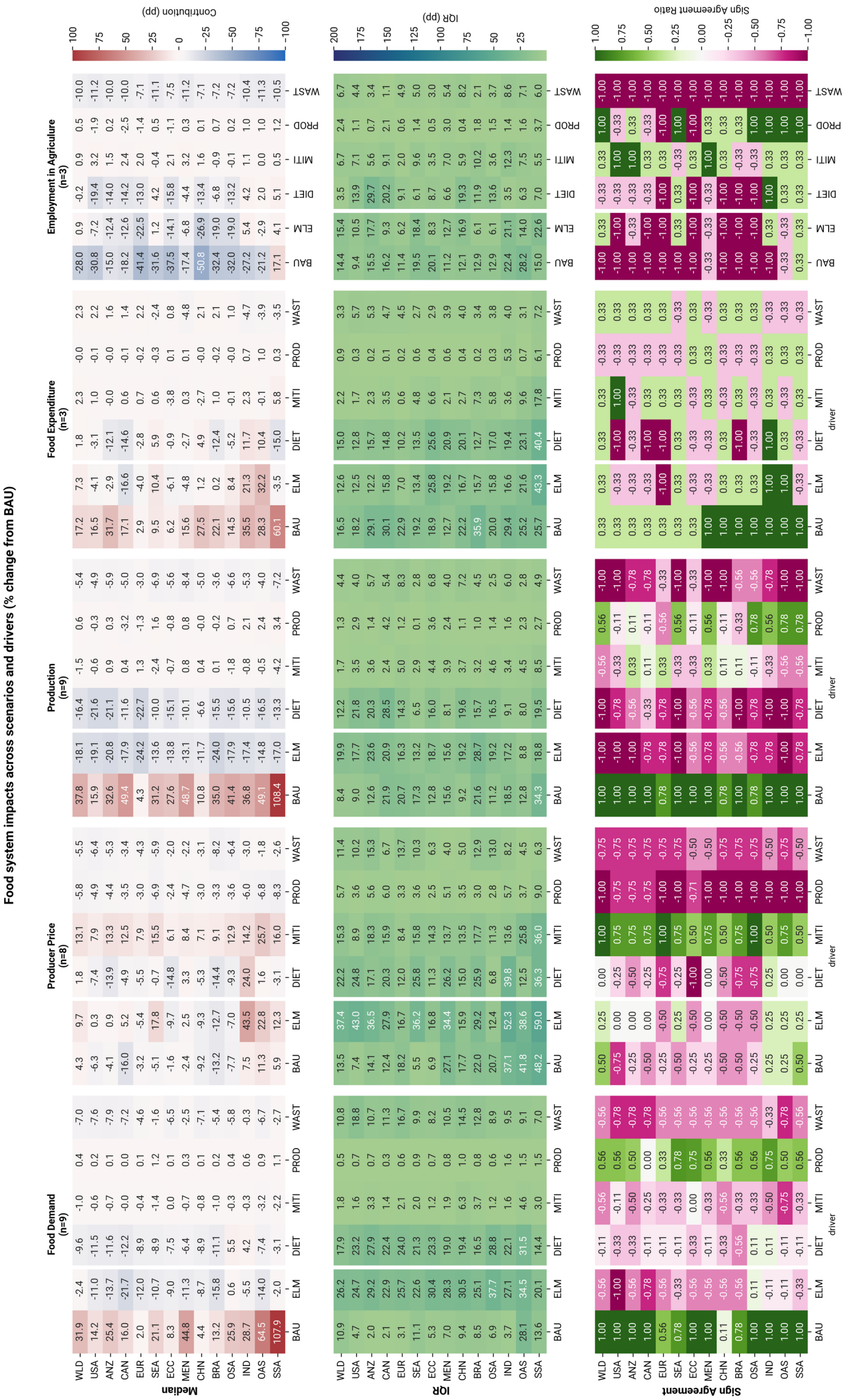
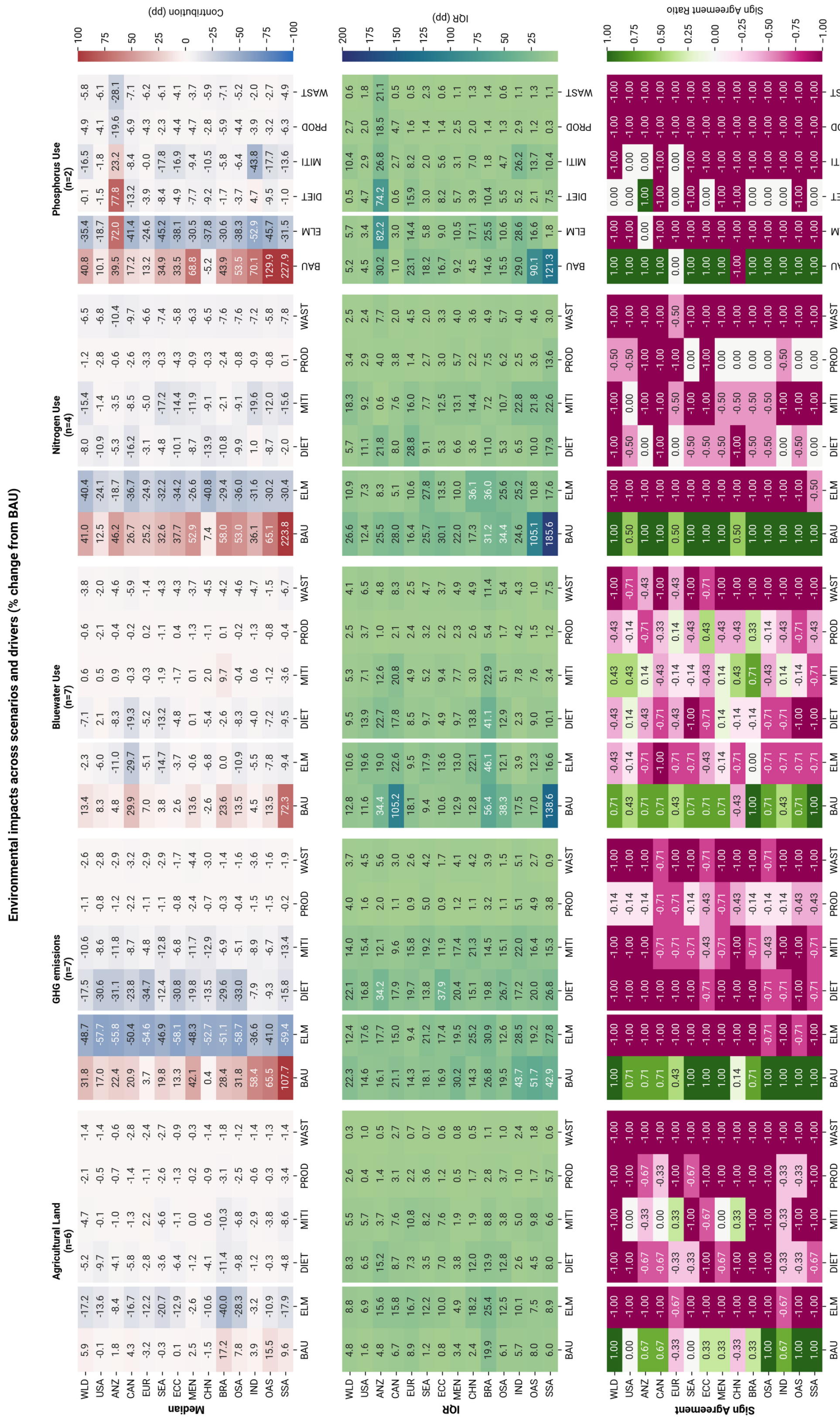


**Figure 3: Environmental impacts across scenarios and drivers (% change from BAU):** first column of each panel shows % change in BAU 2050 from BAU 2020. The second column shows % change in ELM 2050 from BAU 2050. The next four columns show the total effect of the drivers DIET, MITI, PROD and WAST in percentage points (pp).



# References

(to be added)

# Methods

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## Ensemble of global economic models and model intercomparison

In this global multi-model assessment, we facilitate a broader exploration of potential economic and environmental consequences of a food system transformation by applying an ensemble of global economic models, recognizing that each model represents food system dynamics in a somewhat different way (i.e., model structure and spatial and temporal resolutions). This ensemble was composed of ten models, which included a mix of computable general equilibrium and partial equilibrium models: AIM, CAPRI, ENVSIAGE, FARM, GCAM, GLOBIOM, IMAGE, IMPACT, MAGNET, and MAgPIE. Dynamic economic models are essential tools for understanding the complex trade-offs, feedback effects, and potential impacts of food systems transformation, including effects on prices, resource use, and environmental outcomes that can arise from interconnected markets. The models that were included in this exercise have participated previously in model intercomparisons as part of the Agricultural Model Intercomparison Project, and in high-impact global assessments. The model intercomparison process took place from March 14, 2023, to August 19, 2025, involving multiple iterations of scenario submissions to validate and harmonize scenario implementation across the model ensemble.

## Scenario specification and experiment design

To provide a consistent analytical framework, this multi-model assessment of food system transformation is embedded within carefully constructed scenarios. The scenario components and an overview of model implementations are shown in the table. The scenarios modelled follow a middle-of-the-road shared socioeconomic pathway (SSP2), which projects a global population of 9·6 billion (a 23% increase from 2020) and 127% growth in global gross domestic product (GDP) by 2050 compared with 2020.

Input data underlying the three key food systems transformation measures were shared with the participating models. All scenarios were implemented using the latest SSP2 data for population and GDP projections. Data on crop and livestock climate shocks were from Jägermeyr and colleagues, and Thornton and colleagues, respectively. Climate impacts on four main crops (maize, wheat, rice, and soybeans) were mapped to IMPACT's 36 crop commodities according to their biophysical properties. Likewise, the livestock climate shocks for meat and dairy were mapped to beef, lamb, pork, poultry, and eggs, and to milk, respectively. The climate shocks that reflect the biophysical effects of changes in temperature and precipitation, without changes in management, were then combined with projections of agricultural productivity growth, which represent a general technology trend, from the IMPACT model. Agricultural labor productivity trends were based on data from Nelson and colleagues and reflect global reductions in manual agricultural work capacity due to climate change The diet implementation required data on food consumption categorized by food group and region for both the benchmark and flexitarian diet; these data were provided by Springmann and colleagues.

Although we harmonized scenario narratives and input data as best as possible across the ensemble, the participating models differ in their structure, calibration datasets, and native approaches to implementing scenarios. These differences can result in varying baseline projections even when using the same underlying scenario assumptions and input data. Given that our focus was on evaluating scenario impacts rather than absolute values, we standardized results by examining relative changes from a common reference point. Therefore, to compare results across models, we calculated the percentage change to the value from a reference period (the year 2020) for each model independently. If a model did not provide a value for the reference, we linearly interpolated the value using the nearest years before and after the reference year. This ensured that our analysis captured the directional impacts and relative magnitudes of transformation measures while accounting for the inherent diversity in model structures and calibrations within our ensemble.

Unless otherwise stated, we report the median result of the ensemble and the range. Where the range spans both positive and negative change, we include the number of models reporting in the same direction as the ensemble median.

**Table SI1: Middle-of-the-road Shared Socio-economic Pathway (SSP2)**

| SSP 2 | GDP (BILLION USD2017/YEAR) | | | | POPULATION (MILLION) | | | | GDP PER CAPITA (USD2017/YEAR) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2050 | Abs Change | Change (%) | 2020 | 2050 | Abs Change | Change (%) | 2020 | 2050 | Abs Change | Change (%) |
| USA | 19691 | 32001 | 12310 | 63 | 335 | 377 | 42 | 12 | 58710 | 84877 | 26167 | 45 |
| ANZ | 1399 | 2865 | 1466 | 105 | 31 | 37 | 6 | 21 | 45759 | 77761 | 32002 | 70 |
| CAN | 1650 | 3088 | 1438 | 87 | 38 | 42 | 4 | 12 | 43696 | 73237 | 29541 | 68 |
| EUR | 21437 | 35141 | 13704 | 64 | 543 | 540 | -3 | -1 | 39478 | 65113 | 25635 | 65 |
| SEA | 16578 | 34435 | 17857 | 108 | 868 | 950 | 82 | 9 | 19091 | 36251 | 17160 | 90 |
| ECC | 5489 | 10075 | 4586 | 84 | 290 | 301 | 11 | 4 | 18897 | 33438 | 14541 | 77 |
| MEN | 9758 | 26529 | 16771 | 172 | 555 | 762 | 207 | 37 | 17592 | 34808 | 17216 | 98 |
| CHN | 23972 | 55133 | 31161 | 130 | 1432 | 1314 | -118 | -8 | 16738 | 41950 | 25212 | 151 |
| BRA | 2936 | 6623 | 3687 | 126 | 213 | 228 | 15 | 7 | 13811 | 29073 | 15262 | 111 |
| OSA | 5840 | 14257 | 8417 | 144 | 436 | 515 | 79 | 18 | 13397 | 27660 | 14263 | 106 |
| IND | 8504 | 34136 | 25632 | 301 | 1390 | 1620 | 230 | 17 | 6118 | 21067 | 14949 | 244 |
| OAS | 2652 | 10643 | 7991 | 301 | 499 | 730 | 231 | 46 | 5314 | 14580 | 9266 | 174 |
| SSA | 4202 | 16404 | 12202 | 290 | 1127 | 2123 | 996 | 88 | 3729 | 7728 | 3999 | 107 |

## Decomposition analysis

To quantify how different components of the ELM scenario contribute to environmental, economic, and justice outcomes, we conducted a decomposition analysis. Using an approach that has been used in determining the contributions of scenario components to non-CO2 emissions, land-use change, food security, and planetary boundaries, we assessed both the individual effects of each component of the ELM bundle and their interactions with other components (Table 1).

The first set of scenarios isolated individual components by adding each one separately to the BAU scenario (eg, BAU_DIET adds only dietary changes to BAU). The difference between these scenarios and BAU represents the individual effect of each component. The second set of scenarios removed components one at a time from the full ELM scenario (eg, ELM_DIET removed dietary changes from ELM. The difference between ELM and these leave-one-out scenarios quantifies the total effect of that measure within ELM in percentage points, which includes both its direct effect (individual effect) and all its interactions with other components of ELM.