Advances and future needs for modelling sustainable and just food systems transformations

Daniel Mason-D'Croz, Mario Herrero

Food systems underpin human health, livelihoods, and environmental sustainability; yet, they remain major contributors to climate change, biodiversity loss, and inequity. Building on the 2025 EAT–*Lancet* Commission on healthy, sustainable, and just food systems, a special collection of papers in *The Lancet Planetary Health* highlights emerging frontiers for research and modelling. Across models, dietary change remains the most effective lever for reducing greenhouse gas emissions and land-use pressure from food production, although affordability and nutritional adequacy challenges persist, particularly in low-income and middle-income countries. Productivity improvements, reductions in food loss and waste, and the adoption of circular food systems can amplify environmental gains while mitigating cost increases, but their implementation requires safeguards to prevent adverse trade-offs. Labour and equity analyses highlight how transitions might redistribute employment and income, underscoring the need for just transition strategies. Collectively, the studies reveal that bundled interventions combining dietary shifts, productivity growth, food loss and waste reduction, and mitigation policies produce the largest synergistic benefits across environmental and health outcomes. Future modelling must deepen integration of justice, political economy, and behavioural change dynamics and enhance regional specificity to inform feasible and equitable transformation pathways at policy-relevant scales. Together with more robust stakeholder processes, these priorities define a forward-looking agenda for food systems research capable of guiding sustainable, inclusive, and resilient transformations within planetary boundaries.

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Department of Global Development, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY, USA (D Mason-D'Croz MA, Prof M Herrero PhD)**; Cornell Atkinson Centre for Sustainability, Cornell University, Ithaca, NY, USA** (D Mason-D'Croz, Prof M Herrero)**; Agricultural Economics and Rural Policy Group, Wageningen University & Research (WUR), Wageningen, Netherlands** (D Mason-D'Croz)

Correspondence to: Mr Daniel Mason-D'Croz or Prof Mario Herrero, College of Agriculture and Life Sciences, Cornell University, Ithaca, NY 14853, USA
dem286@cornell.edu, **mario.herrero@cornell.edu**

Introduction

Food systems are both a source of global nourishment and economic livelihoods and a driver of multiple planetary crises. At the same time, they fall short on human health and justice objectives, as more than 800 million people continue to suffer from undernourishment even as more than 2 billion people are overweight or obese, and diet-related non-communicable diseases have become the primary cause of premature mortality. Food systems are responsible for approximately a third of global anthropogenic greenhouse gas emissions,[1] while contributing to 70% of freshwater withdrawals[2] and being the leading driver of deforestation and biodiversity loss.[3,4] Agricultural production through the overuse of fertilisers (ie, nitrogen and phosphorus) is the primary driver of the transgression of biogeochemical flows (unpublished data: de Vries 2024). As such, food systems are at the heart of multiple interconnected environmental, health, and justice challenges and are the central topic of the 2025 EAT–*Lancet* Commission on healthy, sustainable, and just food systems.[5]

The COVID-19 pandemic[6] and the war in Ukraine[7] have further revealed the fragility of global supply chains and the interconnectedness of food systems with geopolitical and economic shocks. Rising food and fertiliser prices, supply disruptions, and export restrictions have reverberated across the world, disproportionately affecting low-income and middle-income countries (LMICs) and poor consumers. These events underscore the urgency of building food systems that are not only sustainable and health-promoting but also resilient.

Extended modelling analyses contributing to the 2025 EAT–*Lancet* report

The EAT–*Lancet* Commission on healthy, sustainable, and just food systems recently released its second flagship report[5] and found that 15 million deaths could be averted if a transition to a healthier diet was adopted globally. The report also found that these health benefits would be accompanied by substantial environmental gains in the form of reduced land use, greenhouse gas emissions, and blue water, nitrogen, and phosphorus use if this dietary transition was adopted alongside increased agricultural productivity and efforts to reduce food loss and waste. This bundle of actions could help to reduce the cost of producing a healthy diet on average, even as substantial restructuring of food systems could have heterogeneous regional impacts with important justice implications.

This 2025 *Lancet* Commission used an ensemble of ten global economic models, in addition to the input–output model used in the first EAT–*Lancet* report,[8] to quantify the potential impacts of achieving an EAT–*Lancet*-aligned food system by 2050. The application of a multimodel ensemble facilitated a greater exploration of food system complexity and uncertainty in how food systems could respond to substantial changes on the demand side and supply side, taking advantage of a broader range of models with varying assumptions and representations of regional and global food systems. The scenario design in this analysis further allowed for an exploration of the individual and combined impacts of the components of the EAT–*Lancet* bundle—dietary change, increased productivity, and reduced food loss and waste.[9]

Building on the general framework of scenarios used in the latest EAT–*Lancet* report, the special collection in *The Lancet Planetary Health* presents a range of additional studies that were conducted to explore key questions and challenges to achieving a food system transformation. Importantly, this collection highlights emerging issues in food systems transformation, addressing potential social

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justice, food affordability, and equity outcomes of transformation, which have often been understudied in past modelling efforts. Additionally, there is a greater exploration of potential consequences of a food system transformation across a broad range of environmental outcomes (natural resource use, emissions, and antimicrobial use), responding to concerns highlighted by research on the nine proposed planetary boundaries.[4]

Much attention was focused on the potential of dietary change to contribute to more sustainable food systems. However, both EAT–*Lancet* reports,[5,10] recent high-level studies such as the IPBES Nexus Assessment,[3] and Food System Economics Commission,[11] have highlighted the need for whole-of-food system approaches. To this end, this special collection has focused on better understanding the EAT–*Lancet* bundle, exploring the relative contributions of the components of a food system transformation both in isolation and in combination. These studies, summarised in the table, look to engage with concerns raised after the first EAT–*Lancet* report on questions of nutritional adequacy[20] and affordability[21] and on how such food system transformations could be achieved, while advancing the data and modelling capability of global food system modelling.

Key insights and lessons learned

The role of healthy dietary transitions

Dietary change consistently emerged across the modelling studies as the most impactful lever for reducing environmental pressures from food globally. In the multimodel ensemble analysis by Sundiang and colleagues,[9] a shift toward healthier diets that align more closely with EAT–*Lancet* dietary guidelines resulted in a median –29% (–46 to –16) decline in agricultural emissions and a –7% (–23 to 1) change in agricultural land use globally, driven by declines in ruminant production and reduced grassland use. Results from studies by Beier and colleagues[14] and van Zanten and colleagues[18] are consistent with these findings, with all three studies noting that dietary change alone is insufficient to achieve all environmental objectives. Beier and colleagues[14] explored in greater detail the potential synergies between a food system transformation and ambitious mitigation and found that mitigation efforts could increase pressures on non-emissions planetary boundaries without a food system transformation that included dietary change. The environmental results in this special collection are consistent with findings by Johan Rockström and colleagues[5] in suggesting that the nitrogen and phosphorus boundaries are likely to be particularly challenging, as many foods necessary for a healthy diet require fertiliser inputs. Bringing fertiliser use and agricultural emissions of nitrogen and phosphorus will likely require targeted interventions. Circularity is one such intervention and was assessed by van Zanten and colleagues,[18] who found that more circular food systems could contribute 14 TgN and 2 TgP in additional reductions compared with scenarios that incorporated a dietary transition and food loss and waste reductions, but no circularity component.

Several studies in this special collection highlighted the challenges of achieving global dietary shifts without exacerbating regional inequality if affordability is not specifically targeted, similar to concerns raised by Rockström and colleagues,[5] Sundiang and colleagues,[9] Mishra and colleagues,[17] and Kuiper and colleagues.[16] These authors reported that in many low-income and middle-income regions, a shift towards a healthy diet could increase food expenditure compared with the business-as-usual diet. This finding echoes recent analyses of the cost of a healthy diet, which have found that healthy diets can be cheaper than current diets in high-income countries nowadays, even as they are more expensive in many LMICs.[22] Kuiper and colleagues[16] further explored the potential consequences of these price changes on food affordability for agricultural workers, finding that in many of these countries, the potential price increases would be higher than increases in wages, leading to lower affordability of healthy diets compared with their business-as-usual scenario. This observation supports the call for focusing on justice outcomes in a food system transformation[5] and the importance of not only focusing on food prices but also on just wages, as average affordability can improve even as vulnerable groups face greater challenges.

In response to questions about the adequacy of the diet recommended in the first EAT–*Lancet* report,[21] several studies examined nutrient adequacy. Bajaj and Springmann[12] assessed the state of the underlying evidence used to estimate nutrient requirements, a key nutritional benchmark for assessing and defining healthy diets. Their findings highlight severe data limitations, noting often poor coverage across regions and over time. These findings suggest the need for greater data collection and synthesis to help reduce key uncertainties in these important nutritional benchmarks. This requirement is particularly important in understudied regions in the Global South, where fewer representative studies have been conducted. The need for a more detailed regional study of nutrient requirements and nutrient supply is highlighted further by Mishra and colleagues,[17] whose modelling raised potential concerns of a risk of vitamin A deficiency in individuals in eastern Africa in scenarios wherein dietary transitions do not consider the traditional role of roots and tubers in supplying vitamin A.

The role of more efficient and productive food systems

More efficient and productive food systems will be crucial for achieving environmental objectives. They also play a crucial role within an EAT–*Lancet* style food system transformation, helping to reduce the cost of food production, thereby contributing to a just transition with respect to managing concerns about the affordability of healthy diets.[5]

Within the EAT–*Lancet* bundle, both increased agricultural productivity and reductions in food loss and waste promise to improve the efficiency of food systems, with

Study	Thematic focus	Approach
Sundiang et al (2025)[9]	Environmental and socioeconomic implications of a food system transformation	Multimodel ensemble
Bajaj and Springmann (2025)[12]	Uncertainties around data on nutritional adequacy	Literature review
Thom et al (2025)[13]	Perspective on food system modelling by early career scientists	Perspective
Beier et al (2025)[14]	Environmental impacts of a food system transformation	MAgPIE (PE)
Gatto and Chepeliev (2025)[15]	Challenges and opportunities to reducing food loss and waste	ENVISAGE (CGE)
Kuiper et al (2025)[16]	Policy options for achieving a healthy diet	MAGNET (CGE)
Mishra et al (2025)[17]	The affordability of a healthy diet under a range of scenarios	IMPACT (PE)
van Zanten et al (2025)[18]	Potential contributions of circularity to a food system transformation	CiFOS (optimisation model)
Vittis et al (2025)[19]	Potential labour implications of a restructuring of the food system	DIA-GIO (input–output model)

PE=partial equilibrium model. CGE=computable general equilibrium model.

***Table:* Summary of papers in the special collection**

both contributing to lower food prices and greater food security, and when combined with dietary change or ambitious mitigation policies, can contribute to greater reductions in agricultural emissions and land use.[5,9,14,17] Globally, according to Sundiang and colleagues,[9] both measures contribute to similar reductions to producer prices (5–6 percentage points). However, regional differences were observed, with agricultural productivity contributing larger price declines in food-insecure regions such as India (6 percentage points) and sub-Saharan Africa (8 percentage points), compared with high-income and middle-income regions where reductions in food loss and waste tended to be greater than or equal to increases in agricultural productivity.

Beier and colleagues[14] explored the interactions between productivity gains and environmental limits, finding that yield improvements can support reductions in deforestation and habitat loss. However, they cautioned that without robust sustainability safeguards, intensification could lead to negative trade-offs such as soil degradation and increased reliance on chemical inputs. Similar concerns were raised by Sundiang and colleagues[9] who found that increased agricultural productivity and reduced food loss and waste delivered less environmental benefits when applied on their own.

In optimisation scenarios, van Zanten and colleagues[18] highlighted substantial potential environmental gains if food production were spatially optimised to areas of highest productivity, similar to findings by Castonguay and colleagues[23] for the livestock sector. However, such a reallocation of production would have substantial justice implications and impacts on the global trade system. Further, changes to global trade patterns could alter the distribution of food loss and waste globally and across supply chains, as noted by Gatto and Chepeliev.[15] The optimisation findings by van Zanten and colleagues[18] could also be interpreted as a call not to reallocate production, but to reallocate technology, highlighting the substantial environmental potential of reducing productivity gaps globally.

Implications for agricultural labour

A major restructuring of the food system would have substantial consequences on agrifood labour. A global transition to healthy diets would reorient production away from animal-sourced food production, towards greater production of plant-based foods, particularly fruits, vegetables, nuts, and legumes.[5] An analysis by Vittis and colleagues[19] suggests that a transition to such a flexitarian diet could contribute to a decline of 5% in agrifood labour globally due to reductions in consumption in high-income regions and the reduced demand for many relatively labour-intensive animal-sourced food products, with larger declines in labour possible for vegetarian and vegan diets. These findings are consistent with findings in the latest EAT–*Lancet* report, which also suggested modest declines in aggregate agricultural labour globally by 2050 compared with a business-as-usual scenario.

However, based on evidence from a preprint paper, the global averages can mask substantial sectoral and regional disruptions and dislocations of production, natural resource use, and labour across agrifood systems.[24] Vittis and colleagues[19] observed that in regions where livestock production currently dominates agriculture (eg, Ireland and Denmark), more substantial declines in labour (>60%) could be seen, whereas in regions with larger horticultural sectors (eg, Latin America), substantial increases in agricultural demand (>80%) could be seen. These findings are broadly consistent with recent projections featuring dietary change as a driver of net zero futures in Latin America and the Caribbean by the Inter-American Development Bank and the International Labour Organization.[25]

Managing regional and sectoral labour shocks would be essential for ensuring a just transition and will likely require targeted investments to facilitate shifts across agrifood sectors, including but not limited to investing in improved infrastructure, agricultural research and development, skill development and retraining, and improved access to finance.[11] Similar to the Inter-American Development Bank, International Labour Organization,[25] and Food System Economics Commission reports,[11] Vittis and colleagues[19] highlight the importance of ensuring alternative employment opportunities (eg, nature positive solutions and non-agricultural employment) and investing in training programmes to facilitate labour transitions, which they estimated could cost up to 2% of the gross domestic product if done all at once.

However, a just transition extends beyond labour numbers to encompass the principles of decent work and living wages,[5] without which it is unlikely that vulnerable rural populations would be able to access and afford a healthy diet. Kuiper and colleagues[16] observed this concern, noting that while a shift to a healthy diet could lead to higher wages in sectors producing healthful foods (ie, fruits, vegetables, nuts, legumes, and fish), in some regions, price rises could increase faster than agricultural wages. Consequently, even if average affordability improves, without targeted interventions to support vulnerable agrifood producers, there remains a risk that many of those who contribute to the production of a healthy diet would not be able to afford it.

The need for nexus approaches

One of the most important insights from the special collection is that bundled interventions present important complementarities and co-benefits.[3,26] Sundiang and colleagues[9] compared the outcomes of dietary change, food loss and waste reduction, productivity improvement, and mitigation both individually and in combination. Their results show that bundling all four levers achieved the greatest reductions in greenhouse gas emissions (7·4 $GtCO_2e$), nitrogen application (down 30%), and land use change, while reducing the negative affordability impacts of mitigation. Across the analyses, this theme of complementarity and the need for multiple solutions consistently emerged. Kuiper and colleagues[16] highlighted that equitable dietary transitions require both demand-side nudges and supply-side policies and that these transitions are likely to be more expensive if the transitions are uncoordinated across the whole-of-food system. Similarly, van Zanten and colleagues[18] showed that circularity amplified the benefits of food loss and waste reductions and dietary interventions, and Beier and colleagues[14] noted that mitigation through carbon pricing is more effective when productivity improvements reduce pressure on forests and pastures.

Although the components of a food system transformation are in many cases complementary, they are not perfectly synergistic, and studies have also identified potential points of tension between diverse environmental, health, and socioeconomic objectives. For example, Gatto and Chepeliev[15] showed that a shift to a healthier diet could increase food losses of perishable fruits, vegetables, and seafood in exporting regions if not accompanied by efforts to target inefficiencies in supply chains.[15] van Zanten and colleagues[18] reported that circular food systems that can help to reduce biogeochemical flows might prioritise waste recycling over waste reduction.[21] Beier and colleagues[14] and Sundiang and colleagues[9] highlighted that although mitigation efforts could play a major role in returning food systems to safe operating spaces, they are likely to contribute to higher food prices. Vittis and colleagues[19] and Kuiper and colleagues[16] illustrated potential labour challenges of a food system transformation that would require additional policy interventions to assure a just transition. Collectively, these findings underscore the importance of bundled nexus approaches that combine supply-side and demand-side interventions to amplify positive outcomes while helping to manage negative ones.

Key uncertainties and challenges

Several of the studies in this special collection highlight the difficulty of projecting food system transformations. The uncertainty of the pathways of change is substantial. Without narratives of change, modellers are asked to simulate novel food systems without clear details on the social norms and values that would underpin these future food systems. This approach invariably means letting models solve fairly stylised transformation scenarios. Kuiper and colleagues[16] highlight the importance of policies to inform supply-side adjustments in a food system transformation and that scenarios that do not have these signals ultimately have more costly transitions. Regional disparities present unique challenges to a food system transformation. The scenarios explored were globally focused, assuming relatively linear transitions. Plausible transformation pathways will likely be much less coordinated and would need greater regional specificity, a finding recognised by practically all of the studies in this special collection.

Data limitations continue to present challenges in modelling food system transformation. While the consequences of achieving a food system transformation can be modelled, there are still many questions and uncertainties on how these changes would be implemented. Bajaj and Springmann[12], Gatto and Chepeliev,[15] and Kuiper and colleagues[16] noted data limitations and challenges to estimating nutrient requirements, tracking the sources of food loss and waste, and defining a plausible policy bundle that could achieve dietary change on the scale of a shift to a healthy diet. Similarly, Sundiang and colleagues[9] and Beier and colleagues[14] emphasise that substantial work remains to fully quantify and model changes along all of the environmental dimensions suggested by the planetary boundaries framework.

The future for modelling food systems transformations

As presented by the studies in this special collection, achieving food systems transformation at the pace and scale required to meet environmental and health objectives is technically feasible, but highly complex. Ultimately, achieving such a transformation is a question of economic and political feasibility. While global scenarios and models are essential for understanding aggregate trade-offs and the broad implications of food system change on earth systems, they can be too coarse and stylised to inform specific interventions at the national and subnational levels. As such, a key area for future work is the development of region-specific and national transformation pathways with multiscale modelling approaches that can better engage with local political and economic constraints. Implementation of these processes will require greater inclusion of stakeholders in the development of narratives of change and in assessing not only technical potential and feasibility but also economic, political, and cultural feasibility.

A second key research priority is the enhancement of consumer behaviour modelling. Most food system models treat dietary change as an exogenous variable imposed from outside the system as a scenario assumption. While useful for bounding analysis, this approach obscures the sociocultural, psychological, and structural factors that drive real-world dietary change. More work is needed to develop narratives of change that describe the pathways for changing consumer preferences and behaviour. As noted by Thom and colleagues,[13] most global modelling tools have evolved from a supply-side orientation, with much greater detail in representing interventions impacting primary food production. However, with the continued movement into more urban futures, the need to better represent food processing and value addition grows. This need is relevant not only for improving our representation of economic activities along the value chain (eg, food loss and waste) but also to the potential health, environmental, and socioeconomic implications of these processes.

Additionally, modelling efforts would benefit from increasing focus on building capacity to model changes on the demand side. Kuiper and colleagues[16] explored the potential implications of various pricing and informational and nudge interventions to change demand patterns. However, these analyses still assumed relatively static consumer preferences. Exploring how we might realistically change consumer preferences will be essential for transforming food systems, as the existing demand policies can contribute to improving diets but are unlikely to lead to the wide-scale dietary change required without substantial changes in societal norms and consumer preferences. This change could be done within existing models or by coupling with other modelling approaches such as agent-based models, which might provide more flexibility in simulating changes in consumer behaviour.[27]

Several foundational questions remain insufficiently addressed by current modelling frameworks. First is that of justice. As highlighted by many of the studies in this special collection, transitioning to sustainable food systems is likely to produce winners and losers. Changes in land use, production systems, and diet composition can redistribute costs and benefits along axes of income, geography, gender, and occupation. For example, shifts away from livestock could impact the livelihoods of pastoralists.

Despite these advances, most models still do not have the capacity to robustly assess these justice implications. Whether done directly in global models or with multiscale modelling linking sectoral and more detailed regional models to global models, there is an urgent need to move beyond average effects and incorporate disaggregated, distributional metrics for food access, income, employment, and social protection.

Greater attention must also be paid to the political economy of food systems change. While many scenarios are technically feasible, they might be politically or culturally unacceptable. Large-scale dietary shifts, removal of subsidies, relocation of production, or implementation of carbon pricing in agriculture all face substantial resistance from entrenched interests. There is a need to integrate political feasibility and transition management into future scenario and modelling efforts. A greater focus on the distributional outcomes and the political economy of change would enable better anticipation of transition risks and the design of targeted policy packages to support affected groups.

The intersection of food systems and climate mitigation policies remains understudied at a level that is easily translatable into national strategies. Beier and colleagues[14] and Sundiang and colleagues[9] highlight that while mitigation efforts can reduce land use and agricultural emissions effectively, they might also exacerbate food insecurity unless paired with compensatory measures, similar to findings by Hasegawa and colleagues[28] Modelling the synergies and tensions between food policies and mitigation strategies (eg, afforestation, bioenergy, and land-based carbon removal) with better assessment of potential winners and losers would be crucial for ensuring coherence in climate and food security goals.

Emerging innovations (eg, cellular agriculture, personalised nutrition, GLP-1, and nature-based solutions)[29,30] are rarely included in global food system scenarios due to scarce data and uncertainty. Yet, these could reshape supply chains, labour markets, consumer behaviour, and where and how natural resources are utilised within food systems over the coming decades. Further anticipatory research is needed to encourage more responsible food system innovation and to assess plausible innovation pathways and potential unintended consequences.[31] These pathways need to be developed through the application of robust and participatory processes that can incorporate diverse and transdisciplinary knowledge.[32–34]

Finally, more work is needed to strengthen the science–policy interface. Complex model outputs must be translated into actionable, policy-relevant messages that resonate with national decision makers. Achieving this outcome will require more creative applications of scenarios and models and the development of better synthesis tools to facilitate the communication of these findings to a wider audience. Co-production of knowledge with stakeholders, especially in LMICs, is essential to ensure model relevance and usability. Scenario development processes must include diverse voices and reflect context-specific priorities. While food system transformation cannot be achieved solely through technical modelling, rigorous, equity-oriented, and nationally grounded modelling together with robust stakeholder processes can provide the crucial evidence base for more just, sustainable, and resilient futures.

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The authors declare no competing interests.

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