EAT-*Lancet* Commission on Healthy, Sustainable, and Just Food Systems

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Executive summary

The global context has shifted dramatically since 2019, with increased geopolitical instability, soaring food prices, and the COVID-19 pandemic exacerbating existing vulnerabilities and creating new challenges. Yet food systems remain squarely centred at the nexus of food security, human health, environmental sustainability, social justice and the resilience of nations. Actions on food strongly impact the lives and well-being of all and are necessary to progress toward critical goals as articulated in the Sustainable Development Goals, the Paris Climate Agreement, and the Kunming-Montreal Global Biodiversity Framework, amongst others. While current food systems have largely kept pace with population growth, ensuring sufficient caloric intake for many, they are the single most influential driver of planetary boundary transgression. More than half the world's population struggles to access healthy diets, leading to devastating consequences for public health, social equity, and the environment. Although hunger has declined in certain regions, recent increases linked to expanding conflicts and emergent climate change

impacts have reversed this positive trend. Obesity rates continue to rise globally, and the pressure exerted by food systems on planetary boundaries shows no signs of abating. In this moment of increasing instability, food systems still offer an unprecedented opportunity build the resilience of environmental, health, economic and social systems and are uniquely placed enhance human well-being while contributing massively to Earth system stability.

This updated analysis builds upon the 2019 EAT-*Lancet* Commission, expanding its scope and strengthening its evidence base. The first Commission defined food group ranges for a healthy diet and identified the food system shares of planetary boundaries. In this Commission, we add an analysis of the social foundations for a just food system. It incorporates new data and perspectives on distributive, representational, and recognitional justice, providing a global overview on equity in food systems. Substantial improvements in modelling capacity and data analysis allow for the use of a multi-model ensemble to project potential outcomes of a transition to healthy and sustainable food systems.

The Planetary Health Diet (PHD) remains a cornerstone of our recommendations and can be seen as a framework within which diverse and culturally appropriate diets can exist. Robust updated evidence reinforces a strong association with improved health outcomes, large reductions in all-cause mortality, and a substantial decrease in the incidence of major diet-related chronic diseases. The reference PHD emphasises a balanced dietary pattern, predominantly plant-based, with moderate inclusion of animal-source foods and limited consumption of added sugars, saturated fats, and salt. The successful implementation of the PHD requires careful consideration of cultural contexts and the promotion of culturally appropriate and sustainable dietary traditions. This diversity of contexts, bounded by the PHD's reference values, represents significant flexibility and choice across cultures, geographies and individual preferences. However, confronted with today's multiple crises, transformation will require urgent and meaningful changes in our individual and collective behaviours and culture of unhealthy, unjust, and unsustainable food production and consumption.

For the first time we quantify the global food system share of all nine planetary boundaries. These food system boundaries (FSB) confirm that food is the single largest cause for transgression of the planetary boundaries driving the transgression of five of the six breached boundaries. In addition, food systems exert a significant impact on the transgressed climate boundary and on the Ocean acidification boundary. Food becomes the most significant driver of climate when its transportation, and energy use contributions are included. Unsustainable land conversion, particularly deforestation, remains a major driver of biodiversity loss and climate change calling for zero conversion of remaining intact ecosystems. Food systems account for the near totality of nitrogen and phosphorus boundary transgression, highlighting a critical need for improvements in nutrient management, efficient nutrient redistribution, and the development of circular nutrient systems. The massive use of novel entities in food production, processing, and packaging (ranging from plastics to pesticides) remains of significant concern, yet alarmingly understudied.

Our assessment of justice integrates three dimensions—distributive, representational, and recognitional—within a human rights framing that includes the rights to food, a healthy environment, and

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decent work. Analyses reveal important inequities in access to healthy diets, decent work conditions, and healthy environments, disproportionately affecting marginalised groups in low-income regions. We therefore propose nine social foundations that enable these rights to be met and assess their status. Enabling access to, affordability of, and demand for healthy diets is paramount. Equally crucial is the right to live and work within a healthy environment and a stable climate system, recognising the profound impact of environmental degradation on human health and well-being. Meanwhile, a living wage and meaningful representation would enable individuals to be recognized, heard, and participate in building healthy, sustainable, and just food systems. However, nearly half of the world's population falls below these foundations, undermining their ability to meet basic human rights. At the same time, the dietary patterns of most (6.9 billion people) of the world exert pressures that threaten to further transgress planetary boundaries. The destabilising effect of unhealthy overconsumption on the Earth's systems highlights the critical importance of viewing healthy diets not just as a human right, but also as a shared responsibility.

A model intercomparison including ten integrated assessment models (IAMs) across multiple scenarios reveals the substantial potential for reducing environmental and health impacts through dietary shifts, improved agricultural productivity, and reductions in food loss and waste. Creating demand for and increasing adoption of diets that adhere to the PHD, coupled with ambitious climate mitigation policies, will result in significant reductions in greenhouse gas emissions and land use. However, the results are sobering, showing that even with the ambitious transformations (sustainable intensification, reduced food loss and waste, and transition to eating within the PHD), the world is barely able to come back into the safe space for freshwater use and climate change, while continuing to transgress the biogeochemical boundary for nitrogen and phosphorus loading - albeit with significant reduced pressure.

Deep-dive analyses focusing on sustainable and ecological intensification food production practices, along with more circular nutrient systems, suggest that widespread adoption of these practices could reduce further greenhouse gas emissions , increasing carbon sequestration , reducing the land area dedicated to food production, decreasing water footprints, and make substantial progress on addressing nitrogen and phosphorus boundaries, even in the face of a growing global population and food consumption.

To advance towards the goals of healthy (the PHD), sustainable (within the food system boundaries), and just (above the social foundations) food systems by 2050, eight priority solutions are proposed, each accompanied by specific actions and policy measures: (1) create food environment to increase demand for healthy diets ensuring they are more accessible and affordable; (2) protect and promote healthy traditional diets; (3) implement sustainable and ecological intensification practices; (4) apply strong regulations to prevent loss of remaining intact ecosystems; (5) improve infrastructure, management, and consumer behaviour change to reduce food loss and waste; (6) secure decent working conditions; (7) ensure meaningful voice and representation; and (8) recognise and protect marginalised groups. These proposed solutions and actions should be organized into coherent ‘bundles’ of interventions to enhance political feasibility and policy effectiveness. The most suitable and effective bundles will vary by context and tailored to the specific challenges and opportunities of each region and sector.

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This Commission reinforces the urgent need for a "great food transformation". The targets of the EAT-*Lancet* Commission for healthy people (PHD) on a healthy planet (FSB) with just food systems (social foundations) can only be met through concerted global action and unprecedented levels of transformative change. The Commission calls for cross-sectoral coalitions, that develop context-specific roadmaps, aligning with existing and emerging global frameworks, such as the Paris Agreement, the Convention on Biological Diversity, and the post-2030 SDG agenda. These roadmaps include the setting of science-based targets with monitoring and accountability mechanisms in place. Mechanisms must be established to insulate policymaking from undue corporate influence, while civil society and social movements play a vital role in promoting transparency and oversight.

Significant financial resources, estimated between US$200-500 billion per year, are needed to support the transformation to healthy, sustainable, and just food systems. However, there is good evidence that the price of action is much lower than the cost of inaction, and that the investments rapidly shift to economic benefits, estimated at US$5 trillion per year. There is an opportunity to repurpose existing finance by realigning incentives with goals, such as shifting existing support to producer communities adopting sustainable ecological intensification practices or transitioning to the production of currently under-consumed food groups, while eliminating support to polluting practices or to foods whose overproduction drives poor health.

The Commission positions justice as both a goal and a driving force for food systems transformation. Food systems cannot be just without ensuring healthy diets that meet the PHD are affordable and accessible, and without significantly reducing planetary boundaries transgressions. At the same time, justice is necessary to overcome the deeply entrenched structural barriers that currently impede transformative change. In this sense, justice is not only an outcome of food systems transformation, but a prerequisite means for enabling it.

Introduction: Healthy, Sustainable, and Just Food Systems

The food system has an outsized impact on human wellbeing and planetary health. What we eat, and where and how this food is produced and distributed strongly influences the length and quality of people's lives, as well as our capacity to stay within planetary boundaries. How food systems are governed and managed determine the extent to which people can participate and benefit. Since the 2019 publication of *Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems,*[1] evidence from a growing number of sources show an alarming rise in stress to all natural systems on Earth, escalating diet-related ill-health across the world, worrying inequalities in food consumption patterns within and between countries, and disrupted food supplies. Given this context and the expected increase in the global population to approximately 9.6 billion people in 2050, the need and urgency for a food system transformation to remain within 1.5 degrees C of global warming (**Figure 1**) and to meeting a broad range of global goals related to human health, environmental sustainability and social justice is clear.

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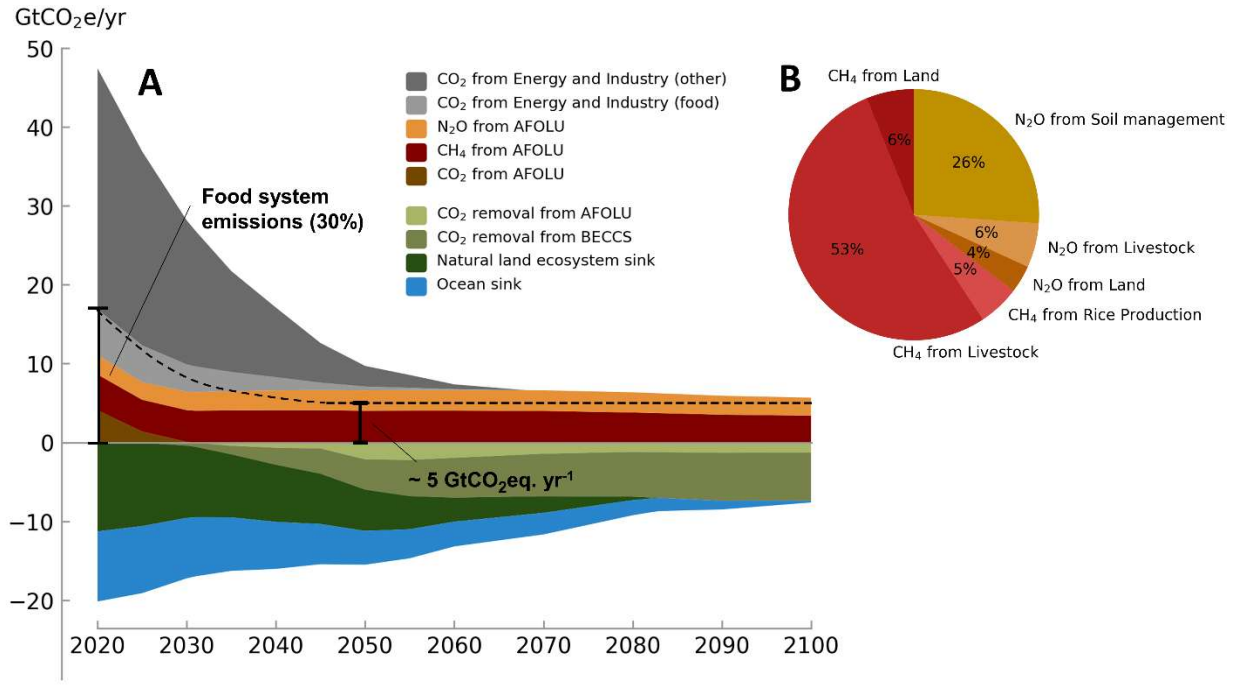


Figure 1: A. Projections of global emission reductions from agriculture, forestry, and other land use (AFOLU) (CO_2, CH_4 and N_2O) and energy and industry (CO_2), including negative AFOLU CO_2 emissions and carbon sequestration from BECSS (Bioenergy with Carbon Capture and Storage) required to limit warming to 1.5 °C with no or limited overshoot (C1). The dashed line shows this report's trajectory of the food systems' share of the safe operating space for climate; the Food System Boundary (FSB) amounting to 5 Gt CO_2eq/yr consisting of minimized flows of CH_4 and N_2O. Data are from IPCC sixth assessment report following selected scenarios (n=62) within the C1 category. Additional carbon sequestration measures (e.g. CCS from Fossil Fuel Use and Industry, not depicted here) are necessary for 1.5 ° pathways. **B**. Non-CO_2 emissions (CH_4 and N_2O) from AFOLU in 2020.

Unsustainable food systems threaten the functioning of the biosphere and the stability of the entire climate system, and underpin unhealthy diets, which accounts for approximately 15 million avoidable deaths each year (see **Panel 2**). Access to food is inequitable, with an insufficient access to healthy diets.[3–5] The food system produces enough calories to feed the world's population, yet average diets trend to low compositional quality with global underconsumption of whole grains, fruits, nuts, and vegetables.[3,6] Unhealthy overconsumption, notably of red meat, is a leading driver of climate and land-use impact.[1] Our food supply is inherently sensitive to water scarcity and climatic variability, and is increasingly sensitive to rapidly rising human climate change induced extreme events, like droughts, floods, heatwaves, or pest and disease outbreaks. Prevailing food production practices are driving biodiversity loss, water scarcity, overuse of pesticides and overloading of fertilisers, climate change, and excessive use of antimicrobials. Food prices do not reflect the true cost of unsustainable production, while rising global poverty makes healthy diets too expensive for billions of people.[7,8] This is a major challenge, as it shows that the planet is subsidizing cheap food as no environmental externalities (e.g., biodiversity loss, nutrient overloading, freshwater use, and GHG emissions) are paid for, while almost one billion people suffer from undernutrition. The economic costs of these challenges are staggering, while global food system generates US$10 trillion in value each year, the negative externalities are estimated at US$15 trillion, with the health sector contributing the most.[9,10]

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These trends drive critical and unacceptable injustices. The current socio-economic situation for billions of people in the world undermines fundamental human rights. Inadequate and inequitable access to safe, sufficient, and nutritious food for nearly 50% of the global population[10] violates the right to food, contributing to malnutrition, ill-health, and maternal and child mortality.[6] The food system drives transgression of multiple planetary boundaries violating the right to a healthy environment and a stable planet, resulting in illness, and the loss of work, food, and life. Poor labour conditions for many food system workers, often underpaid, and lacking social benefits, violate the right to decent work, resulting in exploitation and low purchasing power.[11–13] In addition, the lack of representation and freedom of expression of many food system workers, alongside market concentration, with a few large food system firms influencing decision-making, policies, and prices, undermines the achievement of all of these rights.[14–17]

Growing attention to food systems, but progress is slow

The global food agenda has made significant progress over the past five years. New evidence provides stronger support for the importance of food for human health and planetary stability, and there is a rising recognition that food justice forms an integral part of successful food transformations. Scientific attention to food systems has surged with new evidence emerging daily, including more than 10,500 citations of the 2019 EAT-*Lancet* Commission alone. This evidence spans the development of planetary health diet indices,[18,19] national downscaling of dietary impacts on human health and environmental conditions,[20,21] economic analyses of food systems transformation assessments on novel technologies,[22–24] and behaviour change. Most of this evidence supports the 2019 findings, adding new insights and stronger support for food policy, action on public health, and raising public awareness, but it also signals need for additional attention to socioeconomic dimensions feasibility, and environmental impacts across all planetary boundaries.[25]

Complementing the growing attention by the research community, a diversity of international, national, and local actors is driving a variety of commitments and initiatives. A key moment came in 2021 with the United Nations Food Systems Summit (UNFSS). Since then, two thirds of countries have adopted national food systems transformation pathways and have commitments to integrate foods into their Nationally Determined Contributions (NDCs) to the Paris Climate Agreement. More than 290 cities, with a combined population of 490 million, have signed onto the Milan Urban Food Policy Pact enacting more than 620 specific food system actions. Both the IPCC and IPBES have assessed food systems,[26,27] noting food's dependency, and impacts on biodiversity, climate, water, and health. The Kunming-Montreal Global Biodiversity Framework signed in 2023 set specific food system targets. In these efforts, and other, food is recognised as uniquely central in the nexus of human health, social justice, and environmental sustainability.[28] We are alarmed by recent efforts to undermine, hide, or obfuscate climate science, environmental protections, and attention to justice. Ignoring these trends aggravates, rather than resolves the challenges they represent and their growing impact on human society.

Critical scientific assessment

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The growing attention in science and practice is encouraging. Yet with few exceptions, emerging plans have targets that are poorly articulated, non-specific with no accountability, insufficiently ambitious,[29] include too few and siloed interventions,[30–32] and lack appropriate financial support. The slow rate of action is unjust and dangerous to both current populations and future generations.[33,34] Considering this surge in evidence, and interest in food system action, an updated assessment is critically needed. Our primary objective of this Commission is to provide that update.

First, we review new evidence published since 2019 on diet and health to provide the latest scientific update on the PHD paying specific attention to research on dietary patterns and incorporating evidence from a broader range of populations and world regions. We highlight long-established or traditional dietary patterns that are in line with the PHD and emphasise the potential of achieving culturally diverse healthy diets. However, we also recognise that there is similarly ample evidence that 'modern' diets, appropriately configured, can provide similar health benefits. The diversity of fruits, nuts, vegetables, and whole grains available in many modern societies, and the interest in ethnic cuisines from around the world is unprecedented, as is the number of choices available to those desiring healthy options where they are available. In addition, we provide updated health impacts and nutritional assessments of adopting the PHD and related dietary patterns by country and socio-demographic group.

Second, we review the evidence on the impact of food production systems on the Earth system and assess the current state of food systems across all nine planetary boundaries, updating the five quantified in the 2019 EAT-*Lancet* Commission. For the first time, we propose specific food system boundaries, as a food system share of the safe operating space provided by the planetary boundaries, for use in target setting for food. We provide a novel assessment of how sustainable and ecological intensification food production practices can support a transformation of food production systems within safe food system boundaries.

Third, we establish social foundations of a just food system and assess where current food systems are placed in relation to the foundations. By adding a focus on justice, we place people at the centre of food systems recognising that a just food system is one where human rights can be met. We assess the global distribution of injustices focusing both on where unhealthy food consumption exerts undue pressure on planetary boundaries, and regions where social justice in relation to the food system are not met.

Fourth we include a multi-model analysis to quantify the consequences of a food systems transformation to healthy diets, sustainably produced by 2050. We include ten well-established agro-economic and environmental models with socio-economic rebound effects to expand our understanding of the potential outcomes of the proposed food systems transformation, including direct effects on food production quantities and environmental impacts, and a greater consideration of potential socio-economic impacts.

Finally, based on the reviewed evidence, we propose solutions and actions to ensure access to, and demand for, healthy, sustainable, and just food systems for all. While these solutions are impactful in making healthy and sustainable diets available, accessible, and affordable, we emphasize the opportunity and need to ensure that foods offered must also be delicious and aspirational to ensure that demand

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helps fuel their adoption. We discuss and suggest steps to develop roadmaps that can guide and accelerate the urgent and systemic food systems transformation that is needed.

While the challenges are daunting, we find that achieving access to healthy diets for all, produced, processed, distributed, and consumed fairly within planetary boundaries largely remains biophysically possible. Important synergies between economic, social, and environmental outcomes exist, but are currently missed in today's socio-economic and socio-political systems. These synergies should be better leveraged. Healthy diets are not only a fundamental right, but a shared responsibility. Major efforts are needed to manage an increasingly urgent food systems transformation that secures human and planetary health, addressing the critical lock-ins and political economies inhibiting progress on this necessary transition. The urgency to accelerate the "great food transformation" is undeniable. This Commission provides clear quantitative guidance on health, sustainability, and justice with the aim that this guidance will assist food system actors to navigate this progress with greater confidence and impact. The "great food transformation" needed to achieve healthy, sustainable, and just food systems is huge; it will require the efforts of individuals, organisations and governments at levels from local to global and across essentially all sectors in society.

Treatment of Uncertainty

As with the 2019 Commission, we recognize that few decisions on dietary health, environmental sustainability, and social justice can be made based on absolute certainty. In many cases, existing evidence is incomplete, imperfect, and evolving. This Commission takes stock of how knowledge has evolved over the past five years as one means of reducing this uncertainty. We have based our estimates on the best science acknowledging uncertainties where they exist. Confidence levels are provided and improved through wider systemic reviews and broader community efforts to test the validity of findings. For example, a new contribution of this Commission's work is a multi-model intercomparison, involving 10 integrated assessment modelling teams, testing the contribution of adopting the PHD and transition to sustainable food production practices, in feeding humanity within planetary boundaries (featured in section 4). This work highlights the degree of certainty, and variance, in outcome results. We have adopted treatment of uncertainty in the same manner addressed by IPCC and IPBES. All of the models in the model intercomparison exercise have calibrated their results ensuring that historical trajectories can be reproduced. Considering the 2019 Commission, and the new research summarized here, we have a high level of scientific certainty about the overall direction and magnitude of change required, although considerable uncertainty can exist around some of the more detailed quantifications. Our modelling work considers major trends and opportunities; however, it is important to recognize the myriads of pathways that food systems actors might choose to navigate this transition, and which we encourage them to explore.

This Commission provides scientific measures for healthy, sustainable, and just food systems based on our current understanding. The model results are our current best estimate of plausible change (or lack thereof), and their implications for human health and planetary stability. However, the actual feasibility and impact will vary based on decisions and pathways adopted by individual societies. We do not assess

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how we got to our current state but evaluate a broad range of solutions with demonstrated impacts in the research literature and encourage food system actors to urgently evaluate and adopt appropriate solutions to their contexts. Here it is worth reminding that the PHD and the FSBs merely provide healthy and sustainable boundary conditions, within which a myriad of food dietary compositions and practices fit. It is beyond the scope of this Commission to prescribe which actions should be adopted locally, and we recognize the need for much greater interactions between science, policy, and practitioners in finding context specific solutions.

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Key Messages

1. Food systems sit at the nexus of health, environment, climate, and justice. A food systems transformation is fundamental for solving the climate, biodiversity, crises, and the food related health and justice health crises. The nexus position of food systems emphasizes the interactions between goals, rather than each goal separately. This calls for adopting food system actions as a global integrator across economic, governance and policy domains.

2. The updated Planetary Health Diet (PHD) has an appropriate energy intake, a diversity of whole or minimally processed foods that are mostly plant-sourced, fats that are primarily unsaturated with no partially hydrogenated oils, and limited amounts of added sugars and salt. It allows flexibility and is compatible with a wide variety of foods, cultures, dietary patterns, traditions, and individual preferences. The PHD provides both nutritional adequacy and diminishes the risks of non-communicable diseases. At present, all national diets deviate substantially from the PHD, but a shift to this pattern could avert approximately 15 million deaths per year (27% of total). Such transition would reduce the rates of many specific non-communicable diseases and promote healthy longevity.

3. Food drives five out of six planetary boundary transgressions, including land system change, biosphere integrity, blue water change, biogeochemical flows, and novel entities, while accounting for approximately 30% of greenhouse gas emissions driving climate change. How and where food is produced, which foods are produced and consumed, and how much is lost and wasted, all contribute to planetary boundary transgressions. There is no safe solution to the climate and biodiversity crises without a global food system transformation. Even if the world succeeds with the global energy transition away from fossil-fuels, the food system alone will make the world breach the Paris Climate agreement range of limiting global mean surface temperature to 1.5°C.

4. Human rights related to food systems (the rights to food, a healthy environment, and decent work) are not being met, with nearly half the world's population below social foundations. Meanwhile, across countries and people**,** responsibility for the planetary boundary transgressions from food systems is not equal: the diets of the richest 30% of the global population contribute over 70% of the environmental pressures from food systems. This highlights the large inequalities in the distribution of both benefits and burdens of current food systems. National policies that address inequities in the distribution of both benefits and burdens of current food systems would go some way to meeting human rights as they relate to food systems.

5. The Planetary Health Diet needs to be available, affordable, convenient, aspirational, and delicious. To increase demand for healthy sustainable diets and enable necessary dietary

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shifts, food environment interventions, increased purchasing power, and protection and promotion of healthy traditional diets are important actions.

6. An EAT-Lancet aligned food system transformation that includes a shift to healthy diets, improved agricultural productivity, and reduced food loss and waste would substantially reduce environmental pressures on emissions and land-, water-, nitrogen-, and phosphorous-use. However, no single action is sufficient to ensure a healthy, just, and sustainable food system. Comparing 2050 values to current state, a shift to healthy diets in isolation could lead to a 15% reduction in agricultural emissions, compared to 20% when all three actions are implemented. Individually all three actions modestly reduce future nitrogen- and phosphorous-use (27-34% vs 41% increase compared to 2020 under business as usual), however in combination they substantially reduce future growth in nitrogen- and phosphorous-use (15% increase compared to 2020)

7. Additional nature-positive benefits are accrued through sustainable and ecological intensification practices. Unprecidented investments and effort in these practices potentially making the food system net carbon negative. A diversity of context-specific practices can sequester additional carbon biomass, create and connect habitat, reduce nutrient applications and increase interception and capture of excessive crop fertiliser before it pollutes ground and surface water systems. These practices can be enabled by securing equitable access to land and water resources, strengthening public advisory services, addressing structural imbalances between producers and dominant agribusinesses, and through public and private sector investments that support farmers shifting towards sustainable practices.

8. An EAT-*Lancet* aligned food system transformation could lead to a less resource- and labour-intensive food system capable of supplying a healthy diet for 9.6 billion people with modest impacts on food costs. This would however have profound implications regarding what, how, and where food is produced and those involved in these processes. For example, as a part of this restructuring some sectors would need to contract (e.g., ruminant meat: -33%) and others would need to expand (e.g. fruits, vegetables, and nuts: +63%) compared to 2020 production levels.

9. Justice is needed to unlock and accelerate action for transformation. A fair distribution of opportunities and resources, such that the rights to food, a healthy environment, and decent work are met, and a fair distribution of the responsibility to produce, distribute, and consume healthy diets within planetary boundaries are the basis of a successful food systems transformation. Power asymmetries, discriminatory social and political structures prevent these rights from being met, which results in harms to health of people, precarious livelihoods of food systems workers, and lack of voice undermining freedom, agency, and dignity. Ensuring liveable wages, and collective bargaining while regulating and limiting market concentration and improving transparency, accountability, representation, and access to information are all

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impactful actions. We emphasize the protection of basic human rights in conflict areas a as fundamental foundation of justice.

10. Unprecedented levels of action are required to shift diets, improve production, and enhance justice. A just transformation requires building coalitions with actors from inside and outside the food system; identifying bundles of actions; developing national and regional roadmaps for implementation; unlocking finance for the transformation; and rapidly putting joint plans into action. Such efforts should closely align with other sustainability and health initiatives (Paris Agreement, Kunming-Montreal Global Biodiversity Framework, National Food Based Dietary Guidelines). These frameworks have equally identified food system actions as powerful, particularly in their capacity to integrate across goals. Mobilising and repurposing finance is critical to enabling this transformation

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Glossary

Planetary Health Diet

Based on latest evidence on diet and health, the Planetary Health Diet represents a dietary pattern that supports optimal health outcomes, and which can be applied globally for different populations and different contexts while supporting cultural and regional variation. It emphasizes a plant-rich diet where whole grains, fruits, vegetables, nuts, and legumes comprise a greater proportion of foods consumed, with moderate or small amounts of fish, dairy, and meat. The Planetary Health Diet is entirely based on direct effects of diets on human health, not on environmental criteria. We refer to it as the Planetary Health Diet since there is good evidence that its adoption would lower the environmental impacts and nutritional deficiencies of most current diets.

Food System Boundaries

Food system boundaries are science-based targets representing the share of the safe operating space for food systems. They are based on the available evidence representing the required or possible mitigation of food systems to return or remain within planetary boundaries, including the present-day contribution of food systems to planetary boundary transgressions in relation to other sectors, estimates of minimum environmental impacts from food systems that are hard-to-abate (i.e. through optimization modelling across sectors), and estimates of limited Earth system impact while remaining productive agricultural systems.

Sustainable and Ecological Intensification (SEI)

Sustainable Intensification (SI) entails achieving important reductions in the environmental impacts though increased efficiency, reduced losses, and reduced pollution. Ecological Intensification (EI) is a subset of SI that enhances the environmental performance by promoting ecological processes within agricultural fields, farms and landscapes, such as above and below ground carbon sequestration, nutrient cycling and storage, pollination, and biological pest regulation.

Social Foundations

Social foundations require basic human rights, such as food, water, health, and energy, to be met for everyone. We build on previous work defining the minimum resources required to meet people's human rights, to avoid resource deprivations and harms, and focus on the minimum conditions that enable people's human rights to be met.

Great Food Transformation

An unprecedented commitment globally and nationally to an interlinked range of actions to be taken by all sectors to make healthy food accessible to all—produced, processed, distributed, and consumed fairly within planetary boundaries

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Section 1: What is a Healthy Diet?

We review the evidence on diet and health and present reference values for food group intakes in the reference Planetary Health Diet (PHD) (**Table 1**). Since the 2019 Commission,[1] we included additional health outcomes, considered effects of food processing, and examined implications for young children and women of reproductive age. The relation between the PHD with mortality and other health outcomes has now been examined in numerous epidemiological studies that we summarise. This section also describes gaps between current dietary intakes and the PHD in different regions, and how different dietary cultures may align with the PHD.

Approach to Defining Healthy Diets

Healthy diets should be adequate, diverse, balanced, and moderate.[35] Defining healthy diets for a global population is complicated because nutritional requirements vary by, for example, age, sex, body size, physical activity level, pregnancy and lactation, health status, and genetic factors. However, the effects of diet are similar across ancestry or ethnic groups due to common underlying human biology.[36,37] Here, we focus on diets of generally healthy populations two years and older, although the PHD is also key to resolving health risks in populations facing a high prevalence of undernutrition.

We have described healthy diets as combinations of foods as this most directly connects health with food production and consumption. Nutrient adequacy is important and included in our analyses, but our primary considerations are specific health outcomes related to insufficient or excessive food intakes, rather than numerical targets for essential nutrients (e.g., average requirements (ARs) or estimated average requirements (EARs)). Nutrient requirements are largely based on small, short-term studies, and are often not supported by sufficient evidence for long-term overall health. In addition to food groups, we include added fats, sugar, and salt as they are substantial components of most diets. Our conclusions assume that most foods are consumed whole, unprocessed, or minimally processed.

Although the PHD is based on direct effect of diets on health, we also discuss potential indirect effects of diets on health, including antimicrobial resistance, pandemic risk, and those mediated by environmental changes (**Panel 3**). Control of microbial and other contaminants of food and water is critical but not comprehensively reviewed here. While the cost and affordability of diets, and the environmental impacts of their production and consumption, are critical issues and influence people's access to healthy diets, these factors do not define what is healthy in a diet. We address those separately in other sections.

Review of Evidence on Diet and Health

The goal of this Commission in defining the PHD is to provide the evidence and a quantitative description of a healthy dietary pattern that can be applied globally for different populations and different contexts while supporting cultural and regional variation. In summarising evidence and evaluating causality, we considered prospective epidemiologic studies, randomised trials with intermediate risk factors as endpoints, and the few available randomised trials with health endpoints (**Panel 1**). Because changes in dietary components by individuals or populations are usually made within a constrained total energy intake, isocaloric substitution analyses comparing specific dietary components, such as red meat versus

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legumes, nuts, or fish, are particularly informative because these represent realistic dietary choices. A key part of this Commission is the evaluation of the PHD as an overall dietary pattern in relation to mortality and other health outcomes.

Panel 1: The Planetary Health Diet and Health: Evidence for Causality

Ideally, evidence for effects of specific foods, nutrients, and overall diets on major health outcomes would be based on large, randomised trials with disease and functional endpoints in representative populations across the world. However, this type of evidence is limited because such trials require many thousands of participants, many years or even decades of follow-up, and sustained high adherence to assigned diets. This is neither feasible nor ethical, and randomised trials not meeting these criteria can easily yield misleading, null or negative results. Thus, for studies of diet, and other behavioural and environmental exposures, frameworks to assess causality, such as the Bradford-Hill criteria,[P1] have been developed. For dietary factors, these typically include reproducible evidence from prospective epidemiologic studies (e.g., following a cohort over time) in combination with randomised trials that include intermediate risk factors as outcomes.[P2] Rigorous control of confounding factors by study design and statistical methods is essential.

An example illustrates the value of combined evidence from observational and experimental studies in informing the links between the PHD and health. A central feature of the PHD is the importance of nuts and legumes, including beans, pulses, and soy as major protein sources, with limited amounts of red meat and dairy foods. The far higher ratio of polyunsaturated to saturated fatty acids in these plant foods compared with red meat and dairy products predicts lower LDL-cholesterol levels; this was confirmed in a meta-analysis of randomised trials of red meat intake.[P3] In long-term cohort studies with repeated assessments of diet, mortality was lowest when plant protein was compared to red meat, dairy foods, and poultry;[P4] associations with type 2 diabetes and coronary heart disease have been similar.[P5] Other key features of the PHD include relatively high amounts of fruits and vegetables, shown to lower blood pressure in the Dietary Approaches to Stop Hypertension (DASH) randomised trial;[P6] whole grains, shown to improve blood lipids in randomised trials;[P7] and largely unsaturated plant oils, shown to reduce LDL-cholesterol.[P8] Components of the PHD may operate by additional pathways, including modulation of the microbiome, but at a minimum, beneficial effects on firmly established risk factors are clear. As described in the main text, in multiple large cohort studies with careful adjustment for smoking and other potentially confounding variables, participants with diets most consistent with the PHD have had lower risks of many major health outcomes, including type 2 diabetes, cardiovascular disease, and total mortality.

Important causal evidence for benefits of the PHD also comes from decades of research on the traditional Mediterranean dietary pattern, a specific example of the PHD.[P9] In addition to the types of evidence from observational studies and trials of intermediate endpoints described above,[P10] in a large, randomised trial in people with raised cardiovascular disease risk, a Mediterranean diet with added nuts or olive oil reduced the risk of cardiovascular disease,[P11] type 2 diabetes,[P12] cognitive decline,[P13,P14] and other adverse health outcomes.[P15] In another randomised trial, adherence to a Mediterranean diet reversed the prevalence of a pre-diabetic state by half over one year,[P16] and in a two-year randomised trial, this dietary pattern reduced body weight compared to low fat or high fat diets;[P17] weight loss was sustained at six years.[P18]

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Together, the combination of evidence on the composition of food groups, randomised trials with risk factors as outcomes, and large cohort studies provides strong evidence that adherence to the PHD will have major health benefits. This conclusion is further reinforced by randomised trials of the Mediterranean diet, a dietary pattern that is one example of the PHD, documenting benefits for major health outcomes.

Based on this body of evidence, PHD reference values (**Table 1**) were developed to provide a foundation for optimal health outcomes, and to use as a starting point to evaluate global environmental impacts of food consumption that are addressed in subsequent sections. Importantly, for individuals, these values should not be considered as exact targets, but rather represent approximate ranges and proportions, with potential substitutions among foods to accommodate different total energy intakes and preferences. An updated review of available evidence is included in **Appendix 1A**; a summary is provided here.

Dietary energy requirements vary greatly between individuals depending on age, sex, body size, physical activity, and metabolic factors. We estimated an average global energy intake of 2400 kcal/day for adults using a new doubly-labelled water-based methodology, assuming an ideal BMI of 22 kg/m^2 and an active level of physical activity (**Appendix 1C**).[38] Assuming current average global physical activity levels and BMI among adults of approximately 25 kg/m^2 leads to a similar energy intake.

Grains, including a diversity of options such as wheat, rice, maize, oats, barley, rye, teff, amaranth, fonio, buckwheat, millets, quinoa, and others are the primary sources of energy worldwide and an important source of fibre, protein, and many micronutrients. Consumption of whole grains (100% of the bran, germ, and endosperm in an intact grain), but not refined (depleted) grains, improves blood lipid values and other biomarkers[39] and is inversely associated with risks of weight gain,[40,41] type 2 diabetes,[42] coronary heart disease,[43,44] colorectal cancer,[43] and total mortality.[45] The inverse association between intake of whole grains and weight appears linear, but a concern is that high intake of whole grains could displace other healthy foods and reduce micronutrient absorption. Thus, we used 210 g/day dry weight as a reference value for grains (midway within a ~20-50% of energy), considering this to be flexible and emphasising whole grains versus refined grains.

Tubers, including potatoes, sweet potatoes, taro, yams, and cassava amongst others, are a major energy source in some populations, but commonly consumed white potatoes do not provide the amounts of fibre or micronutrients as do whole grains. Compared with whole grains or non-starchy vegetables, consumption of potatoes is associated with greater weight gain[46] and risk of type 2 diabetes,[47,48] and the association is stronger for fried potatoes than non-fried potatoes.[47,48] Data on other tubers are limited. Because these findings support consumption of whole grains over potatoes as a major energy source, we used 50 g/day as the reference value.

Fruits and vegetables, including seaweeds and other aquatic plants, are a primary source of many nutrients and phytochemicals. Intakes are inversely associated with risks of weight gain,[40,49] type 2

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diabetes,[50,51] coronary heart disease,[51] some cancers,[52,53] and total mortality.[54] More recent evidence supports a reduced risk of cognitive decline and dementia.[55–57] Because of differences in the composition of specific fruits or vegetables and their distinct associations with health outcomes, a variety is desirable, specifically including green leafy and dark orange foods. Most health benefits accrue with about five servings per day; we used 500 g/day as the reference value with no specified upper limit.

Nuts, legumes, and seeds provide protein, unsaturated fats, fibre, and many micronutrients. Nuts and legumes have beneficial effects on blood lipids,[58] and consumption of nuts, including peanuts, have been associated with lower risks of type 2 diabetes,[51] coronary heart disease,[51,59] and total mortality.[60,61] Soy foods contain substantial amounts of both omega-3 and omega-6 fatty acids and are uniquely high in phytoestrogens, and consumption has been associated with lower risks of cardiovascular disease[62,63] and breast cancer.[64] As nuts and legumes are healthy sources of protein, the reference value includes 125 g/day dry weight (about 3-5 servings per day of legumes, nuts, and seeds, including at least 1 serving of nuts); a variety is encouraged.

Red (mammalian) meat is high in protein, haem iron, and other minerals, but is also high in saturated fat and cholesterol and low in essential polyunsaturated fatty acids. In populations consuming very high amounts of carbohydrates, small amounts of red meat or other animal-source foods can provide critical amounts of essential nutrients that have positive health benefits. Consistent with the fatty acid composition, and compared with plant sources of protein such as nuts, soy, and other legumes, consumption of red meat increases blood levels of LDL-cholesterol[39,65] and is associated with increased risk of coronary heart disease.[51,66] Also, consumption of red meat is linearly associated with elevated risk of type 2 diabetes among different populations, including Asia, Europe, and North America; both unprocessed and processed red meat contribute to risk but the latter association is stronger.[37,67] Red meat intake has also been positively associated with unhealthy weight gain and risks of gestational diabetes,[67] colorectal cancer (especially processed red meat),[68] frailty,[69] and unhealthy ageing.[70,71] Consumption of red meat is associated with higher risk of total mortality in countries that have been consuming high amounts for many decades.[72]

Because the association of red meat with type 2 diabetes has been documented in many large studies,[37,51,66,67,73–75] and diabetes is a sentinel disease for many adverse cardiometabolic outcomes, this dose-response relationship was used to determine the reference value in **Table 1**. According to data from three large US cohorts with over 22,000 incident cases of diabetes and many repeated measures of diet over three decades, the increase in diabetes incidence with increase in red meat consumption was approximately linear with a minimal risk close to zero consumption of red meat.[76] We used 15 g/day (about one serving per week) as the reference value with a range including zero to allow a modest intake while avoiding statistically significant increases in risk (see **Appendix 1A** for additional details).

Poultry meat has nutritional values similar to red meat but an intermediate polyunsaturated fat composition between red meat and plant protein sources. Associations with risks of non-communicable diseases and mortality have also generally been intermediate;[37,77,78] an inverse association with stroke has

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been an exception.[51] Because these relationships suggest a priority of poultry over red meat, we used 30 g/day of poultry (about two servings per week) as the reference value.

Eggs are a concentrated source of protein and essential nutrients and can play an important role in childhood diets. They are also high in dietary cholesterol and have generally been intermediate with respect to non-communicable diseases risk[79,80] except for positive associations with risks of coronary heart disease among people with diabetes.[81,82] Consistent with other guidelines, we used 15 g/day or about two eggs/week as the reference value.

Milk and derivatives have broad nutritional value but high content of saturated fat and little polyunsaturated fat. High calcium content has been a primary justification for substantial lifetime consumption. However, calcium requirements have been based on short-term studies, and milk intake has not been clearly related to risk of bone fractures.[83] Consistent with its fatty acid composition, dairy fat substantially increases LDL-cholesterol compared to unsaturated plant oils.[84] Epidemiologic evidence is largely based on cow milk; as predicted, dairy fat is positively associated with cardiovascular disease.[85] Risks of cardiometabolic disease[51] and overall mortality[86,87] associated with milk intake are intermediate between red meat and healthy plant sources of protein. Consumption of dairy foods is associated with low risks of colorectal cancer[88] but elevated risks of prostate cancer.[89] Some evidence suggests that yoghurt consumption, and possibly other fermented products, may be associated with less weight gain[90] and reduced risks of type 2 diabetes[51] compared with other dairy foods. We used 250 g/day of milk or the equivalent amount of milk derivatives (one serving per day) as the reference value because of its intermediate relation with non-communicable diseases risk and substantial contribution to calcium intake; the range includes zero because many populations globally do not consume milk and still have low fracture risk.[83] In a recent meta-analysis, a small decrease in risk of cardiovascular disease was seen with about one serving/day of dairy foods, especially low fat milk and cheese, but little further change in risk with higher intakes. [91]

Fish, shellfish, and other aquatic animal-source foods are major sources of protein and essential nutrients for many populations, including in low and middle-income countries. In many diets, small fish and bivalves are often overlooked as potential foods. Collectively, these foods are particularly important as a source of omega-3 fatty acids (minimally present in terrestrial animal-source foods); low intakes of omega-3 fatty acids can slow down neurologic development in childhood[92] and possibly with cognitive decline in adults;[93] high intakes of omega-3 fatty acids are associated with reduced risk of cardiovascular disease.[94,95] The relation between intake of fish or omega-3 fatty acids and cardiovascular diseases appears to be non-linear;[94] most of the benefit is achieved with 30 g/day of fish (about two 100-g servings per week), which is used as the reference value.

Added fats Evidence from prospective cohort studies and randomised trials has not suggested a reduction in cardiovascular disease[96] or cancer[97] by decreasing total fat intake. However, added fats differ greatly in their composition and health effects; partial hydrogenation creates deleterious *trans* isomers that are associated with increased risks of cardiovascular diseases[98] and all-cause mortality[99] and this process is now banned in many countries.[100] Non-hydrogenated plant oils that contain mainly unsaturated fatty

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acids reduce LDL-cholesterol,[101] and intake is strongly related to lower risks of cardiometabolic diseases and total mortality.[102] These inverse associations appear linear within the ranges studied. Palm oil is relatively high in saturated fat and low in polyunsaturated fatty acids; although studies of health outcomes are limited, available evidence favours relatively unsaturated plant oils.[103] Compared with plant oils, dairy fat increases LDL-cholesterol and is associated with increased risk of cardiovascular disease and total mortality.[84,85,91] Because non-hydrogenated plant oils have positive health effects, intake can be flexible within limits for total energy, for example, if exchanged isocalorically with whole grains. We used an intake of 17% of energy (primarily as unsaturated plant oils including both omega-6 and omega-3 fatty acids) as a reference value, which is similar to that in a Mediterranean diet that reduces incidence of cardiovascular disease.[104]

Added or free sugars provide no nutritional value and can cause harms in excessive intakes. Intakes, particularly in the form of sugar-sweetened beverages, have adverse cardiometabolic effects and have been positively associated with weight gain,[105] type 2 diabetes,[106] coronary heart disease,[107] and total mortality.[106] Consistent with conclusions of the WHO[108] and national guidelines, a maximum intake of 5% of energy from added or free sugars is used as a reference value.

Sodium, commonly consumed as salt or mono-sodium glutamate, is essential, but intakes greater than 1500 mg/day increase blood pressure, and intakes greater than about 2000 mg/day are linearly associated with an increased risk of cardiovascular disease.[109] Thus, up to 2000 mg/day sodium (5 g/day as salt) was used as the reference value.

Food processing Minimal processing, such as drying grains, pulses and nuts, chilling or freezing fruits and vegetables, pasteurizing milk and fermenting milk into yoghurt, reduce food microbial contamination, extend freshness, enhance sensory properties, facilitate preparation, add variety to diets,[110] and reduce the time and labour costs of food preparation. Micronutrient fortification can improve micronutrient density, notably for nutritionally vulnerable populations. However, processing can also have adverse effects, including reduction in food nutritional content, addition of excessive salt and sugar, and use of unhealthy fats and refined grains. Processes that destroy the structure of whole foods, chemically alter their components, and assemble them with a variety of sensory-related additives into products that are liable to displace unprocessed or minimally processed foods and freshly prepared dishes and meals are considered ultra-processing.[110] Dietary patterns high in ultra-processed foods have been associated with thirty-two adverse health outcomes spanning mortality, cancer, and mental, respiratory, cardiovascular, gastrointestinal, and metabolic health outcomes.[111] The Commission concluded that most foods should be consumed whole, unprocessed, or minimally processed.

Overall Dietary Patterns and Health

Evaluations of overall dietary patterns in relation to risk of health outcomes represent the combined effects of all dietary components, including their interactions (**Appendix 1A**). Dietary patterns have been developed to describe traditional diets of specific regions or cultures (e.g., Mediterranean or Japanese),[112,113] using statistical approaches such as principal components or reduced rank regression

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analysis,[114] or, as for the PHD, based on available evidence relating dietary components to health outcomes.

In meta-analyses, dietary patterns similar to the PHD were associated with lower risk of all-cause mortality.[115,116] Within three large cohorts, the Mediterranean dietary score and five other commonly used indices of diet quality were similarly inversely associated with overall mortality and a composite outcome of major chronic diseases.[117] Within-person improvements in dietary quality scores over time were associated with lower risks of all-cause mortality.[118] These and other dietary patterns have also been associated with many other outcomes, including lower risks of depression and dementia.[119,120] Over recent decades, supported by extensive analyses in many populations, a substantial convergence has developed over the broad definition of a healthy dietary pattern.

Since the 2019 Commission, multiple investigators have created indices representing consistency with the PHD, which is strongly correlated with other dietary quality indices.[18,121] In prospective studies across the world, significant inverse associations were reported for the PHD and a number of health outcomes including total cardiovascular diseases, ischaemic heart disease, myocardial infarction, atrial fibrillation, stroke, heart failure, type 2 diabetes, obesity, colorectal cancer, lung cancer, and other cancers. A few studies reported null associations, but these findings need to be placed in the context of methodological limitations (see **Appendix 1A**).[122–124] In an analysis of 206,404 men and women followed for up to 33 years, over 54,000 deaths were documented; overall mortality was 28% lower comparing the highest to the lowest decile of adherence to the PHD (**Appendix 1A**).[18] Although findings on the PHD and mortality in two cohorts of Chinese adults[125,126] are consistent with what has been seen in the United States and Europe (**Appendix 1A**), data from low- and middle-income countries are limited by the lack of large cohort studies in most regions. Associations could vary depending on dietary preferences within food groups, and further research from those areas is needed.

Table 1 presents reference values of the PHD pattern for flexitarian adults. Scenarios for vegetarian or pescatarian dietary patterns and different total energy intakes are presented in **Appendix 1A**. The PHD pattern described in the current Commission is not substantially different from the 2019 Commission.[1] The dietary components in **Table 1** have been re-ordered to facilitate interpretation and with slight rounding of several numbers. Total population level adult energy intake is specified at 2400 kcal/day (instead of 2500 kcal/day as in the 2019 Commission) based on updated values (**Appendix 1B**) and recognising that energy requirements vary by individuals.[38]

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Table 1: Dietary targets for a healthy reference diet for adults, with possible ranges, for a population level energy intake of ~2,400 kcal/day[a] Most foods are assumed to be unprocessed or minimally processed. The targets, ranges, and exchanges (see footnotes) in this flexitarian version of the PHD are intended to provide flexibility within a specific energy intake while limiting intake of animal-source foods to approximately two servings per day with one being dairy (250 g milk equivalents) and one being non-dairy (e.g. 75 to 100 g from among fish, poultry, red meat or eggs). Various versions of this dietary pattern, including specific vegetarian, vegan, or pescatarian diets, those of different food cultures, and with different total energy intakes are described in **Appendix 1B**.

	Per capita recommended intake	
	g/day (range)	**kcal/day**
Plant foods[b]		
Whole grains[c]	210 (20-50% of energy)	735
Tubers, starchy roots[d]	50 (0-100)	50
Vegetables[e]	300 (200-600)	95
Fruits[f]	200 (100-300)	145
Tree nuts/peanuts	50 (0 -75)	275
Legumes[g]	75 (0-150)	275
Animal foods[b,h]		
Milk or equivalents (e.g. cheese)	250 (0-500)	145
Chicken, other poultry	30 (0-60)	60
Fish and shellfish[i]	30 (0-100)	25
Eggs	15 (0-25)	20
Beef, Pork or Lamb	15 (0-30)	45
Fats, sugar, and salt		
Unsaturated plant oils[j]	40 (20-80)	355
Palm, coconut oil	6 (0-8)	55
Lard, tallow, butter[k]	5 (0-10)	-
Sugar (added or free)	30 (0-30)	115
Sodium (mg)	<2000	-
Total		*2,400*

[a]At individual level, the optimal energy intake to maintain a healthy weight in adults and growth in children depends on body size, level of physical activity and physiologic status (e.g., pregnancy, lactation in women). [b]Mostly whole, unprocessed, or minimally processed foods; when processed, added sugar, refined starch, saturated fat, and sodium to be minimal. [c]Whole-grain rice, wheat, maize, oats, millets, sorghum, and other whole grains are all exchangeable and replace refined grains; [d]E.g., Potatoes, yams, cassava, sweet potatoes, and taro. [e]Combinations of dark green, red and orange, and other vegetables, including aquatic plants. [f]All fruits and berries. [g]Beans, lentils, and peas (50%) and soy foods (50%). [h]Beef, lamb, and pork are exchangeable. Red meat, chicken, and other poultry can be replaced with eggs or fish, or plant protein sources. Dairy food servings are exchangeable for approximately 30 g servings of poultry, fish, or pork, provided calcium intake is satisfied by other food groups. [i]Including fish and shellfish (e.g., mussels and shrimps) from capture and farming. [j]Unsaturated oils include olive, soybean, rapeseed (or canola), sunflower, peanut oil, and most other plant/vegetable oils. [k]Energy value for butter, tallow, and lard included with dairy and meats.

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Nutrient Adequacy of the PHD

The primary evaluation of nutrient adequacy of an overall diet is based on health outcomes, which represent the cumulative consequences of all aspects of diet quality, including intakes of total calories, essential nutrients, other dietary components, effects of processing, and their interactions. We evaluated the nutrient adequacy of the PHD for adults compared to current diets by pairing estimated intake with nutrient densities and comparing those to the average requirements of each population group (Appendix 1D). [127]Current intake was estimated by triangulating waste-adjusted food availability data with data from dietary surveys and estimated energy requirements (Appendix 1F).

For most nutrients, the PHD is adequate and performs better than current average diets, notably for fatty acid profile, protein, free/added sugar, fibre, folate, magnesium, potassium, and zinc (**Appendix 1D**). Intakes of calcium, vitamin B12, iron, and iodine from the PHD warrant further attention, especially in populations that have low dietary diversity. Important differences are observed by national income (**Appendix 1D**). In low-income countries, required intakes of most nutrients in the PHD are substantially higher than current intakes, while in higher income countries, intakes of some micronutrients like vitamin B12 and B6 are lower than current intakes, while remaining adequate. Optimisation within the PHD reference values for general food groups (e.g., increasing the proportion of green leafy vegetables for iron, fermented soy foods for B12, and algae for B12 and iodine) can ensure nutritional adequacy for all population groups.[128] On average, calcium intake in the PHD is higher than current intakes, but it was estimated to be lower than recommended intake in some countries without optimisation (**Appendix 1D**). However, calcium requirements are likely overestimated because they are based on short-term studies.[83] Notably, Indonesia has the lowest calcium intake (approximately 250 mg/day), and the lowest fracture rate.[83] Global average vitamin B12 intakes, already currently slightly below adequate intake, were slightly reduced in the PHD when not optimised. Vitamin B12 intakes are likely to be low if intakes of all animal-source foods are on the lower end of the PHD ranges (e.g., in vegan and vegetarian diets) and no supplementary foods are consumed; this merits attention because deficiencies can result in permanent neurologic damage.[129] Dietary modifications with traditionally available food sources (e.g., fermented soybeans and algae in East Asia, fermented sesame in Western Africa, bivalves in coastal areas, and nutritional yeast more widely) can ensure vitamin B12 adequacy.[128] In populations with biochemical evidence of inadequate intake, fortification or micronutrient supplementation should be considered.

Absorbed iron intake in the PHD reference diet is similar to the current global average intake. Absorption efficiency was estimated by accounting for regulatory components such as phytates, vitamin C, and haem and non-haem iron in diets (**Appendix 1D**). The iron needs of women of reproductive age merit specific attention (see section below). Specific attention should be placed to ensure adequate intake of iron-rich food sources, including legumes, soy products, dark green vegetables, and whole grains. Increases in red meat consumption (as an iron source) above the recommended ranges of the PHD are associated with other adverse health outcomes as outlined above and in **Appendix 1A**. Estimated iodine intake currently and from the PHD appear marginal, but intake depends strongly on soil composition where foods are produced (proximity to marine environments) and seafood consumption including algae.

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Absorption of nutrients like iron, zinc, and vitamin A can be compounded by parasitic and other infectious diseases common in low and middle-income countries (LIC, MIC). Because of complexities in estimated nutrient intake, absorption, and losses, monitoring the prevalence of nutrient deficiency is critical. Improvements in diet quality, together with appropriate fortification (e.g., of salt for iodine deficiency) or micronutrient supplementation strategies and non-nutritional interventions (e.g., water, sanitation, and infectious disease control), are possible approaches to address nutrient deficiency.

The PHD provides approximately 14% of energy from protein, which exceeds requirements (EAR 0.7 g/kg body weight, approximately 10% of energy intake), and will provide sufficient essential amino acids.[130] The relation between protein intake and health outcomes will depend on the protein sources. In a meta-analysis, protein intake was inversely associated with lower overall mortality, but this apparent benefit was entirely due to plant rather than animal sources of protein.[131] Somewhat higher protein intakes (e.g., 15 to 30% of energy) have been suggested as important for older adults.[132] This was supported in an analysis on healthy ageing, where the benefit was almost entirely due to plant rather than animal sources of protein.[133] The PHD provides approximately 53% of calories from carbohydrates and 35% from total fat, which is compatible with the flexible amounts of these macronutrients.

Women of Reproductive Age

More than one billion adolescent girls and women suffer from undernutrition, anaemia, and other micronutrient deficiencies which can result in devastating health impacts.[134] The overall health of women of reproductive age is supported by the PHD as presented in **Table 1** and **Appendix 1E**. The iron needs of women of reproductive age merit specific attention due to menstrual loss, pregnancy, and lactation.

A healthy diet during pregnancy is critical to prevent adverse maternal outcomes, support healthy foetal development, and avoid foetal programming that can transmit metabolic dysfunction to future generations.[135] Overall food intake should be adjusted for optimal weight gain, and include a variety of healthy foods,[136,137] consistent with the PHD (**Table 1)**. Although balanced vegetarian diets can support healthy foetal development,[138] use of micronutrient supplements or fortified foods may be indicated if animal-sourced foods are below the reference intakes. Because of extra nutritional demands of pregnancy, the WHO recommends[136] routine iron and folic acid supplementation to prevent maternal anaemia, puerperal sepsis, spina bifida, and anencephaly. Other context-specific recommendations include specific micronutrient supplementation (calcium, vitamin A, and zinc) or routine use of multiple micronutrient supplementation during pregnancy, which is now used routinely in many countries because of benefits beyond those provided by iron and folate alone.[139]

Dietary needs of Infants and Young Children

Young children under the age of two years have unique requirements for rapid growth and development. Exclusive breast feeding, including timely access to colostrum, in the first six months of infancy is strongly advised to ensure optimal nutrition, reducing risk of infectious disease, prevention of both undernutrition and obesity, and for other benefits for infants and their mothers.[140] From around six months of age, introduction of safe complementary foods based on diverse, locally available, and nutrient-dense food is

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essential for optimal growth and development.[141] Continued breast feeding is important and deserves promotion, protection, and support.

Dietary habits and taste preferences are developed in early childhood, and it is important that children become familiar with healthy foods that lays the foundation for a healthy life. Fish, meat, eggs, and dairy foods are rich sources of some key nutrients for children of this age, including iron, vitamin B12, zinc, and calcium.[142,143] The amounts of these animal-source foods in **Table 1** would be suitable for most young children 6-24 months of age.[140] Lower amounts of animal-source foods can result in nutritional deficiencies if not adequately replaced, including Vitamin B12 deficiency, which is associated with poor neurodevelopment in young children.[142] For children with animal-source food intakes below the PHD reference values, complementing their diet with the use of nutrient supplements or fortified foods can make nutrient intakes adequate.[140,143,144] Minimally processed foods should be prioritised, while ultra-processed foods and beverages should be minimised as most are nutritionally unbalanced and may contain harmful additives.

Adopting the PHD pattern globally

The components of healthy diets, described broadly in **Table 1** as reference values with ranges and potential exchanges among food groups, allow great flexibility because they are compatible with a wide variety of foods, agricultural systems, cultural traditions, and individual dietary preferences.[128] Possible ranges for individual components are described, but with overall intakes of animal-sourced foods being approximately two servings per day. The suggested daily or weekly amounts can be consumed at once or spread out in small amounts; for example, red meat might be consumed as an 80 to 100 g serving once a week or as small amounts in mixed dishes or soups, as is customary in many food traditions.

The balance of healthy animal- and plant-source foods presented in the PHD is consistent with many dietary patterns, including Indigenous diets,[145,146] the well-studied Mediterranean diet,[113,147] and other traditional diets from around the world. The traditional diets have in common with the PHD a base of whole grains or tubers, a wide variety of greens and other vegetables, legumes, and small to modest amounts of fish or meat with herbs and sauces that add flavour, variety, and nutritional value.[145,148,149] Moreover, many traditional food practices support improved bioavailability of nutrients and build on rich knowledge of the seasonality of cultivated and wild food species, supporting year-round food and nutrition security.[145,146] Although more research on traditional diets in different regions is desirable, many of these patterns are consistent with high dietary quality[150] and low rates of chronic disease. Protecting healthy traditional diets and food systems can be a critical way to avoid transitions to unhealthy consumption. Examples of healthy meals based on traditional foods and flavours and consistent with the PHD are described in **Appendix 1H**.

In settings with humanitarian crises, deep food insecurity, or in populations where diets remain dominated by staple carbohydrates (e.g. largely rice or cassava), food supplements, including fortified foods, may be required while improving diet quality.[151,152] The time-cost and labour, mainly of women, for food preparation needs to be considered, and if cooking fuel is limited, this can prevent the preparation

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of nutrient-dense foods, such as legumes. Availability of refrigeration and cooking facilities may also constrain food preparation. In some situations, processed, ready-to-eat foods may be necessary, and care is needed to ensure these are nutritionally balanced. Adequate amounts of safe water for drinking and sanitation are always essential. Importantly, achieving PHD-aligned diets represents an important goal for populations shouldering a high burden of undernutrition.

Figure 2 describes the gaps between the PHD reference values and current diets that vary greatly among regions. Notably, red meat and tuber/starchy root intakes are excessive in most regions except South Asia. Tuber/starchy root intake in Sub-Saharan African substantially exceeds the reference value and is higher compared to other regions. Free or added sugars intake is higher than the reference value in all regions except Sub-Saharan Africa and East Asia-Pacific. In most regions, intakes of many healthy foods are low, including vegetables, fruits, legumes, nuts and seeds, and whole grains (replacing refined grains); increasing consumption of these foods offer important opportunities to improve health.

Summary and Conclusions of Healthy Diets

We draw on key evidence from long-term observational studies relating individual dietary components and overall dietary patterns to major chronic disease outcomes, randomised trials with intermediate-risk factors as outcomes, together with randomised trials of health endpoints.

New evidence, including dose-response relationships, has added substantial support for the health benefits of the PHD described in the 2019 EAT-*Lancet* Commission (**Appendix 1A)**.[1] This further supports emphasising whole grains over refined grains and potatoes,[48] plant sources of protein (legumes, pulses, and nuts) over red meat (unprocessed or processed),[51,76] unsaturated plant oils over saturated fats,[85,153,154] including generous amounts of fruits and vegetables,[52] moderate amounts of dairy, fish, eggs, and poultry, and limiting free or added sugars and salt.[109,155,156]

The elements of a healthy diet and the recommended intake ranges for main food groups outlined in **Table 1** allow great flexibility because they are compatible with a wide variety of foods, agricultural systems, cultural traditions, and individual dietary preferences. They can be combined in various types of omnivorous or flexitarian diets as well as vegetarian and vegan diets. The findings of health benefits in many populations for this and similar dietary patterns show that healthy dietary patterns can be achieved in contemporary populations and in many countries globally.

In making global estimates of impacts of diets on health, another general conclusion is that available data on the composition of foods, national dietary intakes, and the relation of dietary factors to health are far from optimal. Notably, large cohort studies with long follow-up are lacking from Africa, Latin America, and most parts of Asia. Because aspects of diet strongly influence health, enhancements in data availability and quality are needed to provide better precision in future analyses and more specific regional and local dietary guidance.

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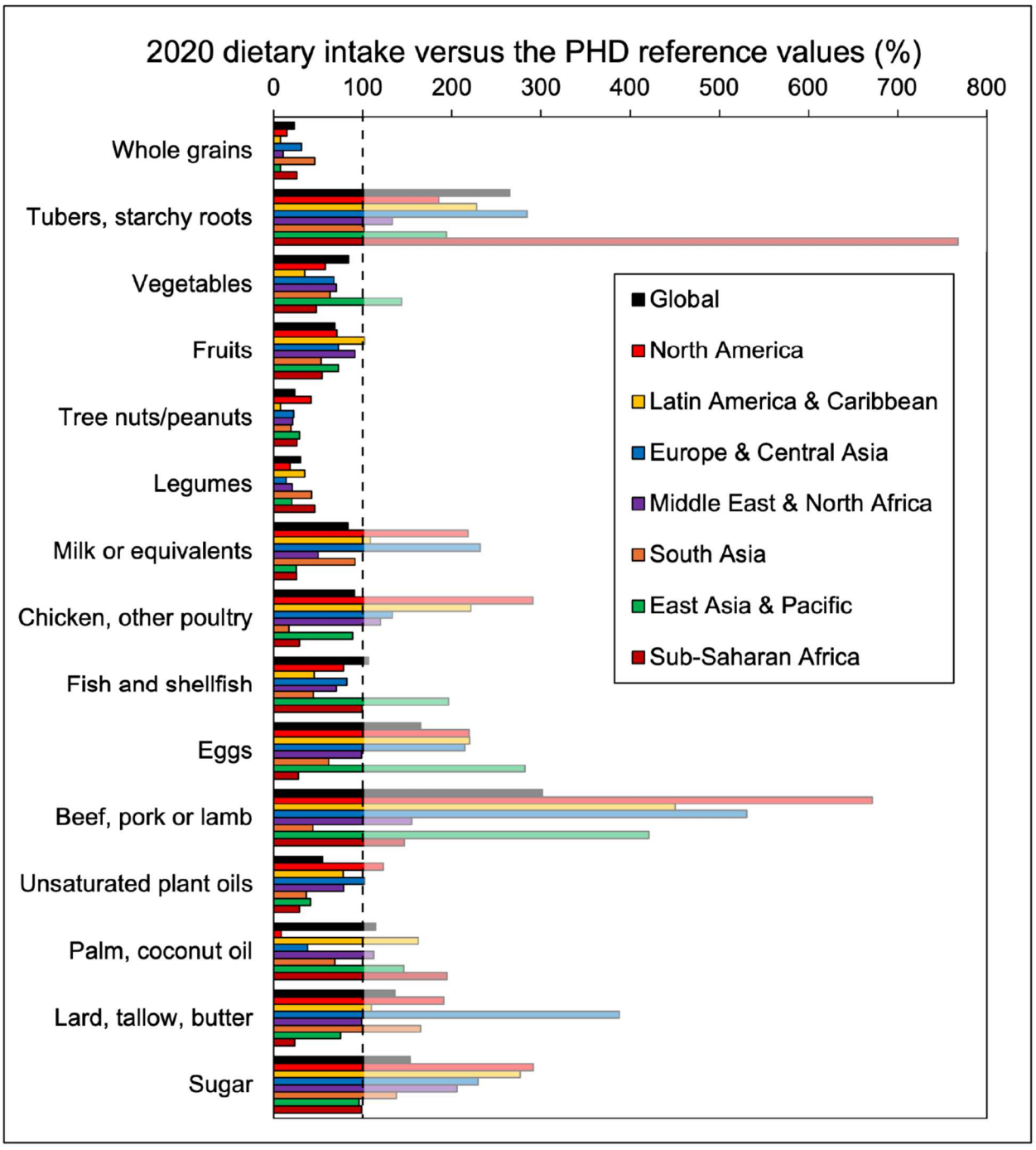


Figure 2: Differences between adult diets in 2020 and planetary health diet globally and by region. The vertical 100% line represents the reference values of the flexitarian version of the Planetary Health Diet (PHD) from **Table 1** (see **Appendix 1B** for source).

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Panel 2: The Planetary Health Diet and Estimated Reduction in Avoidable Deaths among Adults

The potential reduction in avoidable deaths among adults by adopting the planetary health diet (PHD) has been estimated in two ways for this Commission. One approach used an updated comparative risk assessment (CRA) analysis based on relative risks for specific dietary factors and incidence of specific diseases (e.g., red meat intake and type 2 diabetes) using published meta-analyses of cohort studies, most having a single assessment of diet **(Appendix 1G)**. These associations were then applied to country-specific data on diets and cause-specific mortality. In this approach, adoption of the PHD was estimated to prevent about 10 million avoidable deaths per year among adults globally, representing 17% of total mortality.[P19] About half of the reduction in avoidable deaths was due to composition-related risks, including increased whole grains, fruits and vegetables, legumes and nuts, and less red and processed meat consumption. The remaining half was due to anticipated reductions in underweight, overweight, and obesity.

To estimate more comprehensively the potential population level impact of adopting the overall PHD pattern on mortality, the PHD reference values[P20] were used to create the PHD Index (PHDI), a score for the consistency of individual or national diets with the PHD pattern.[P21,P22] The association between individual PHD scores and mortality was estimated from the follow-up of over 200,000 men and women over more than 30 years; diet was assessed every four years to account for changes in food consumption over time and to reduce measurement errors **(Appendix 1A**).[P21]

Combining the relative risks for PHD scores and mortality with the same data on country-specific diets and mortality used for the CRA analysis(described above), an estimated 15 million avoidable deaths per year among adults (27 % of total deaths) could be avoided globally by achieving a PHD score of 120 (140 being perfect consistency).[P22] This estimate did not include assumptions about reductions in overweight or obesity; including such benefits would result in greater reductions in mortality. Notably, when only the baseline dietary assessment was used in the follow-up study, about two-thirds of the mortality reduction was missed. Because achieving a global PHD score of 120 is ambitious, we also estimated the potential benefit from achieving a global PHD score of 100 (only 15 points above current diets); the estimated reduction of avoidable deaths was seven million annually (13% of total deaths).

In both the CRA and the PHD pattern analyses, effects of sodium intake were not included due to difficulties in measurement, and both analyses did not include indirect effects of diet mediated by the environmental impacts of food production. Both analyses used data primarily from high-income countries for estimating relative risks because studies from other world regions are currently lacking, representing an important research gap that should be addressed. However, much evidence supports that relative risks for diet and health outcomes are quite generalizable across populations. Additional benefits due to substantial improvements in diet quality are also likely for children, but these are difficult to estimate quantitatively because of major interactions between diet and infectious diseases, which are particularly important in low- and middle-income countries.

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In summary, different methods for estimating the impacts of adherence to the PHD yield different estimates of the population level impact on mortality. As expected, the use of an overall dietary pattern that incorporates the additive and interactive effects of most major dietary components, combined with repeated assessments of diet over the follow-up period to calculate relative risks, provides a higher estimate of avoidable deaths. For thoroughness and transparency, we have provided results from two approaches; with continued improvements in data sources, further refinements can be expected in the future.

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Panel 3: Indirect Effects of Diet on Human Health

In addition to the direct effects of diet on human health, food systems and diets also have many indirect effects on health mediated by their environmental impacts (**see section on Sustainable Food Systems within Planetary Boundaries**) or societal factors (**see section on Justice in Food Systems**). Here we provide some examples mediated by environmental impacts which we recommend merit greater attention by the scientific community.

Climate Change has many extensively documented effects on human health, including heat stress directly affecting human health, extreme weather events such as windstorms, flooding, and prolonged droughts affecting food production, water security, and attendant deterioration in sanitation putting people at risk of malnutrition, and increases in geographic areas and number of people affected by infectious diseases such as dengue, malaria, and West Nile fever.[P23] Moreover, climate change affects crop yields,[P24] nutritional content,[P25] and food-based pathogens, with major indirect effects on human health through effects on the availability and affordability of nutritious food.

Air Pollution resulting from food production includes small particulate matter and ground level ozone, which increase rates of cardiovascular, pulmonary, and neurogenerative disease, and premature deaths.[P26] Globally agriculture accounts for 650,000 deaths or 20% of mortality related to poor air quality.[P27] This is largely from nitrogen pollution from fertilizers leading to emissions of nitrogen oxides, and nitrogen dioxide pollution associated with around 4 million new cases of paediatric asthma a year.[P28] Biomass burning, notably in the global south, accounts for a smaller proportion, including from land clearing and cooking fuel (164,000 deaths, 5% of mortality related to poor air quality). An estimated 3 to 6% of global exposure to small particulate air pollution could be avoided by adoption of more plant-rich diets, resulting in approximately 100,000 to 300,000 avoidable deaths annually.[P29]

Nitrogen Pollution of drinking water due to excess fertiliser use has been associated with methemoglobinemia, colorectal cancer, thyroid disease, and birth defects.[P30] Other adverse effects of nitrogen pollution in waters may be mediated by eutrophication of water bodies and overgrowth by toxic algal blooms.[P31] The ground water threshold is exceeded in 38% of agricultural lands globally[P32] particularly impacting the health of vulnerable rural populations with strong groundwater dependencies.

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Biocides (including pesticides, herbicides, and fungicides) are used extensively in agriculture.[P33] Although biocides are regulated in most countries to prevent risks to human health, their misuse (i.e. overapplication and lack of appropriate protective measures, particularly for agricultural workers) and co-exposure resulting from mixtures in the environment, has multiple adverse effects on health.[P34] Chronic exposure to pesticides, including by consumption of contaminated foods, is associated with risks of Parkinson's disease, diabetes, cancer, cardiovascular disease, and possibly with infertility.[P35]

Antimicrobial Resistance and Pandemic Risk have increased in part due to increased animal–human contact (either through direct interaction with wildlife or indirectly through vectors or intermediate, domesticated species) which is a prerequisite for zoonotic spillover.[P36] The large-scale global increases in consumption of animal-source foods coming from a very small number of species, often produced in highly concentrated systems, increases risk.[P37,P38] Cattle and hogs now make up ~43% of the mammalian biomass on the planet (humans make up ~38%),[P39] and domestic poultry makes up ~70% of the avian biomass.[P40] This large biomass poses a risk for the emergence of novel pathogens affecting humans and animals, with an acceleration in the frequency of such epidemic/pandemic disease events.[P41] The scaleup in animal-source food production has been enabled by using antimicrobials as growth promoters, and antimicrobials used for animal production represent about two-thirds of the global production of antimicrobials.[P42] The risk of antimicrobial resistance emerging from the use of antimicrobials in animals is well-documented,[P43,P44] and an estimated 1.4 million people die each year from untreatable microbial infections.[P45] We estimated that adoption of the PHD would decrease antimicrobial use by ~42% due to reductions in animal sourced foods.[P46]

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Section 2: Sustainable Food Systems within Planetary Boundaries

Planetary boundaries is an Earth system's framework[157] that quantifies limits for biophysical processes that regulate the stability and resilience of life-support systems on Earth. Transgression of these boundaries pushes the Earth system into an unsafe environmental space for humanity. The latest update of the planetary boundary framework[158] concludes that six of nine planetary boundaries have already been transgressed. The 2019 EAT-*Lancet* Commission assessed five of these boundaries — land, biodiversity, climate, blue water flows, and biogeochemical flows — and found that food systems carry the greatest responsibility for boundary transgressions. Here we re-evaluate the evidence on food systems impact on all nine planetary boundaries, including four boundaries not included in the 2019 Commission: aerosol loading, ozone depletion, ocean acidification, and novel entities (**Table 2)**.

We quantify specific food system boundaries that represent the share of the Planetary boundaries allocated to food systems (**Figure 3**). In contrast to planetary boundaries, food system boundaries are not based on increasing risk levels in the Earth system but represent science-based environmental targets for the global food system, aligned with the planetary boundary framework. As there is no consistent framework to define such targets, we define food system boundaries based on three principles from the existing literature: (i) through proportional reductions necessary to move back to the safe operating space (based on present-day food system contributions to transgressions); (ii) through top-down sectoral optimization of mitigation costs using integrated assessment models; and (iii) by considering food system boundaries equal to planetary boundaries (based on large uncertainties or the on dominant contribution of food systems to planetary boundary transgressions). In some cases, food system boundaries are based on evidence that considers limiting Earth system impacts while retaining the productivity of agricultural systems (see Text A2.1 and **Table A2.1).**[159]

Meeting rising food demands must be achieved from less land, with food production that generates rather than degrades ecological functions.[160,161] Sustainable Intensification (SI) entails achieving important reductions in the environmental impacts through increased efficiency, reduced losses, and reduced pollution.[162] Ecological Intensification (EI) is a subset of SI that enhances the environmental performance of food production by promoting ecological processes within agricultural fields, farms and landscapes, such as above- and belowground carbon sequestration, nutrient cycling and storage, pollination, and biological pest regulation.[163,164] We synthesise evidence on the impacts of key groups of practices for sustainable and ecological intensification (SEI) across field-scale indicators, to assess the potential of SEI in mitigating planetary boundary transgressions (**Section Reducing the Environmental Foodprint of Food Production**). We use a novel ecological intensification module from the FABLE model[165] to assess the global potential of these practices across planetary boundaries (**Panel 6**).

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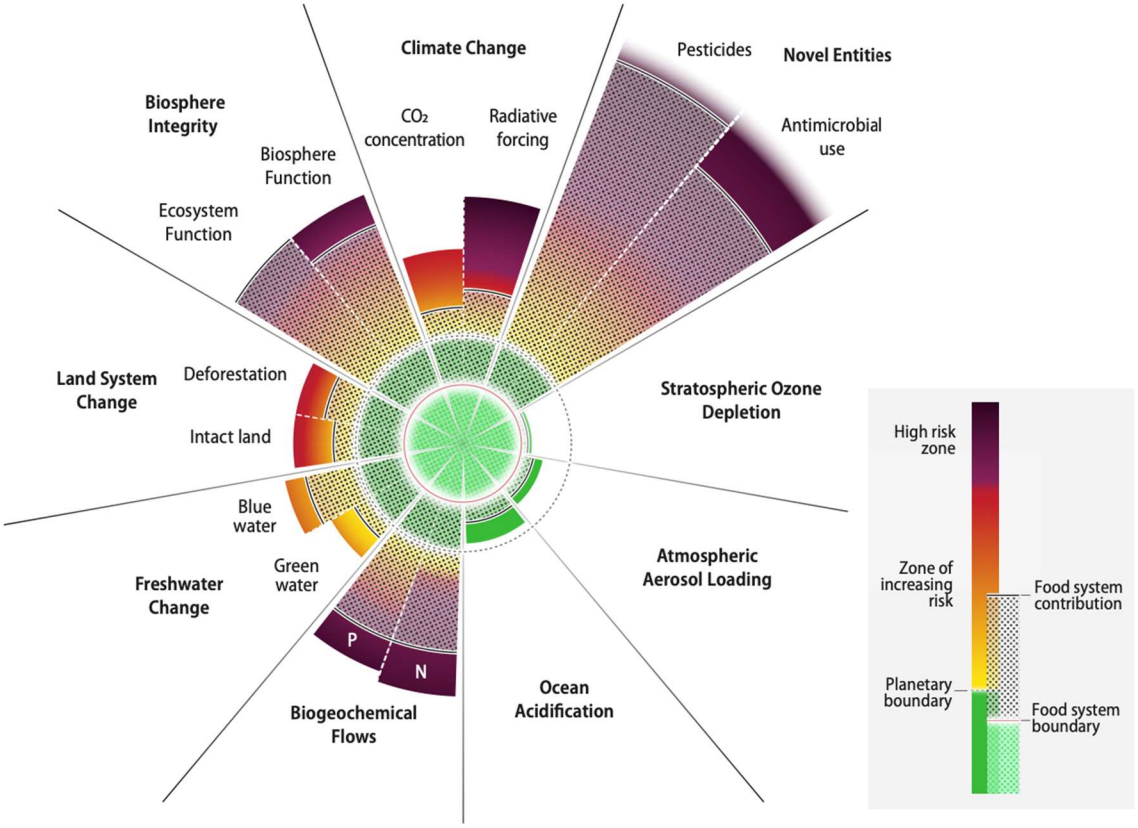


Figure 3: Status of the food system pressures across all nine planetary boundaries (indicated by the black dotted pattern) and the food system boundaries (red line). The food system boundaries are normalised in relation to planetary boundaries (green sphere). Radar plot is adapted from (Richardson et al., 2023[153]). The contribution to the food system (in percentages, see Table 2) is projected based on the length of each wedge starting from the planetary boundary. Note that CO_2 concentration is provided here in terms of CO_2, in contrast to the CO_2- equivalents in Table 1. Adapted from te Wierik et al., 2025.[159]

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Table 2: Planetary boundaries, current food system pressures (relative contribution in brackets), and the proposed food system boundary. Food system pressures and food system boundaries are defined in te Wierik et al., 2025.[159] The planetary boundaries control variables are predominantly based on Richardson et al., 2023[158], except if indicated otherwise.

Earth System Process	Control Variables	Planetary Boundary	Current state	Current food system state	Food system boundary
Climate change	Atmospheric CO2 concentration (ppm CO_2)	350 ppm CO_2	419 ppm CO_2	16–17.7 $GtCO_2e\ yr^{-1}$ (30% of total anthropogenic emissions)	5 $GtCO_2e\ yr^{-1}$
	Total anthropogenic radiative forcing at top-of-atmosphere	1.2 W m^{-2}	+ 2.91 W m^{-2}	24% of total net radiative forcing	
Land system change	Global: Area of intact land as the percentage of original cover [a] Ecoregions**:** Area of intact land as the percentage of original cover by ecoregion [a]	Global: 50–60% remaining intactness Ecoregions: 50-60% remaining intactness (with particular attention to forest ecoregions)	Global: 50% remaining intactness Ecoregions: 10-95% remaining intactness	Global: 48 Mkm^2 (34% of total land surface) Ecoregions: 33% of ecoregions below the intactness threshold (50%) due to agriculture alone	Agricultural land < 48 Mkm^2 (requires halting land conversion of intact nature; <40–50% agricultural land at ecoregion level; restoring 8.5 Mkm^2 intactness in forest ecoregions
Biosphere integrity	Biosphere Functional integrity (HANPP, in GtC yr^{-1})	5.5 GtC yr^{-1} (<10% of Holocene NPP)	13–16.8 GtC yr^{-1}, (25–30% of HoloceneNPP)	9.9–11.7 GtC yr^{-1} (72–85% of total HANPP)	5.5 GtC yr^{-1}
	Ecosystem Functional Integrity [a]	>20–25% habitat per km^2 for supporting agroecosystem functioning.	30–60% of agricultural lands below boundary	88% of agricultural lands used for food production	100% of all food-producing lands within the boundary
Stratospheric ozone depletion	Stratospheric O_3 concentration (global average) (Dobson Unit, DU)	<5% reduction from preindustrial level assessed by latitude (~276 DU)	284 DU	3.9–4.2 Tg N_2O-N yr^{-1} (54-69% of total N_2O emissions)	1.8 Tg N_2O-N yr^{-1}
Ocean acidification	Carbonate ion concentration, average global surface ocean saturation state with respect to aragonite (Ω_{arag})	≥80% of the mean pre-industrial surface ocean Ω_{arag} of 3.44	2.8	25% of CO_2 emissions, as main driver of change in Ω_{arag}	Zero CO_2 emissions from land use change and fossil energy use in the food chain
Biogeo-chemical flows: N and P	Phosphorus: P loss to surface water (Tg of P yr^{-1}) [b]	6.1 Tg of P yr^{-1}	9.7 Tg P yr^{-1}	7.2 Tg P yr^{-1} (75% of total delivery)	4.6 Tg P yr^{-1}

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	Nitrogen: N surplus (Tg N yr^{-1}) [c]	57 Tg N yr^{-1}	119 Tg N yr^{-1}	50, 70, 80% to deposition, surface water load, and groundwater leaching	<57 Tg N yr^{-1} (agricultural N inputs <134 Tg N yr^{-1} with current NUE)
Freshwater change	Consumptive blue water use (km^3 yr^{-1}) [d]	2,800 km^3 yr^{-1}	1,800–2,600 km^3 yr^{-1}	>1,200–1,800 km^3 yr^{-1}, including groundwater	2,000 km^3 yr^{-1}
	Green water (% ice-free land area beyond 5th–95th variability envelope)	11.1% of land area with local deviations	15.8% of land area with local deviations	16.8% of agricultural lands are beyond local variability envelope	Remaining within pre-industrial green water variability envelopes on all agricultural land
Atmospheric aerosol loading	Interhemispheric difference in AOD	0.1 (mean annual interhemispheric difference)	0.076	Northern hemisphere: >80% of NH_3 emissions forming PM2.5 Southern hemisphere: >50% of PM2.5 emissions from biomass burning	Northern Hemisphere: <20 Tg NH_3) Southern Hemisphere: halting biomass burning emissions from land conversion
Novel entities	Percentage of synthetic chemical released to the environment without adequate safety testing [e,f]	0%	Transgressed	Pesticides Active Substances (PAS) application: 3.3–3.7 Tg PAS yr^{-1} (85–90% of total pesticide use)	1 Tg PAS yr^{-1} to avoid high pollution risk; 0.2 Tg PAS yr^{-1} to remain below low pollution risk
				Antimicrobial use in food-animals: 73–130 kilotons yr^{-1} (73% of total antimicrobial use)	Halting prophylactic use; Limiting use to max. 36,000–75,000 tons yr^{-1}

[a] Rockström et al., 2023[34]; [b] Beusen et al., 2022[166]; [c] Schulte-Uebbing et al., 2022[167]; [d] Willet et al., 2019[1]; [e] Maggi et al., 2023[168]; [f] Van Boeckel et al., 2015[169]

Climate change

Our food systems release almost a third of the emissions driving climate change, and are also especially vulnerable to global warming, with profound effects on people's food supply and health.[170] Agriculture and food release 16–17.7 $GtCO_2e$ yr^{-1}, or about 30% of total global greenhouse gas (GHG) emissions.[170–172] Around a third of these emissions come from agriculture, including both livestock and crop production, a third from conversion of natural ecosystems to cropping and grazing lands, and a third from non-agricultural aspects of food supply — including transport, cold storage, processing, retail, catering, food management in the home, the manufacture of fertilisers and other agricultural inputs, and waste management (**Table A2.2**).[170,172] Most agricultural emissions come from production of animal-source food (**Figure 10a**). Enteric fermentation from ruminant animals (i.e. beef and lamb, and dairy) and manure management linked to red meat and poultry account for large shares (Figure 1). Ruminant farming is the primary driver of land use change.[164] Up to a third of food system-wide emissions derive from off-farm food-related processes, including fertilizer production and distribution, post-farm food processing and transformation and transportation. For example, more than 10% (1.9 $GtCO_2e$ yr^{-1}) of the global food

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system emissions are attributed to food that is lost or wasted along the supply chain.[173] Reaffirming the boundary set in the 2019 Commission, we propose that GHG emissions from food systems are kept under 5 $GtCO_2e\ yr^{-1}$ by 2050 to keep global warming below 1.5 or 2°C (Figure 1). Several recent analyses support a 5 $GtCO_2e\ yr^{-1}$ boundary, highlighting that a more ambitious boundary is possible when mitigation options include dietary change (**Table A2.3**). The residual emissions in this food system boundary comprise only methane (CH_4) and nitrous oxide (N_2O) emissions from biological processes in agriculture. These emissions are difficult to abate even with global adoption of the PHD, though the boundary could in theory be further reduced with wider adoption of increasingly plant-rich diets or major advances in emission-reducing technologies.

To meet the climate boundary involves tremendous ambition. Full energy decarbonisation and zero land use change would together eliminate two-thirds of food system emissions, by largely eradicating CO_2 emissions. Energy use would need to be decarbonised throughout the food system, including in food transport, refrigeration and preparation, on-farm machinery, and manufacture of agricultural inputs. Net-zero land use change, aligned with the Land System Change and Biosphere Integrity boundaries, needs a combination of secure land governance, increases in productivity, and reductions in demand. The remaining third – the residual CH_4 and N_2O emissions from agriculture – can be reduced through dietary change, management of food waste, and farming practices (e.g. improved livestock feed and fertiliser use efficiency). A further opportunity to keep food systems within the boundary is carbon sequestration in agriculture, which, when coupled with emissions reductions, could make food systems a net carbon sink **(e.g. Panel 5 & 6, Section Improving Environmental Performance of Food Production**) by removing by removing 1.4–5.5 $^{-1}GtCO_2e$ (estimated economic potential at a carbon price of US$100 per tonne).[170,174,175] Sustainable and ecological intensification practices that sequester carbon include soil carbon management and agroforestry with an estimated 0.4–0.9 $GtCO_2e\ yr^{-1}$ and 0.4–1.1 $GtCO_2e\ yr^{-1}$ respectively with a soil carbon prices of US$100 per tonne.

A systems approach is essential to navigate trade-offs and rebound effects. Since options to reduce emissions diminish as our remaining carbon budget falls below 200 $GtCO_2$, direct capture of emissions is now a universal component of scientific pathways to achieve 1.5 or 2°C (Figure 1). The preferred technology is Bioenergy, Carbon Capture and Storage (BECCS), a land-intensive solution that would compete with afforestation and offset reduced demand for land to feed livestock.[176]

Land system change

Human activities have substantially altered the Earth surface through conversion of intact lands to croplands, grazing lands, and other industrial and urban land uses. Approximately 50% of ice-free lands can still be considered largely 'intact' (natural ecosystems with low human appropriation or use).[31] Halting further conversion of these lands, particularly protecting large forest biomes, is necessary to halt biodiversity loss, reduce human climate forcing, and secure hydrological functioning of ecosystems.[31,158,177] We set the land boundary at 85% intactness of ecoregions included in boreal and tropical forest biomes and at 50–60% for all other ecoregions as defined in the Planetary Boundaries and Earth

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Commission.[34] These levels are required to mitigate the impacts of climate change, and to halt the loss of biodiversity.

Currently, 48 Mkm^2 (37% of the global land area) are used for agricultural production, of which croplands and grazing lands cover 33% and 67% respectively.[178] Almost 70% of ecoregions fall below the 50% intactness boundary,[31] predominantly driven by historical conversion of intact nature to agriculture (**Figure A2.1**). Agricultural land alone breaches the local intactness boundary (>50% agricultural land cover) in a third of the ecoregions (**Figure A2.2**). The continuing loss of intact ecosystems, notably forests, is predominantly driven by agriculture,[179] and is particularly high in tropical forests that are cleared for pasture, oil crops and soy production.[179,180]

Remaining within the land system boundary requires zero conversion of intact lands, by keeping global agricultural area well below 48 Mkm^2. This is a modification of how the land boundary was articulated in the 2019 EAT-*Lancet* Commission as 13 M km^2 which only included croplands. In addition to halting conversion, reducing agricultural land and restoring intactness is critical across ecoregions, and particularly important in forest biomes that are currently strongly transgressed, and require 5.5 Mkm^2 and 3 Mkm^2 of tropical and temperate forest restoration, respectively, at the expense of agricultural land (**Figure A2.3**).

The key strategy to reduce agricultural land area is a shift to healthy diets, particularly away from animal-based products and associated feed production (**Section 4**).[181,182] Decreasing food loss and waste is a lever with which the demand-side pressure can be further reduced. In aggregate, maintaining or increasing yields is critical to keep agriculture within a reduced land area, recognising regional differences depending on current yield levels. Sustainable and ecological intensification (SEI) practices chiefly demonstrate either improved (desirable effect sizes) or maintained (negligible effect sizes) productivity (**Section Reducing Environmental Foodprints of Food Production**). EI would require slightly more land than other practices aiming to improve production but still fall below the land boundary globally (**Panel 4**).

Biosphere integrity

Life on our planet depends on the capacity of the biosphere to safeguard critical Earth system functions, which in turn requires healthy, functioning ecosystems. Two complementary control variables for biosphere integrity include *biosphere functional integrity* and *ecosystem functional integrity*. *Biosphere functional integrity* refers to the sum of Net Primary Productivity (NPP) from all ecosystems on Earth and thus is used as an Earth system-wide control variable.[183] NPP captures the photosynthetic energy and material flows into the biosphere, with the deviation between potential NPP of intact ecosystems and the actual NPP of converted systems. The biosphere integrity boundary sets a limit to human appropriation of this energy (HANPP) at <10% of Holocene NPP (5.5 GtC yr^{-1}).[158] *Functional integrity of ecosystems* is defined as ecosystems' capacity to sustain nature's contributions to people (e.g. food production).[184] Intact ecosystems are functionally intact, i.e. with high functional integrity. This boundary, which is set at 20–25% natural or semi-natural habitat per km^2, is thus applied to agricultural and urban land-use systems. From an Earth system perspective, functional integrity contributes to ensuring gene and species

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flow within and between ecosystems, reducing the risk of species extinctions when complemented with the land boundary described above. The 2019 Commission used a 10% threshold with evidence that below this value ecosystem services to and from food production are lost. Recent reviews have increased this threshold to 20–25% necessary to maintain minimal functioning, rather than complete loss of function.[184,185]

Agricultural systems, notably extensive monocultures, are the single largest drivers of both biosphere and ecosystem functional integrity loss, through lowering actual NPP from land conversion, extracting NPP by harvesting biomass, and below threshold retention of habitat within agricultural lands. Agriculture is responsible for appropriating 72–85% of the total HANPP (9.9–11.7 GtC yr^{-1})[186], while a significant portion of agricultural lands (33–66%) are below functional integrity thresholds, and 88% of agricultural land are used for food production (**Figure 4a**).[184,187]

Remaining within the food system boundary for biosphere integrity requires a reduction of HANPP back within the safe planetary boundary level (<5.5 GtC yr^{-1}),[159] by increasing productivity on existing cropland (i.e. closing agricultural yield gaps from e.g. nutrient deficits, see **Section Nitrogen**), and restoring ecosystems on former agricultural lands (e.g. reforestation), to increase actual NPP back to levels of potential NPP (**Section Land System Change**). Ecological Intensification practices, while not directly assessed against HANPP here, include practices that ensure that larger portions of NPP are retained in or returned to fields, for example as crop residue, manure, or perennial vegetation. Maximum field scale HANPP of sustainable production systems merits attention as a key scalable sustainability metric. Furthermore, reducing HANPP from harvested crops (currently ±2 GtC yr^{-1})[186] is only possibly through dietary shifts that reduce HANPP from crop production for animal feed, and by reducing food loss and waste and feeding losses. Globally, around 775 kcal per capita per day is lost or wasted (representing approximately 20% of the agricultural land use), of which the majority are crops. These losses occur along the full supply chain (post-harvest, retail, food service, households), see **Panel 4**[173,188] (**Section Transformation)**.

Increasing the functional integrity on productive lands requires widespread inclusion of embedded habitat in agricultural lands to reach the planetary boundary safe zone.[184,185] This target can be achieved by protecting and restoring riparian buffers and hedgerows, improved fallows, returning crop waste to fields, and other practices fitting agroecosystem context. Agricultural diversification practices support the ecosystem functional integrity directly and can be managed to further enhance carbon sequestration (**Climate Boundary**), increase biological pest control and pollination (**Novel Entities Boundary**), and reduce losses of nutrients to the environment (**Biogeochemical Flows Boundary**).

Freshwater change

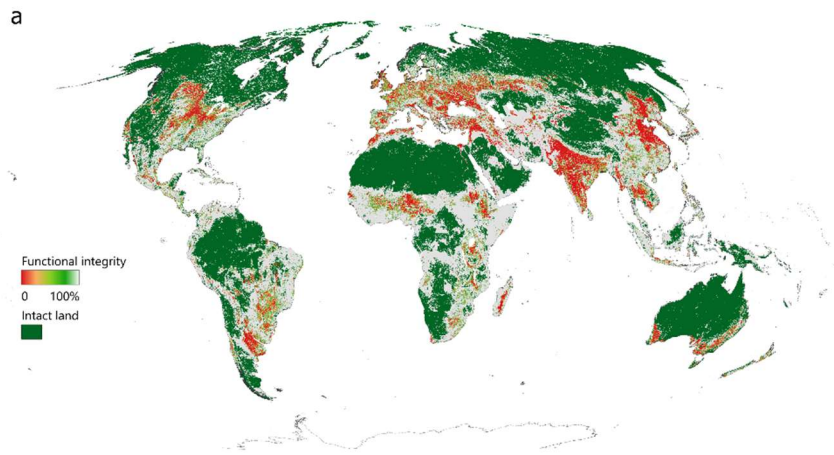
Freshwater availability is critical to support drinking water needs, ecosystem functioning, and climate mitigation by enabling carbon sequestration in the biosphere.[189] The freshwater cycle is increasingly altered by human actions, affecting both blue water (rivers, reservoirs and groundwater) and green water (held in soil and in plants).[190] Recent planetary boundary assessments show that we have transgressed boundaries for both blue and green water.[158,191] These boundaries propose limits to the occurrence of

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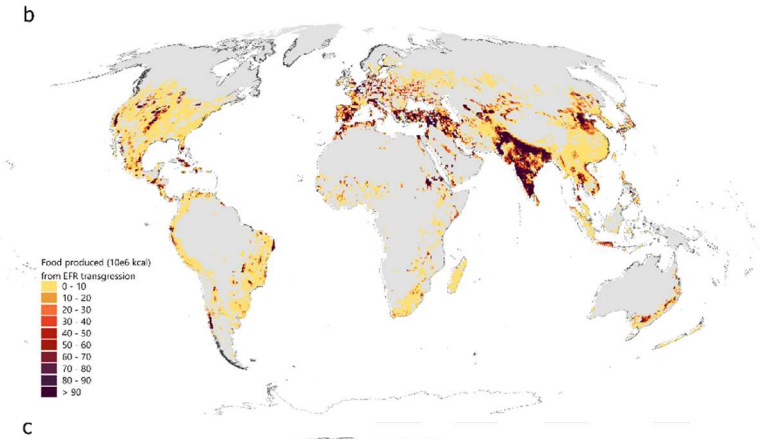
exceptionally dry and wet local events (including blue and green water availability), and deviate from the blue water boundary proposed in the 2019 Commission, which is based on volumetric limits to consumptive water use. It constrained the global agricultural consumptive use to <2,500 km^3 yr^{-1} [192] to preserve regional ecosystem flow requirements (hereafter 'EFR', meaning the minimum water volume, timing and quality needed to maintain good ecological status of aquatic systems). Here, we adopt the novel boundary definition for green water (i.e. global land area beyond pre-industrial local green water variability baseline), while keeping – although updating – the volumetric limit for blue water.

Food systems are major blue water users, mainly via irrigation.[159,193] Water withdrawal estimates from rivers and groundwater range between 2,700–3,100 km^3 yr^{-1} ,[171,193] of which between 1,200–1,800 km^3 yr^{-1} are consumptive use.[193,194] Irrigation is responsible for around 70–90% of the global consumptive water use, although estimates vary depending on the accounting methods and models used.[159,194] The majority of agricultural land and production[159] is rainfed and hence depends solely on green water[193], but soil moisture availability is changing across the world,[191] including on agricultural lands (16.8% of agricultural land is currently transgressed).[196,197] We preliminarily define the food system boundary for green water based on the latest planetary boundary definition (i.e. limiting the land area beyond pre-industrial variability baseline to 11%)[159]). For blue water, we propose that agricultural water consumption remains below 2,000 km^3 $yr^{-1,}$ which is lower than in the 2019 Commission (2,500 km^3 yr^{-1}), that allocated 90% of the safe operating space to agriculture. We propose a more stringent approach considering uncertainties in agricultural consumptive water use [193], and acknowledge the lower (stricter) end of the planetary boundary uncertainty range (1,100 km^3 yr^{-1}).[192] While this suggests that food systems are within the safe operating space globally (**Table 2**), many rivers are experiencing severe water stress from irrigation water withdrawal alone.[198] In fact, >5% of the global food production depends on regional blue water transgressions by tapping into EFRs (**Figure 4b**).[198] In those areas, limiting irrigation water demand without affecting crop yield could be achieved through shifting production to less water demanding foods,[199] reducing food loss and waste (currently wasting 20-25% of freshwater withdrawals),[171,173] and increasing water productivity through the adoption of agricultural practices that improve soil water holding capacity (**Section Reducing Environmental Footprint of Food Production).** SEI practices are significantly effective in increasing soil organic carbon (SOC) content, which in turn improves the water-holding capacity of soils.[200] Crop and non-crop diversification, especially agroforestry (e.g., Muchane et al., 2020[201]), exhibit strong desirable effects on the water regulation of soils by e.g. creating diverse root-systems and enabling infiltration.

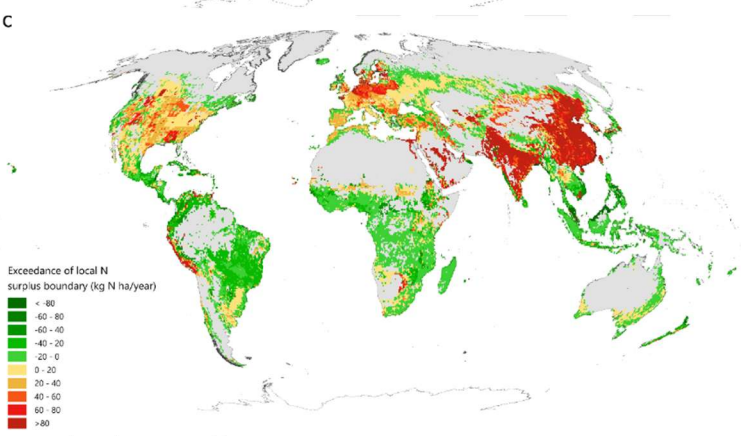
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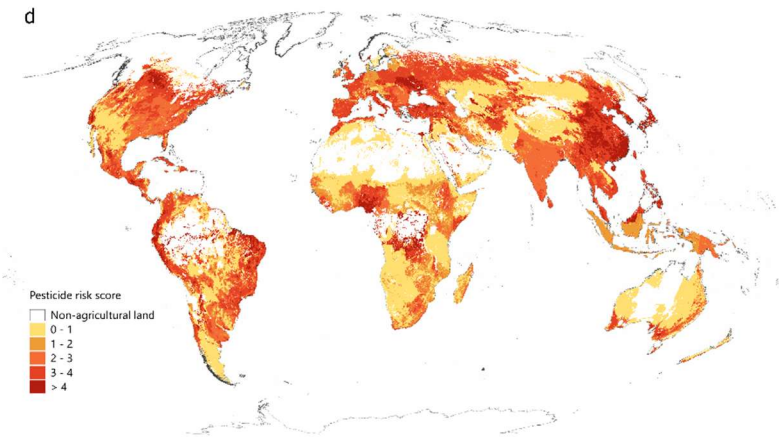


Figure 4a-d: Present-day status of planetary boundaries for land, biodiversity, water, nitrogen and pesticide use. **a.** Intact land (dark green) based on Rockström et al., 2023[34] and ecosystem functional integrity on existing agricultural land based on Mohamed et al., 2024[184] **b**. Blue water, with regions where irrigation use exceeds freshwater ecosystem flow requirements (EFR), expressed as kcal of food produced yr^{-1} from water use that taps into EFRs. Restricting irrigation without compensatory measures can affect yields in half of irrigated croplands (data from Jägermeyr et al., 2017[198] and Gerten et al., 2020[202]) **c.** Regions where local N boundary is exceeded (values > 0), and regions where N surplus boundaries are not yet exceeded and allow for increase in N to meet crop demand (kg N ha yr^{-1}, data from Schulte-Uebbing et al., 2022[167]) **d.** Pesticide risk scores, indicating the exposure of agricultural land to pesticide pollution, classified into risks scores following average species sensitivity curves: low risk (0–1), medium risk (2–3), high risk (>3). Data from Tang et al., 2021.[203] Gray areas indicate no data.

Biogeochemical flows: nitrogen and phosphorus losses

Nitrogen (N) and phosphorus (P) play a critical role in biological life, including crop and pasture production. In some regions, crop yields are below their potential due to deficient N and P availability, while in others, agricultural N and P surplus from excessive inputs cause environmental pollution, leading to biodiversity loss and human health impacts.[166,204] In addition, N_2O emissions from fertiliser and manure contribute to climate change (**Section Climate Change)** and stratospheric ozone depletion (**Section Stratospheric Ozone Depletion**). Here, we adopt the 'N surplus' from agricultural land as control variable,[167] defined as N input minus the removal of N via crops and grasses. In contrast to 'N input' adopted in the 2019 Commission, N surplus covers remaining reactive nitrogen that can lead to environmental harm via deposition on natural ecosystems, groundwater leaching and surface water load.

Unlike N input, estimates of N surplus are not affected by nitrogen use efficiencies (NUE, i.e. N removal from plants compared to total N input), but ignore N removal from plants that moves up the food supply chain and can end up in the environment via waste-water streams (i.e. via human excreta). The planetary boundary for N surplus on agricultural land is 57 Tg N yr^{-1}, allowing for an increase in N use in regions that are currently deficient (**Figure 4c**). For P, we adopt 'P losses to surface water', which strongly depend on the available P stocks in soils and erosion rates. Unlike the 'P application' control variable used in the 2019 Commission, we use P losses since applied (excess) P can be adsorbed and build up soil P stocks without directly causing harmful environmental effects (unlike N). Based on critical P concentrations to preserve

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good ecological status of global surface waters,[205,206] we propose a global P loss boundary of 6.1 Tg of P yr^{-1}.[207]

Current agricultural N inputs on cropland and managed grasslands (233 Tg N yr^{-1}) are partly removed by crops (114 Tg N yr^{-1}), while 119 Tg yr^{-1} remains as surplus.[167] This surplus — together with other N sources from wastewater, aquaculture, NOx deposition from transport, and natural sources (i.e. allochthonous matter)— contributes to N deposition on terrestrial ecosystems (23 Tg N yr^{-1}, around 50% from food systems), N loading in surface water (71 Tg N yr^{-1}, around 70% from food systems), and leaching to ground water (56 Tg of N yr^{-1}, around 80% from food systems) (**Table A2.4**).[159,207] Furthermore, almost 10 Tg of P yr^{-1} is delivered from soils to surface water, with 75% of the P delivery (7.2 Tg P yr^{-1}) derived from food systems (**Table A2.4**).[166]

Bringing agricultural N surplus back within global safe levels (< 57 Tg N yr^{-1}) requires a reduction of agricultural N input from 233 to 134 Tg N yr^{-1},[167] (**Panel 4**) based on current NUE. Assuming proportional reductions across other sectors can only slightly relax this value (to 140 Tg N yr^{-1})[167] since most N sources are attributed to the food systems (including agriculture, aquaculture and N from waste water) (**Table A2.4**); while further reducing the contribution from natural N sources (from allochthonous organic matter) is not possible. We therefore propose the food system boundary for N surplus to be equal to the planetary boundary.

Increasing NUE from 0.48 (current global average) to an achievable 0.67 [208] may bring us close to the safe operating space without compromising yield.[167] Nutrient surpluses are highly unevenly distributed, with redistribution being as important as a reduction in fertilizer rates to limit planetary boundary effects (**Figure 4c**).

Agricultural diversification and fertiliser management show significant potential to reduce nutrient losses to the environment, improve NUE, with some increased and chiefly neutral yield effects (**Section Reducing the Environmental Foodprints of Food Production**)**.** While reduced disturbance showed mixed results for reducing nutrient losses in general, no-tillage significantly reduces phosphorus losses. Soil P stocks below target levels should be increased globally, and P application should maintain this soil P status by replacing P removed during cultivation and harvest and reducing physical loss via erosion control.

Returning within boundary conditions remains a challenge without greater attention to food system losses originating from food consumption. Recovery of N and P sources from sewage water must similarly be implemented to prevent post-consumption losses (i.e. around 26 Tg N yr^{-1} from human excreta of which 12 Tg N yr^{-1} is lost to surface waters).[166] The impact of circular systems remains poorly assessed (but see **Panel 4**) and merits attention. Recycling of N and P on fields, not only by using manure but also compost and sludge, decreases losses to the biosphere, although these practices are increasingly challenged by novel entity contaminants (e.g. Forever Chemicals or PFAS) in organic waste streams which can make agricultural fields toxic.[209]

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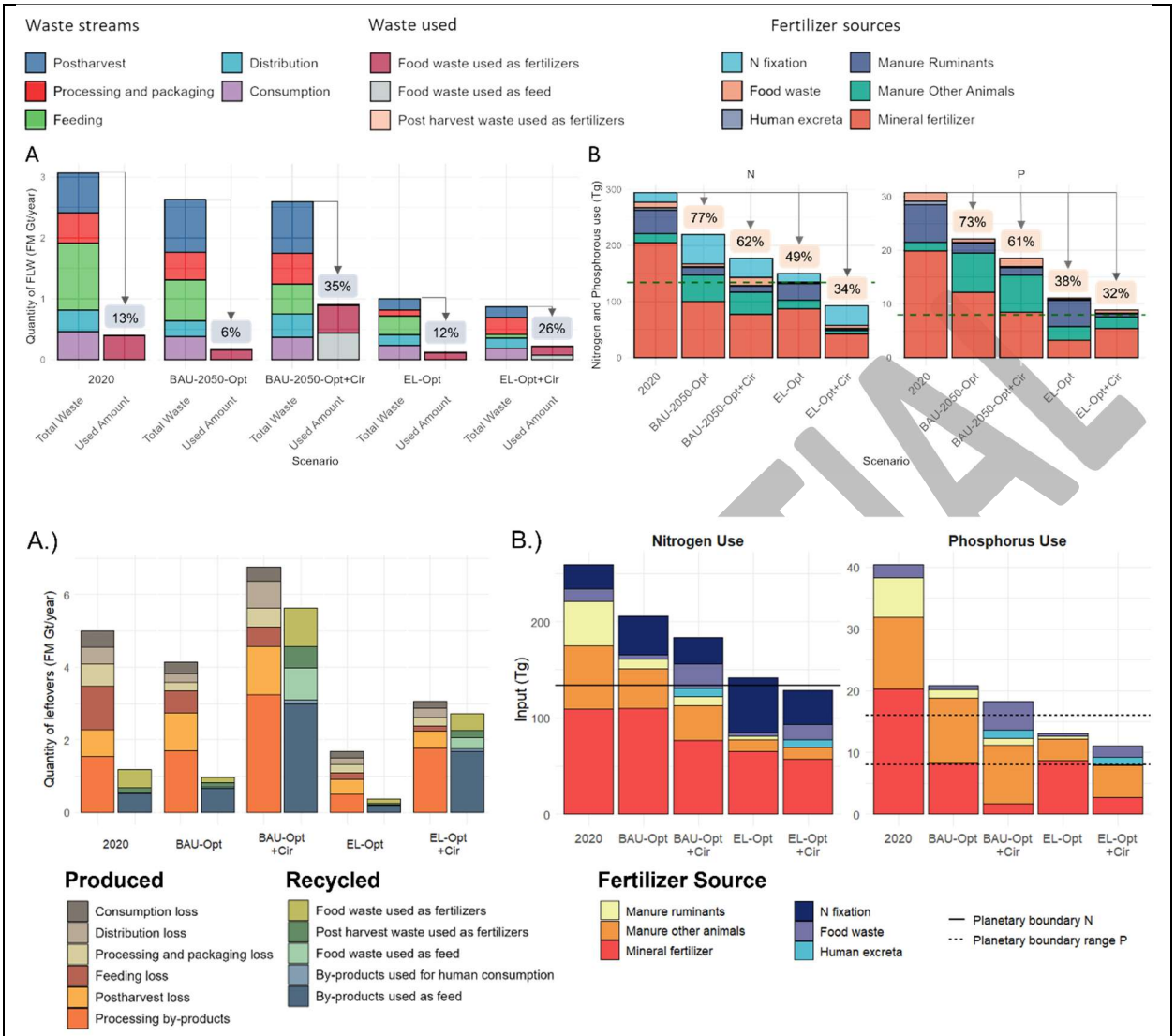
Panel 4: Circular food systems

Transitioning to more circular systems is thought to potentially reduce (mineral) N and P use. To assess these potential contributions, we used CiFoS,[P47] a biophysical optimization model to simulate four 2050 scenarios that were benchmarked to a 2020 simulation (see Van Zanten et al., 2025[P48] and **Appendix 2** for more details):

1. BAU-2050-Opt: scenario optimizes a future 2050 scenario by minimizing multiple environmental impacts (use of land, N and P and GHG emissions) towards the food system share of planetary boundaries, by reallocating production globally. The economic and social implications of this reallocation were not assessed.
2. BAU-2050-Opt+Cir: in addition to the BAU-2050-Opt, allows a transition to a more circular food system where leftovers (e.g., by-products, human excreta, feeding losses and food loss and waste) are recycled.
3. EL-Opt: simulates a scenario which takes into account dietary shifts compatible with the Planetary Health Diet, allows food loss and waste (FLW) reductions of 50% and production increases (in line with the multi-model ensemble described in **Section 4**).
4. EL-Opt+Cir: scenario adds circularity components to EL-Opt.

In the BAU-Opt scenario the production of leftovers was lower (4.1 Gt) compared to BAU-Opt+Cir (6.8 Gt) and the difference between EL-Opt (1.7Gt) and EL-Opt+Cir (3.1Gt). Utilized leftovers increased from 24% in BAU-Opt to 84% for BAU-Opt+Cir and from 22% in EL-Opt to 90% for EL-Opt+Cir (**Panel Figure A**). Results in the circular scenarios (BAU-Opt+Cir and EL-Opt+Cir) show a preference for recycling over reducing the production of leftovers. In 2020, the total use of N is 259 TgN and total use of P is 40 TgP, including both mineral fertilizers and organic sources (**Panel Figure B**). Compared to 2020, in an optimized but not circular food system (BAU-Opt) the use of N decreased by 21% to 205 TgN, and the use of P decreased by 49% to 21 TgP. Adding circularity measures (BAU-Opt+Cir) reduced N by 29% to 184 TgN and P by 55% to 18 TgP and EL-Opt reduced N by 45% to 142 TgN and P by 67% to 13TgP. Combining circularity with an EAT-Lancet-aligned food system (EL-Opt+Cir) reduced N by 50% to 128TgN and P by 73% to 11TgP. N and P use in both EL scenarios are in line with staying within their respective planetary boundary (boundary value of 134 TgN total N input to stay within the N surplus boundary of 57 TgN per year (**Table 2)** and between 8 - 16 Tg of mineral P fertilizer per year based on Springmann et al., 2018 [P49] to limit the amount of P reaching surface waters). Although the results of EL-Opt and EL-Opt+Cir only slightly differ, there are clear differences in the fertilizer sources used, e.g. more organic fertilizer sources are used in EL-Opt+Cir (**Panel Figure B**). Nevertheless, despite substantial reductions in mineral fertilizer use due to increases in circular sources of N and P (El-Opt+Cir), mineral fertilizers remain a critical input into agricultural production.

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Panel Figure AB. Effect of circularity on leftovers use and biogeochemical cycles on a global food system level. (A) Total leftovers and total leftovers used per scenario. (B) Nitrogen use and phosphorus use per scenario by source.

Novel entities

The planetary boundary for novel entities proposes limits to the release of human-made substances in the environment — ranging from synthetic chemicals, such as plastics and endocrine disruptors, to radioactive materials and genetically modified organisms. The risk posed to Earth system stability and resilience from novel entities is uncertain, but potentially large and persistent following cumulative and mixing effects (i.e. chemical interaction of multiple substances in the environment), thereby threatening all life on Earth. There are >350,000 synthetical chemicals produced and released in the environment, and many are insufficiently tested for their potential environmental risks.[210] Uncertainties regarding the associated risks of novel entities continue to frustrate the definition of a novel entities boundary, which

is therefore preliminarily and precautionarily placed at zero release of synthetic chemical compounds without adequate safety testing that can demonstrate that no harmful environmental effects occur upon release.[158,210]

While novel entities were not assessed in the 2019 Commission, food systems contribute to the release of various novel entities, such as pesticides,[168,203] genetically modified crops, antimicrobials, (micro-)plastics, [211] and 'forever chemicals', such as PFAS, throughout the food chain.[212] Here, we adopt 'pesticide application' and 'antimicrobial use' as indicators for novel entities, because their widespread use in agriculture and potential risks to the environment and human health.[159,213,214]

Pesticides are widely used in crop protection and weed control and pose major health risks to non-target species. Global pesticide application amounts to 3.3–3.7 Tg of pesticide active substances (PAS) yr^{-1} [213], of which 85–90% is used in agriculture.[215] Safety levels for individual pesticide concentrations are crossed throughout terrestrial and aquatic systems (**Figure 4d**). Although most pesticides degrade over time, remaining residues build up in organisms and pose risks through mixing-effects in the environment.[216] Furthermore, legacy contamination can continue for extended periods of time, decades in some cases, in soil, surface water and groundwater.[168] These factors challenge the definition of safe levels of pesticide use. To minimise exceedance of high risks (i.e., a greater than 90% probability for a random species to be affected by pesticides), we propose a global reduction of 70% compared to current levels equating to a maximum application of 1 Tg of PAS yr^{-1} (**Figure A2.4**). A further reduction of more than 95% (max. application of 0.2 Tg PAS yr^{-1}) is required to remain below "low" environmental risks (i.e., a less than 5% probability for a random species to be affected by pesticides).[159,203]

Ecological intensification practices can manage pest outbreaks without compromising crop yield, while enhancing biosphere ecosystem functional integrity (**Figure 5**).[217] However, some agricultural practices such as reduced soil disturbance can result in higher weed loads (**Figure 5**), highlighting the importance of employing integrated complementary practices (**Panel 5**).

Antimicrobial use for food-animal production is estimated at 73–130 kilotons yr^{-1} [169,218,219] and has increased antimicrobial resistance prevalence.[66] Setting a boundary for antimicrobial use is challenging due to the uncertainties in the environmental risks from increasing antimicrobial resistance.[214] Based on WHO recommendations and available evidence on lowering average application rates while keeping effective production systems,[219] we propose the complete halting of prophylactic antimicrobial use, and halving of existing average application rates from 2020 values of 50 to 25 mg kg^{-1} animal.[159] Global shifts to flexitarian diets can reduce global antimicrobial use by around 42% compared to baseline values for 2050, whereas combining with moderate biosecurity measures could reduce global use by 49%.[221]

Aerosol loading

Air pollution is a major human health issue (**Panel 3**), negatively affects crop production by changing the photosynthetically available light,[222] and can have critical Earth system impacts on precipitation and circulation patterns of the atmosphere and ocean. The planetary boundary for aerosol loading is

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expressed as the mean annual interhemispheric difference in the aerosol optical depth (AOD),[158] capturing the reduction in sunlight from air pollutants, such as nitrogen components (NH_3, NOx and N_2O), SO_2, CO, organic compounds, and particulate matter (PM). Increased AOD affects regional rainfall patterns, and changes in the interhemispheric difference are associated with abrupt transitions in monsoon systems. Although the planetary boundary for atmospheric aerosol loading is not transgressed (**Table 2**), food systems are a prominent source of air pollutants (**Figure A2.5**), such as ammonia from fertiliser use and livestock production (37–47 Tg N yr^{-1}, 86% of total NH_3 emissions);[167,223] airborne dust from human-driven land system change (e.g. desertification and land management practices); and primary $PM_{2.5}$ emissions, i.e. aerosols' diameter smaller than 2.5 micrometre (>28% of total primary $PM_{2.5}$; emissions), mostly from burning for clearing vegetation.[223] Dominant sources of emissions vary regionally and between hemispheres.[224] In parts of the northern hemisphere, N-based emissions from livestock and fertiliser are the dominant source of aerosol-loading, accounting for >80% of NH_3 emissions forming secondary $PM_{2.5}$ particles, while in the southern hemisphere, biomass burning is the predominant source of trace-gas emissions and PM2.5 concentrations.[224] Emissions from biomass burning (globally estimated to contribute 42 Tg yr^{-1} PM2.5),[225] that can be attributed agriculture are uncertain, although some estimates suggest that 28% of the global direct PM2.5 emissions are food related (**Table A2.1**). Regionally, shares can be higher, particularly in countries in the southern hemisphere (i.e. biomass burning contributes 90% to PM2.5 in Angola).[224]

Remaining within aerosol boundaries requires emission reductions in both the northern and southern hemisphere. The boundary for nitrogen surplus (**Section Biogeochemical Flows**) suggests a reduction of NH_3 emissions (>45% reduction of current emissions, from 37 to 20 Tg N yr^{-1}) is required, mostly in the northern hemisphere where N surplus (and associated NH_3 emissions from manure and fertilizer[167]) is high (**Figure 4c**). Dietary shifts can reduce agricultural NH_3 emissions with more than 50% in North America and Europe.[226] In the southern hemisphere, biomass burning from land conversion and on agricultural lands should be eliminated in line with the Land System change and Climate change boundaries. However, it is uncertain how much reduced NH_3 emissions and biomass burning can bring back total PM2.5 concentrations across hemispheres.[159]

Ocean Acidification

Ocean acidification is linked to loss of marine species dependent on calcium carbonate, and changes to marine carbon storage. Acidification also aggravates impact of other biogeochemical changes (e.g. ocean warming and associated thermal heat stress) and therefore is considered a threat multiplier to marine life.[228] Ocean acidification, measured through the change in the aragonite saturation state (Ω_{arag}),[158] is driven by atmospheric CO_2 concentration (i.e. 25% of historical anthropogenic CO_2 emissions are absorbed by the ocean[229]) and is therefore strongly related to the climate boundary. Although the ocean acidification planetary boundary is not transgressed (**Table 2**),[158] it is moving rapidly into the zone of increasing risk following relatively constant CO_2 emissions (total of 40.6 $GtCO_2$ yr^{-1} [illegible] of which food systems are responsible for nearly 25%.[159,172] Remaining with the food system boundary for climate change and biosphere integrity can effectively bring back CO_2 emissions close to zero and allows us to remain within ocean acidification boundary.

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Stratospheric ozone depletion

The planetary boundary for stratospheric ozone depletion limits the breakdown of ozone that protects life on Earth from harmful solar radiation. Coordinated global intervention phasing out production of ozone-depleting chlorofluorocarbons and halons (i.e. through the Montreal Protocol adoption in 1987) has restored the ozone layer.[158] However, the most important ozone-depleting substance remaining is N_2O, which is not regulated under the Montreal Protocol. Agriculture is the largest emitter of anthropogenic N_2O (54–69% of total N_2O emissions),[230] but ozone depletion rates remain insignificant. Even without reductions in N_2O emissions, stratospheric ozone levels are expected to recover by the end of this century.[167] We therefore restate the nitrogen surplus boundary that respects local boundaries for biodiversity and water quality (**Section Nitrogen and Phosphorus losses)**, and thereby reduces N_2O emissions from reduced fertilizer and manure applications with 55% compared to current levels (from 3.9 to 1.8 Tg N yr^{-1}).[159,167]

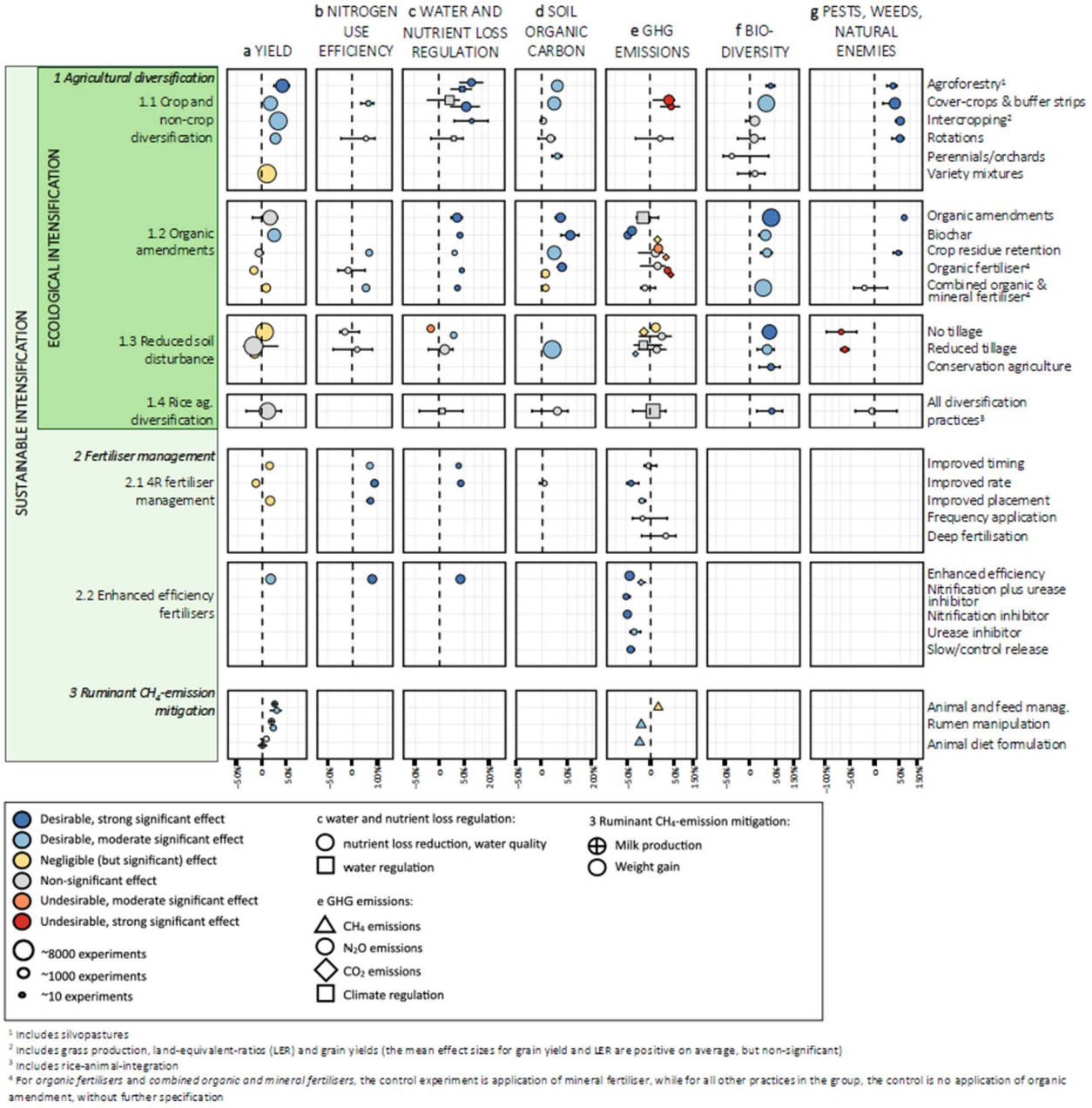
Reducing the environmental footprint of food production

Sustainable and ecological intensification (SEI) practices offer considerable potential to mitigate planetary boundary transgressions without negatively affecting yields (**Figure 5**). Importantly, many practices offer simultaneous benefits across several boundaries. Soil organic carbon (SOC) accumulation can be enhanced with agricultural diversification practices that promote plant root-formation, microbial activity, and the return of organic matter to soils, thereby reducing HANPP, while uncertainties remain regarding the permanence of soil carbon pools which challenge estimates of this potential.[231,232] Agricultural diversification increases agroecosystem biodiversity, which can be specifically managed to assist in weed and pest abatement, or to reduce the prevalence of crop diseases and nutrient losses while maintaining or improving yields. Improved fertiliser management enhances crop NUE, reduces nutrient losses, and contributes to SOC, although with higher variability for GHG emissions and yields.

The effects of the practices (**Figure 5)** are not directly additive, since they were typically obtained from studies comparing a single practice against a controlled alternative. Practice effects vary depending on context-specific, biophysical factors such as climatic and soil conditions, as well as the exact implementation of the practice. Working farms typically implement multiple practices simultaneously, and the evidence to date suggests synergies leading to enhanced environmental, as well as social, benefits.[233] While the meta-analyses provide valuable information on the technical potential at the field-scale, estimates of the global potential of selected SEI practice groups have also been explored in modelling studies such as, but not limited to those mentioned in Panels 5-7. These modelling studies, using different methodologies, factor in additional constrains and moderators, such as our current understanding of applicable areas. When applied to all suitable areas globally and assuming maximum complementarity among measures, sets of SEI practices were found to provide a potential increase in nitrogen use efficiency, from its average of 48%, to 78%,[208] and a global carbon sequestration potential between 0.44 and 0.68 Gt C yr^{-1}. When limitations of application as well as current application levels were factored in, the carbon sequestration potential was estimated to be 0.28 to 0.43 Gt C yr^{-1},[175] while the GHG mitigation potential of 4.4 Pg CO_2e on average, was estimated to occur by 2050.[234] Despite these

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limitations, our synthesis shows substantial evidence that the evaluated, key groups of SEI practices can contribute to maintaining or improving yields while mitigating planetary boundary transgressions, based on the indicators considered (**Figure 5; Table A2.5, Appendix 2B**). The potential global benefits of accelerating adoption of ecologically intensive practices on cropland vary across boundaries, but in combination with other food system practices enable significant impacts notably on climate and biosphere integrity boundaries (**Panel 6**).



[1] Includes silvopastures
[2] Includes grass production, land-equivalent-ratios (LER) and grain yields (the mean effect sizes for grain yield and LER are positive on average, but non-significant)
[3] Includes rice-animal-integration
[4] For *organic fertilisers* and *combined organic and mineral fertilisers*, the control experiment is application of mineral fertiliser, while for all other practices in the group, the control is no application of organic amendment, without further specification

Figure 5: Sustainable and ecological intensification (SEI) practices' relative contributions across field scale planetary boundary indicators (see Table A2.5, Appendix 2B), measured in percentage changes.[208,235–241] Rows indicate practices (e.g. no tillage), organised into principles (e.g. reduced disturbance), and further into groups (e.g. agricultural diversification). The effect sizes represent the mean relative change when a practice is applied, in comparison to a conventional alternative, or absence of applying the practice. Positive effect sizes are desirable for

all indicators except greenhouse gas emissions (column e), where the desired effect is a reduction and hence negative. Sizes of the symbols represent the amount of experimental data used for calculating the effect size, as indicated in the legend. The error bars show the 95% confidence intervals (CI) for the mean effect sizes. When the CIs do not overlap with zero (dashed vertical line), the effect is considered statistically significant. Missing values indicate no evidence found. The horizontal axis, where the grid cell width corresponds to a 50% pts, is square-root-transformed. The data used for the figure is provided in **Data S1**. See also **Appendix 2B** for details on the planetary boundary indicators (**Table A2.6**) and the practice typology (**Table A2.6**).

Integrating livestock in food production systems, when respecting local environmental capacities, such as nutrient loads and grazing intensities, can represent an SEI strategy that supports ecological processes in agricultural ecosystems (**Panel 8**).[242] Livestock can play an integral role in the food web, such as nutrient and energy cycling, as well as promoting biodiversity. Animals and crop production practices can be interlinked via feed production, for both terrestrial livestock and farmed fish, with synergies to be gained through e.g. cover-crop grazing,[243] forage rotations, or integrating animals for weed or pest management.[244] While grazing can increase SOC of grasslands, the evidence is variable,[237] but shows that grazing intensity has a significant effect, with less intensive systems enhancing SOC.[245] Some of the practices assessed here (**Figure 5**) include livestock-integration, namely silvopastoral systems, using manure as organic amendments, and rice-animal co-cultures.

A comprehensive assessment of foods from aquatic systems is provided by the Blue Foods Assessment.[246] For wild fisheries, improved yields and environmental performance can be achieved by fishing within ecological limits, informed by scientific advice[247,248] and using production methods that limit indirect impacts to ecosystems (e.g. habitat destruction and bycatch,[249] including co-management of marine areas with local communities.[250,251] In aquaculture, most environmental impacts are driven by feeds[252] that emit GHG and use cropland,[253] while aquatic farms impact local ecosystems through acidification, eutrophication, and disease risks for wild populations.[254,255] These impacts can be limited through SEI practices that improve nutrient cycling and feed efficiencies. For mariculture, integrated multitrophic systems such as those growing bivalves and seaweeds near fish farms can increase yields, capture carbon, and reduce nutrient pollution.[256] Targeted feed improvements through continued reductions in wild fish use,[255] improved by-product utilisation,[257] and higher conversion efficiencies of plant ingredients, can further help improve environmental performance of 'fed' aquatic foods.[258]

Panel 5: Conservation Agriculture, a combination of sustainable and ecological intensification practices with impact at scale

Conservation agriculture (CA) is a well-established[P50,P51] widely applicable and applied[P52] example of the complementarity of SEI practices, whereby reduced soil disturbance, continuous soil cover, and crop diversification form the basis of the system. In this integrated approach, reduced soil disturbance protects the soil from erosion and conserves moisture, continuous cover suppresses weeds, and crop diversification reduce pests and disease. Global models applying CA, which here consists solely of *no* tillage, crop residues on field, and non-leguminous cover crops, on all agricultural lands resulted, estimate there will be an overall decrease in nitrogen leaching (-22%), and an increase in root-zone soil moisture (+15%) and SOC (+2%) by 2050, when compared to a land-use scenario without CA (averaging over two Integrated Assessment Models and five Global Change Models; **Appendix 2B).** Importantly,

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other SEI practices can be combined with CA. When rainwater harvesting was combined with CA, global modelling results showed a minor added reduction (–2%) for nitrogen leaching and a small increase in root-zone soil moisture (+2%), but effectively no change for SOC. While field studies have shown that the exact outcomes of CA are context-specific, evidence shows that CA improves crop productivity, especially in dry climates and rainfed production systems, thus offering a climate-change adaptation strategy.[P53,P54] In resource-poor and vulnerable smallholder farming systems, socio-economic challenges in the appropriate adoption of CA need to be carefully considered.[P54]

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Panel 6: Initial estimates of environmental gains made through ecological intensification (EI) by the Food, Agriculture, Biodiversity, Land-use and Energy (FABLE) Calculator

The FABLE Calculator is a demand-driven food and land use system model designed to explore the food, biodiversity, climate, water, and socioeconomics impacts of future development pathways.[P55] It includes 88 agricultural products to model how demand for these products drives land use change and associated impacts on food and nutrition security, climate mitigation, biodiversity, and socio-economic outcomes.

The FABLE Calculator differentiates between types of agricultural practices used on cropland and can therefore be used to explore the impact of scaling ecological intensification practices. Here, ecological intensification (EI) represents crop and non-crop diversification, including intercropping, cover crops, crop rotations, agroforestry, cultivar mixtures, and embedding natural vegetation into cropped landscapes. We modelled the effect of continuing current trends (BAU pathway), compared to expanding EI practices across all cropland by 2050 in combination with the EAT-*Lancet* (EL) population growth, economic growth, climate change, diet, productivity, food loss and waste assumptions as described in the modelling section and **Table A.4.3** (EL+EI pathway). The EL pathway represents a decomposition scenario on the EL+EI pathway, where agricultural practices match BAU assumptions, allowing us to isolate the effects of EI. See **Appendix 2** for further methodological details.

	Land for Agriculture (Bha)	**Cropland Use (Mha)**	**Land Available for Biodiversity (%)**	**GHG Emission (GtCO2e)**	**Blue Water Use (M km3)**	**Nitrogen Use (Tg N)**	**Phosphorus Use (Tg P)**
Boundary (Current State)	***4.80 (4.56)***	***None (16.08)***	***50% (50%)***	***5.00 (6.76)***	***2 .00 (4.63)***	***134 (234)***	***12 (29.4)***
BAU	4.82	18.53	48%	7.35	5.37	306	35.9
EL	3.49	16.00	56%	2.75	4.52	214	35.4
EL+EI	3.46	15.69	56%	-0.51	4.41	211	34.4

Panel Table: Environmental impacts of food and land use systems projected to 2050 under three future scenarios representing Business as Usual (BAU), EAT-*Lancet* assumptions (EL) and the addition of ecological intensification practices to EL (EL+EI), compared to food system planetary boundaries (**Table 2**) and the current state (2020).

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Cells are coloured according to whether results fall inside our proposed food system planetary boundaries: within boundary (green), close to boundary (orange), beyond boundary (red).

FABLE model results show that under BAU, the food system boundaries for land, biodiversity, emissions, water and nutrient use are exceeded by 2050. Under an EL pathway, the food system stays within land, biodiversity, and emission boundaries. Increases in productivity, dietary shifts, and reduced food loss and waste, reduce the land area needed for agricultural production which in turn drives the expansion of natural land available for biodiversity. Annual net GHG emissions would fall from 7.35 Gt CO_{2e} in 2050 under BAU to 2.75 Gt CO_{2e} under EL (~60% reduction compared to 2020). This reduction in GHG emissions is greater than those suggested by the economic model ensemble (median 20%), or DIA-GIO (32%) (**Figure 10b**), which may be explained by differences in how emissions are computed across models. GHG emission reductions in the FABLE EL pathway are driven by a decrease in emissions from agricultural production for both crops and livestock, and increased carbon sequestration from avoided deforestation and restoration of abandoned agricultural land to forest and other natural land (with higher rates of carbon sequestration in living biomass and soil). Nitrogen use is reduced by 30% compared to BAU, while there are relatively small reductions in water consumption and phosphorus use, yet nutrient and water use continue to exceed food system boundaries.

Combining EL with ecological intensification (EL+EI pathway) further reduces agricultural land area, water and nitrogen use, and substantially reduces emissions to -0.51 Gt $CO_{2e.}$ Many of the EI practices that the FABLE Calculator are not used in many of the ensemble models. Emission reductions are driven by increased sequestration on croplands (in soil) and, to a lesser extent, additional conversion of agricultural land to other uses due to enhanced productivity for some commodities. The FABLE model results suggest that significant effort in integrating EI practices could contribute to achieving a net zero-emission food system. Estimates of the effect of the practices on soil organic carbon sequestration are taken from global meta-analyses, and do not account for regional or local soil carbon saturation limits,[P56] which mean the results should be interpreted with caution.

The most effective application of EI practices needs to be tailored to local contexts and should be co-selected with local farmers and landscape stakeholders, integrating local and scientific knowledge. The complexity of implementation at scale across multiple domains, and local carbon sequestration saturation points may limit both the speed of implementation, and duration of carbon sequestration potential of ecological intensification.

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Section 3: Justice in Food Systems

What is a Just Food System

Justice involves the 'fair treatment' of people, both individuals and groups. Although various articulations of justice exist across disciplines and sectors (e.g., Philosophy, Economics, Sociology, and Law), here we draw on three interrelated dimensions of justice that feature prominently in the literature on social and environmental justice: namely, Distributive, Representational (or Procedural), and Recognitional (**Figure 6**).[259,260] Distributive justice involves the fair distribution of important resources, opportunities, or capabilities (healthy food, wages, clean, healthy, and sustainable environment) as well as the fair allocation of benefits and burdens.[33] Representational justice concerns decision-making and power, including formal policymaking processes as well as broader societal decision-making processes.[259,261] It requires fair processes and a fair distribution of power, the protection of key freedoms, and political voice and representation, including meaningful participation by those most affected by injustice. Recognitional justice manifests in the structures and norms of society and recognises a diversity of intersecting identities and experiences, shaped by cultural, legal, historical and spatial contexts, and involves people from all social groups being able to participate as equals.[259,261,262]

Our analysis concerns how these three dimensions of justice play out both within and across societies. For a society to be just, all people must experience distributive, representational and recognitional justice, and for global and international justice this must also exist among nations and people throughout the world.[261,263] Our analysis also encompasses both justice among people living at the same time (intra-generational justice) and justice among people in different generations (inter-generational justice).[33] For example, intergenerational justice requires that there be distributive justice across generations, including a fair distribution of benefits and burdens between current and future generations of people. Keeping food systems within planetary boundaries can help to ensure that in the future, people have a safe environment, and ensuring healthy diets are accessible to all, particularly for women of childbearing age and young children, can help ensure the health of future generations. Justice of all these forms is central to our analysis and recommendations. Another form of justice, interspecies justice, concerns whether humans treat other species fairly.[33] However, beyond recognising the need to transition to within the planetary boundaries, including keeping the Earth within 1.5 degrees C of global warming, and the need to minimise biodiversity and environmental losses, we do not focus on interspecies justice in our justice analysis.

Establishing what counts as 'fair treatment' for an analysis of justice, requires consensus,[264] and in the absence of a global process relevant to food systems, we chose to align substantially our account of 'fair treatment' with international human rights treaties and other instruments (**Figure 6**).[265,266] These human rights instruments represent a consensus view of what constitutes minimum acceptable standards for specific resources (e.g., food) and opportunities (e.g., work).[265] We appeal to the content of recognized human rights to identify justice-based entitlements, and to specify, and quantify minimum acceptable levels (**Figure 7, Appendix 3, Table 3**). Our account of justice within food systems can thus be seen as the minimum conditions for what would constitute justice. Recognising that all human rights are universal,

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indivisible, interdependent, and interrelated, we focus on three rights closely related to food systems: the right to food, the right to a healthy environment, and the right to decent work. We also draw on international human rights' commitments to non-discrimination, participation, and civil and political rights. Central to our account is agency, understood as people's capacity to make choices that shape their own circumstances and to exercise voice through participation in broader societal decision-making processes. Agency is recognized as an important contributor to food security, secure livelihoods and to addressing inequities within food systems (Clapp et al., 2022) (**Appendix 3**).

Justice thus requires that everyone everywhere, regardless of social identity, has their rights to food, a healthy environment, and decent work realized, and has political voice and fair representation. Achieving justice therefore requires recognizing the social systems and other conditions that can promote justice, or, conversely, can function as structural barriers to it. These include political institutions and economic systems, and the interplay between them, resulting in different kinds of voice, power, and agency for government, businesses, formal and informal food producers and workers, civil society organizations, and the public; food, health, educational, and other social systems, which provide important resources and opportunities; and other social structures and norms. People are unevenly impacted by these social systems, with some groups systematically having fewer resources and opportunities, and less voice, power, and agency, thus experiencing structural inequality that leaves them vulnerable and marginalised (**Panel 7**) Achieving justice may require fundamental transformation of these political systems. However, here our focus is that justice requires paying particular attention to these people and addressing their specific needs.[262]

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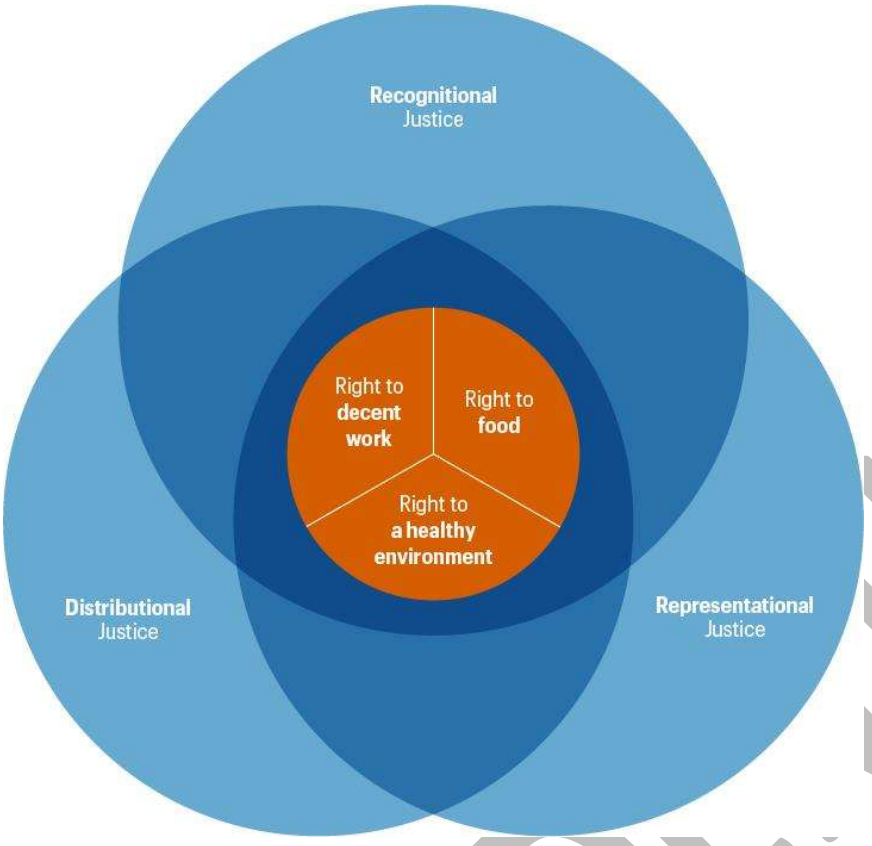


Figure 6. Conceptual framework of the justice section. The three justice dimensions and three human rights are interrelated and interdependent. Achieving the three justice dimensions of distributive, recognitional, and representational justice requires meeting the human rights.

Panel 7: Recognitional Injustices: The need for attention to gender and intersectionality
Different groups of people – women, men, and children – of different wealth and social groups, age and stage in the life cycle, of different ethnicities, and from different geographic locations have different livelihood opportunities and often have differential nutritional needs. They also have differing levels of choice in terms of how far they can access and afford healthy diets and decent work. Not paying attention to these group differences can lead to significant harm, not only for the individuals concerned, but for humanity more broadly by losing contextual knowledge and practices (e.g., Indigenous farming practices). Ethnic minorities and Indigenous peoples are often at the greatest risk of losing their livelihoods and access to healthy and culturally important food, processes that start with a loss of access to land or natural resources (e.g., forests) through unjust conservation or extraction policies (e.g., exclusion from management),[P57] or the lack of protection policies. Many of these marginalised groups, including women, and particularly women from minority groups, also face significant structural barriers and discrimination, rooted in colonialism, racism, and patriarchy leading to lower access to technology,

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training and underrepresentation in political and managerial positions,[P58,P59] making it difficult for them to build decent and resilient livelihoods.

People living in countries with conflict are especially marginalised in numerous ways. Hunger and starvation have often been used as political weapons of war, and continue to be used as such today, through intentional destruction of food systems, especially agricultural lands (e.g., Sudan, Ukraine and Palestine), withholding/restricting food aid (e.g., Yemen and Palestine), and unilateral coercive measures (e.g., Sudan, Venezuela and Syria). The impact of these conflicts spread across the whole food system, affecting the availability and price of food and other resources (e.g., fertilizer), regionally and globally, though particularly amongst the rural and those in poverty.[P60] Thus, conflicts and war lead to further marginalisation and directly or indirectly cause hunger, food insecurity, and famines undermining the right to food for all,[P61] with worse effects on people in poverty, minority groups, women, and children.

These characteristics are not exhaustive as marginalisation can manifest differently across and within regions/countries. Furthermore, the opportunities people have access to often differ based on the intersection of key characteristics, such as wealth or poverty with gender, geographic location, age, and ethnicity. For example, in middle-income countries (MIC) women tend to be more food-insecure than men (**Appendix 3, Figure A3.1**). Yet, women appear to have greater dietary quality than men, especially in higher income countries (**Appendix 3, Figure A3.1**). Meanwhile poverty is increasingly urbanising at a global scale, with the urban poor lacking access to healthy food, patterns that emerge in part due to a changing climate and the migration of the rural poor to urban areas.[P62]

An intersectional lens (i.e. paying attention to multiple injustices and aspects of identity that intersect to exacerbate the experience of marginalisation) is therefore key to identifying the specific vulnerabilities affecting marginalised people.[P63] This requires sufficient levels of data disaggregation across contexts, as well as recognition of alternative knowledge systems, especially Indigenous knowledge.[P64] Yet, data remains skewed towards particular social groups and geographic regions. For example, evidence from Canada and the US suggests that migrant workers face poor and dangerous working conditions and food insecurity, but literature on migrant workers in other regions, especially LMICs, is limited.[P65] Similarly, some geographies, such as the Middle East, are persistently underrepresented in English published literature.

Social Foundations

We operationalise our justice analysis through the lens of social foundations which require basic human rights, such as food, water, health, and energy, to be met for everyone.[267,268] Previous work has focused on defining the minimum resources required to meet people's human rights, to avoid resource deprivations and harms.[33,268] However, the availability of resources alone is insufficient to avoid these harms.[269] Therefore, we instead focus on the conditions that enable people's human rights to be met. We specify conditions (i.e., social foundations) that would help enable each of the three rights (food, decent work, healthy environment) to be realized (Table 3). Through a combination of expert consultation and a

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review of the literature, we first identify the individual and cross-cutting food system components relevant to each human right. Next, and drawing on the outcomes from a recently completed multi-stage, multi-stakeholder evaluation of food systems indicators,[29] we identify a suite of candidate indicators for each component and screen for coverage, scale, relevance, and overlap. Where indicators for key food system components were not available (e.g., individual and collective agency) we reviewed the literature to propose additional indicators for development and monitoring.[270] The final selection included a limited set of indicators that conveyed discrete dimensions of the conditions that enable people's rights to be met, rather than outcomes of these rights being (un)met, which act as our proxy variables. (**Appendix 3**). For each proxy variable, we specify the level at which the social foundation would be considered met, estimate the number of people falling below each social foundation globally, and examine the extent of harms associated with each of the three human rights not being realized (**Table 3, Figure A3**).

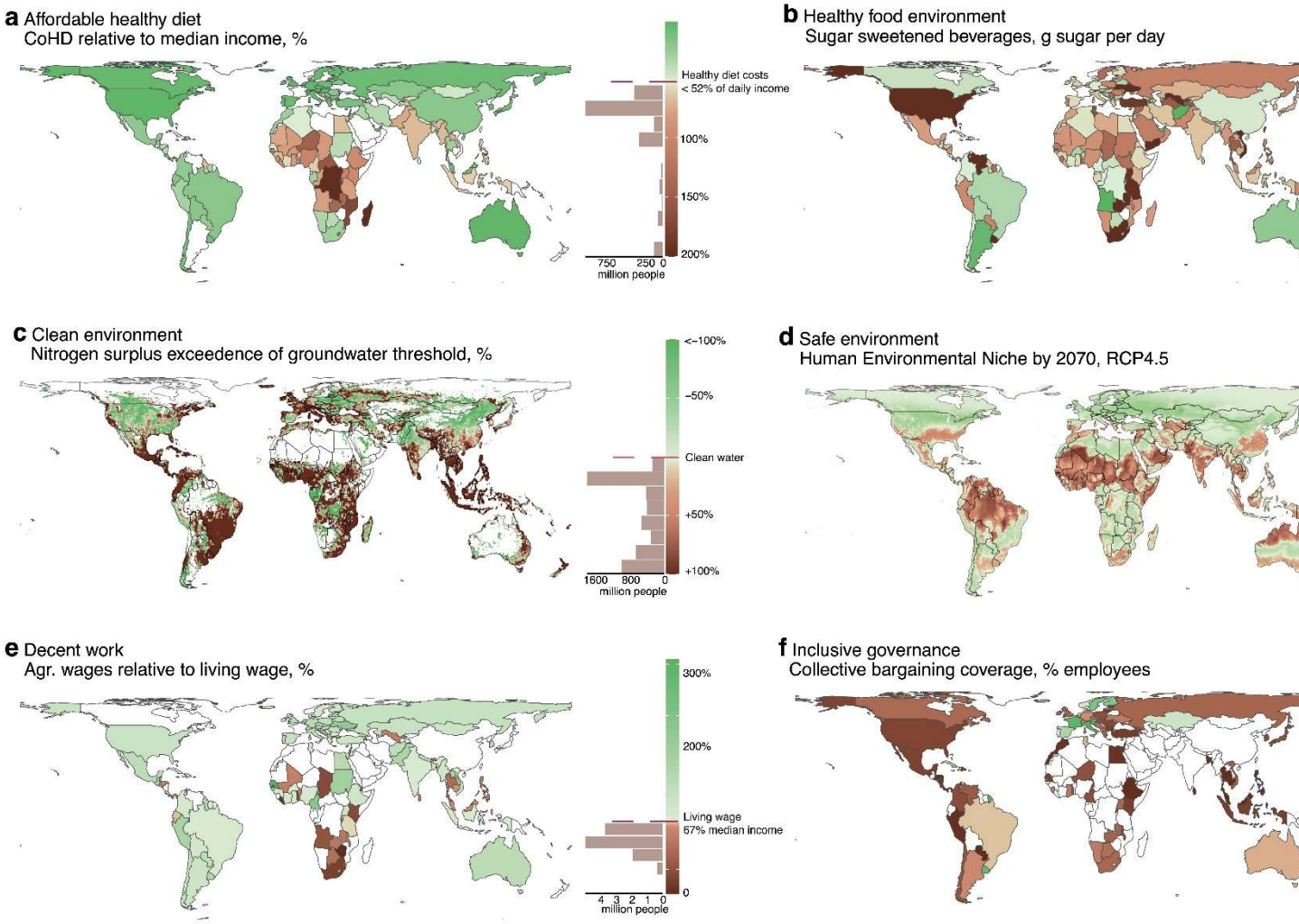


Figure 7a-f: The global status of social foundations in food systems. Each panel visualizes one of six (out of 8), proxy variables and its corresponding social foundation (**Table 3**). Maps show the global distribution of values, with places that fall below the social foundation in brown, and those where the social foundation is intact in green (white indicates no data available). Histograms on the colour legends indicate the total number of people that fall below

each social foundation. Variables are: a) cost of a healthy diet (CoHD) (foundation: healthy diet cost <52% of national average income); b) consumption of SSB (foundation: consumption added or free sugar <10% of total energy intake); c) nitrogen leaching into groundwater (foundation: exceedance of WHO safe limit for drinking water = 0); d) changes in the suitability of the human environmental niche, between current conditions and RCP8.5 in 2070 (foundation: heat exposure, ≤29C Mean Annual Temperature, MAT); e) agricultural wages relative to a living wage (foundation: wages > 67% or 55% of median incomes in each country); f) access to collective bargaining (foundation: Employees covered > 75% of workforce). Data sources and variable definitions are described in **Table 3**, **Appendix 3A, and Table A3.1**. Data were unavailable for countries in white, except for nitrogen exceedance (c), where white values indicate non-agricultural lands.

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Table 3: Human rights, social foundations, and the proxy variables that allow conditions to be tracked. For each variable we specify the level at which the social foundation could be met. Falling below these social foundations results in a range of specified harms. We estimate globally, the number of people currently falling below these social foundations and the extent of social harms.

Human Rights	Social foundation	Proxy variables	People below foundation	Social harms	Extent of harm	Harms Figures
Right to food	**Affordable Healthy Diets** (CoHD <52% average income)	Cost of Healthy Diet (CoHD)	2.8 billion people globally cannot afford a healthy diet	Moderate or severe food Insecurity Low Birthweight Unsafe drinking water Anaemia in children	2.3 billion people (29%)[1] 19.8 million newborns (15%)[1] 2.1 billion people (27%)[1] 269 million children[2] (40%)	Fig A3.1
	Healthy Food Environment (National intake of sugar from SSB at <10% of total energy intake)	Intake of Sugar Sweetened Beverages (SSB)	5.6 billion people globally live in countries with a national average intake of sugar >10% of total energy intake	Diets high in SSB Unhealthy diets Obesity	75,725 deaths 3.6 million DALYs >1billion people (16%)[1]	
Right to a healthy ~~e~~nvironment	**Non-toxic Environments** (N leaching < 50mg nitrate/L)	Nitrogen leaching from Agriculture	5 billion people exposed to unclean water above WHO limit	Disability adjusted life years (DALYs) from unsafe water source	42 million DALYs	Fig A3.2
	Safe Climate (Temp ≤29C, Mean Annual Temperature (MAT))	Mean Annual Temperature (MAT) change	419 million people will be exposed to ≥29C MAT by 2070	DALYs from high temperatures	14 million DALYs	
Right to decent work	**A Living Wage**[3] Food system worker (FSW) wages > living wage	FSW wages	394 million (32%) FSW earn below a living wage	Child labour	159 million children	Fig A3.3
	Meaningful representation (coverage >72%)	Collective bargaining coverage	2.6 billion people w/o access to collective bargaining	Gender wage gap	50%	
Cutting across all rights (Individual and Collective Agency)	**Freedom from corporate control** (CR4 <40%)	Market share held by the top four firms in the sector (CR4)	Not determined	Higher food prices, suppressed wages, weakened livelihood opportunities, undermining working conditions, lobbying, weakened representation	Clapp et al 2025	Fig A3.4
	Civil and political freedoms	Freedom of Expression Index				
	Non-Discrimination	Social institutions and Gender Index				

[1] Percentage of global population
[2] Children aged 6-59 months
[3] Living wage is defined as being > 67% median wage in developing countries and 55% in developed (ILO 2020)

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Evaluating Injustices

The Right to Food

The right to food involves the right to a secure and stable supply of sufficient quantities of affordable, healthy, culturally appropriate and sustainably produced food that considers peoples' practices and customs, to ensure all forms of malnutrition can be avoided, and a dignified life supported.[271,272] The right to food has been interpreted not only as a right to have access to sufficient food to enable a healthy diet but also as placing responsibilities on states to promote good nutrition and health, for example through regulating food advertising, labelling requirements and other measures that shape food environments to encourage healthier diets.[271,273] We thus identify two social foundations linked to the right to food, namely healthy affordable diets and food environments that do not undermine people's capacities to make healthy choices, which we refer to as "healthy food environments."

Healthy diets are considered, by the FAO, to be affordable when they cost less than 52% of average household income.[274] We therefore align our minimum condition/social foundation for affordable healthy diets with the FAO's definition of an affordable healthy diet (**Table 3**). In 2022, 2.8 billion people globally were below the social foundation of an affordable healthy diet. This causes diet-related harms that extend beyond their immediate impacts to damage economies and increase risk of conflict and disease. Indeed, in the same year 2.3 billion people were food insecure and 1.8 billion had no access to clean water- strongly linked conditions to poor food safety and nutrient absorption (**Table 3, Figure 7**).

The extent to which regions fall below these foundations, and the severity of the associated harms, differ across geography and social group (i.e., ethnicity, gender, and wealth). While the rapid globalisation of the food system through trade and subsidies has made more food available globally and brought food prices down, it has also suppressed wages and the prices producers receive, leaving healthy diets least affordable in Low-Income Countries (LIC) and Lower Middle-Income Countries (LMIC), where food insecurity, low-birth weights, and anaemia are also most prevalent (**Figure 7, Figure A3.1**). It is also these contexts where most food system workers live, leaving them often least able to afford a healthy diet.

Although justice requires that healthy food becomes more affordable and available, this will not necessarily result in healthier diets.[4,275] As economies develop and family incomes grow, healthy diets become more affordable but ultra-processed foods, animal-sourced red meats, and sugar sweetened beverages also become more available and exposure to unhealthy food advertising increases.[275–277] As a result, diet quality globally is lowest in Upper Middle-Income Countries (UMIC) and High-Income Countries (HIC), particularly among men, while rates of overweight and obesity are highest in these same regions, particularly among women (**Figure A3.1**). Furthermore, while healthy diets are more affordable in HIC, they remain unaffordable or inaccessible to many people, resulting in lower diet quality and higher obesity rates for those on low incomes.[278,279] In contrast, in UMIC such as places in Latin America, higher income groups, despite being food secure, have a poorer diet quality than low-income groups, likely due to the hyper-availability of unhealthy foods.[280] Rapidly changing food environments and unequal access to housing, water, health and market services mean LMIC and UMIC, particularly in urban and peri-urban

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areas, are now epicentres of multiple forms of malnutrition and associated outcomes (**Figure A3.1**).[4,281] These regions are also where most of the global population currently lives, and where most future population growth will occur, underscoring the critical global importance of healthy diets being available and affordable, in a food environment that is conducive to healthy choices.[25]

Food environments are the physical, economic, political, socio-cultural and digital contexts in which consumers engage with the food system to make decisions about acquiring, preparing and consuming food.[282] Food environments and food choices are increasingly shaped by advertising and commercial marketing, thus expenditure on marketing of unhealthy food would be an apt proxy variable for healthy food environments. However, global data on this exposure is lacking. As an alternative proxy indicator for an unhealthy food environment, we use intake of sugar from sugar sweetened beverages (SSB), which is associated with cardiometabolic disease and social inequities.[283] We align our *minimum condition* for a healthy food environment with the WHO's recommendation of less than 10% of total energy intake from free or added sugars (ideally reduced to less than 5%, as used in the PHD).[108] In 2018, 5.6 billion people globally, were below the minimum condition/social foundation of a healthy food environment, with their intake of free or added sugar exceeding this level. These patterns are associated with over 75,000 early deaths, 2.5 billion adults, and 360 million children and adolescents who are overweight or living with obesity **(Table 7, A3**).

Food environments determine food choices in a range of ways depending on context, and considering the affordability, availability, accessibility or convenience, and desirability of foods in the food environment, especially for healthy food versus unhealthy food.[284] Thus, while higher incomes can promote greater diet diversity, the type of food environment can weaken or strengthen this relationship.[284] In the face of rising corporate concentration and marketing of unhealthy food, territorial and local markets, with a focus on small-scale and informal actors, are seen to have the potential not just to revitalise and stabilise local production but also enhance healthy consumption choices for poor people.[281] This becomes critically important where rapid urbanisation is changing food environments in UMIC and LMIC, creating food voids (environments 'lacking in food'), food deserts (areas where sufficient *healthy* food is inaccessible)[282] and food swamps (areas where unhealthy, usually ultra-processed, foods[285] are abundantly available, accessible, and affordable),[282] earlier seen only in HIC (HLPE Report 19). In each of these cases, people are at higher risk of food insecurity, micronutrient deficiencies, overweight/obesity, and NCDs,[281,282,286,287] but for different reasons. Low diet quality could be due to lack of availability, accessibility, and/or affordability of healthy foods, or because unhealthy foods are abundantly available, affordable, and convenient.[282]

Changes in food environments have also accompanied changes in food cultures. The shift to unhealthy diets is characterised by a loss of traditional foods and food deskilling – a loss of cooking skills and knowledge.[275,288] Changes in food cultures can be explained by several factors. First, time poverty has increased especially for families due to greater women's participation (who largely remain in charge of food provisioning despite improvements in gender equality) in the labour force and generally low food involvement of fathers.[289,290] Second, the loss of local biodiversity, notably cultivated and foraged species, and resource access have impacted healthy food provision in some regions, especially amongst Indigenous communities.[291] Children are especially susceptible to unhealthy food advertising, leading to unhealthy

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food habits, which can persist to adulthood. Shifts to unhealthy diets can involve moving food culture away from traditional foods, including family meals. These changes have implications for diets and health, but equally for the acquisition of food knowledge and skills, especially for children.[293]

The Right to a Healthy Environment

The right to a healthy environment rests on the recognition that realizing the right to food and many other rights requires having a clean, healthy and sustainable environment. This right is understood as encompassing several substantive rights, including to a safe climate and non-toxic environment, which we adopt as two social foundations of this right.[294] Climate conditions habitable for humans have been broadly characterised as land with a mean annual temperature of ≤ 29 C°,[297,298] and we use this as our minimum condition for a safe climate. By 2070, 419 million people globally will fall below the social foundation of a safe climate, and already in 2022[33] high temperatures accounted for the loss of 14 million DALYs[6] (**Figure 7, Table 3, Figure A3.2**). Climate impacts are and will continue to be experienced inequitably, intersecting with poverty and geography to disproportionately impact certain peoples and regions. Despite being the least responsible, climate change will exacerbate experiences of food insecurity for many LICs across Africa and for people living in poverty.[299,300] Meanwhile, women, particularly in rural areas, LMICs and Indigenous communities, and agricultural producers and workers are more likely to have their livelihoods undermined by climate change, and experience physical injury and ill-health.[296,301–303] More generally, within food systems, women, children, Indigenous and rural communities, and those in poverty, because of their marginalization, are most impacted by unsafe and unhealthy environments,[295,296] underscoring the importance of human rights for all.

A wide range of food system pollutants exist that create toxic environments and have negative human health effects (**Panel 3**).[33] We focus on only nitrogen leaching to groundwater, 75% of which comes from agriculture,[33] due to data availability. Nitrogen pollution is connected to adverse reproductive effects, and cancer in humans.[33,167] WHO guidelines specify a safe level of nitrogen for drinking water as 50 mg NO_3^-/litre,[304] thus defining our minimum condition for healthy environments. In 2022, 5 billion people globally fell below this social foundation and were exposed to unsafe levels of nitrogen leaching, which was associated with the loss of 42 billion DALYs (**Figure 7, Table 3, Figure A3.2**) and 4 million new cases of paediatric cancer a year.[6,33,167,304] As with the right to food, these harms are not distributed equally with rural dwellers most likely to be affected by agricultural pollution[305,306] and with the poorest regions of the world particularly across Africa, South Asia, and China experiencing the greatest number of DALYs due to unsafe water, with as few as 10% of rural populations having access to clean water (**Figure A3.2**).

The Right to Decent Work

The right to decent work[15,307] entails the right of everyone to live in dignity,[13,307,308] to work in just and favourable conditions, to be free to choose their work with a salary that allows them to live and support a family, and to receive equal pay. We identify two social foundations linked to the right to decent work, namely a living wage and meaningful representation. A living wage conveys the minimum level of renumeration necessary to support an acceptable standard of living for the worker and their family.[307,308] Although not always put into effect, a legal minimum wage has been set in 90% of the 187 ILO countries.

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It equates to an average of 67% of the median wage in developing and 55% in developed nations,[13] which we use as the social foundation of a living wage. In 2022, an estimated 34% of the food system workforce, including agricultural (agriculture, forestry, fishing) and non-agricultural, formal and informal workers, was below the social foundation of a living wage, women earned 50% of what men did, and 159 million children were involved in child labour, predominantly in agriculture (**Table 3, Figure 7, Figure A3.3**).[309,310] However, trade-offs exist and policies must balance the competing need of ensuring healthy food is affordable while providing adequate and liveable renumerations (**Section 5**).

Women's work in agriculture remains undervalued and often seen as an extension of domestic chores.[311] Women are often paid by the piece instead of hourly rates like men, and their wages are sometimes given to male relatives, limiting their economic independence.[312] If gendered wage gaps in agricultural labour remain unaddressed, conditions will likely worsen because of the ongoing "feminisation of agriculture" in all regions other than HICs.[313] This is due to men leaving for non-farm work in sectors such as construction to obtain more stable and lucrative livelihoods, inflating the presence of women in a low-paid sector.[314] Furthermore, sexual harassment due to power imbalances between female farmworkers and employers remains pervasive (for example, studies have reported incidences of 24-93% in the US), with few opportunities for reporting due to stigma and risk of retaliation.[312] However, food system injustices are not limited to women as male migrant farm workers, for example in the US, also face abuse and exploitation.[312] Justice and the right to decent work require living wages for all food systems workers, regardless of gender and other forms of marginalisation.

Collective bargaining is one way to enable the meaningful representation of both workers and employers and ensure opportunities to regulate the conditions of work are present.[316] The right to collective bargaining is a fundamental ILO convention (No 98)[317] and an enabling right that paves the way for inclusive and effective governance of work, ensuring decent wages and working conditions, and social protection.[316] Collective bargaining coverage varies considerably around the world, but when present facilitates equality, contributes to safe and healthy work places, and builds resilience. We set our social foundation for meaningful participation at a collective bargaining coverage rate of 72% of employees, which although below the EU's threshold of 80%,[318] is equivalent to that found by the ILO in multi-employer settings, that tend to be more successful. Between 2008-2020, 2.6 billion people globally were below the social foundation of meaningful representation, with no access to collective bargaining (**Figure 7, Table 3**).[319]

Collective bargaining is highest in HICs, reaching close to 100% in some countries (e.g., Italy, France), but low in LMICs, where it ranges from 0%-40% and can be close to 1% (e.g., in Malaysia and Paraguay).[316] The majority (69%) of the approximately 1.02 billion people employed in food systems (**Figure A3.3**),[320] who support an estimated 3.8 billion people,[310] are found in LMICs (i.e., Asia or Africa). Most of these jobs are informal, seasonal, unregulated, and unmonitored, with workers living in poverty, reflecting the low levels of representation. Average agricultural wages are near or below national minimum wages (**Figure A3.3**),[13] leaving food system workers likely one of the groups least able to afford a healthy diet. Yet, in these contexts, agricultural livelihoods account for over 50% of employment (**Figure A3.3**) underscoring the considerable and cascading importance of meaningful representation for these workers.

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Despite generally high levels of collective bargaining in HIC, recent shifts in food systems towards more concentrated systems and specialized units of production (e.g., intensive production of a single crop or species with high technological inputs such as salmon or chicken) has undermined worker participation resulting in poor labour standards and animal welfare.[315] This is partly due to informal contracts being the norm among small and medium enterprises in LMICs and some HICs.[321,322] There is evidence that informal enterprises are highly organized and streamlined, yet the labour conditions can be exploitative, including exploitation of child labour.[323,324] Forced labour is prevalent on land and at sea, not only in LMICs but also in some HIC, including the US food supply chain.[325] Therefore, a just food system would include food systems workers (especially smallholders) earning a living wage, with access to collective bargaining and the ability to advocate for their rights and working conditions.

Individual and Collective Agency

Agency, people's capacity to make choices that shape their own circumstances and to participate in broader societal decision-making processes, has been recognized as an important contributor to food security and nutrition, secure livelihoods, decent work, healthy environments, and to addressing wider inequities within food systems. Meanwhile, ample evidence exists on how people's freedoms and agency are curtailed within current food systems.[296,326,327] We thus recognise individual and collective agency as not just important in themselves, but specific forms of agency are also, arguably, guaranteed by human rights. Human rights emphasise the importance of rightsholders participating in decisions that affect them, and human rights treaties and other instruments include many rights guaranteeing civil and political freedoms, and specific forms of choice or control for individuals and groups. Human rights is committed to eliminating discrimination. Taken together, these components of human rights embody a broad commitment to individual and collective agency. Recognising that it is not possible to fully quantify agency, and that it remains challenging to identify proxy variables that capture agency in this capacious sense, we propose three social foundations and related proxy variables that capture three facets of agency: non-discrimination, freedom from corporate control, and freedom of voice and expression.[270,328–330]

Non-Discrimination

People's agency – their capacity to make choices and participate in decision-making -- can be constrained by structural inequalities shaped by social position and identity, particularly class and gender. Ensuring that all people have agency thus requires addressing discrimination in all its forms, including inequalities in access to key resources and services, unjust power differentials between different groups and intentional discrimination. As a proxy variable for non-discrimination, we use the Social Institutions and Gender Index which measures discrimination against women, though this indicator is partial given the presence of discrimination against many distinct groups.

Discrimination against women is prevalent globally, although highest in South Asia, the Middle East & North Africa, and across many parts of sub-Saharan Africa **(Figure A3.4**). In no country in the world are women afforded the same opportunities as men that allow them equal representation in government or in the workforce more broadly, undermining their access to decent work and healthy food.[331] Agency is

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therefore about inequality and choice; what matters is the "*inequalities* in people's capacity to make choices rather than in *differences* in the choices themselves".[270,296,326–328]

Freedom from corporate control

Highly concentrated market structures, where just a few firms dominate key steps along food supply chains,[332] can signal power imbalances where dominant firms, due to weakened competition, can exercise market power that enables them to generate excess profits[14,333,334] The exercise of market power by large firms can in turn undermine the agency within food systems, especially for the most marginalized people. Most economists consider that the likelihood of firms exercising market power increases where the top four firms control over 40% of the market.[334] Although other metrics are also often used, due to data limitation we focus on CR4, for which data is more available, and specify 40% as our minimum social foundation for freedom from corporate control, CR4 above 40% would indicate people's agency is at risk of being curtailed and thus requires further investigation **(Table 3**).

Strong evidence has shown a very high degree of corporate concentration all along food supply chains, with just a few large firms dominating international markets for agricultural inputs (seeds and fertilisers), agricultural commodity trade (soybean, poultry), certain processed and packaged foods (biscuits, confectionary, soft drinks) and national markets for food retail.[14] Evidence suggests that access to market power is extensive in food systems, allowing dominant firms to set prices and generate excess profits.[14,17] Concentrated firms' capacity to raise prices for seeds, fertilizer, grain, or packaged foods, has an impact on people's access to food, influencing which foods they can and cannot consume. Dominant firms that source from smaller scale food producers have a degree of 'buyer power', meaning they can dictate the prices they are willing to pay to producers and other suppliers, such as workers, thus directly impacting suppliers' incomes and ability to access food.[17]

Large firms and concentrated commercial activity also shape broader conditions within food systems through business decisions. Corporate strategies to increase the level of processing of packaged convenience foods, for example, have widespread impacts on both food production and consumption environments, and can encourage people to eat less healthy foods because of limited product choices and manipulative advertising and packaging.[17,335] Business decisions of dominant firms have a disproportionate effect on agricultural production technologies, labour conditions for food systems workers, including in some cases forced labour,[336] and environmental practices,[337] which directly impact producers' and consumers' options. Large and dominant firms in concentrated markets can influence policy and governance processes in ways that influence democratic participation in food systems governance, which can directly undermine agency.[14] This influence is through direct lobbying as well as indirect means including sponsorship of research and revolving door appointments between industry and government, influencing measures such as dietary guidelines and regulations within food systems,[338,339] often crowding out citizen voices in the policy process.

Measuring the impact of corporate power on human agency in food systems is not straightforward, in large part because well-established metrics for agency do not exist,[330] and firms' market share data and other indicators like firms' marginal profits and markups (the amount firms charge over and above their

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costs) are not always publicly available. Corporate concentration (as measured by CR4) and profit data can usefully serve as proxy indicators to identify where corporate power may exist within food systems. However, food systems market data, at both global and national scales is often unavailable or behind prohibitive paywalls presenting challenges for assessment of these dynamics. We therefore underscore the need for companies to make profit and markup data available, enabling the tracking of an indicator of market power.

Although this approach would benefit from more transparent data reporting from firms, these indicators highlight markets where dominant firms are more likely to influence food systems in ways that can constrain people's agency. Stronger policies are needed at the national and international levels to prevent corporate concentration from subverting agency through market and other forms of power available to large and dominant firms. More robust competition policies, for example, can help in preventing excessive market power and ensure prices remain fair for both buyers and sellers.[17,340]

Freedom of expression and participation in decision-making

We focus on freedom of expression as an important facet of individual and collective agency, because it allows citizens and governments to be better informed, enables civil society to hold corporations to account, and helps to sustain a range of other human rights[16] However, in many parts of the world, most notably in parts of the Middle East, North Africa, Eastern Europe, and Asia, freedom of expression is significantly curtailed, which in turn undermines agency (**Figure A3.4).** Although indicators can never fully capture complex concepts, as policies and laws are mediated by social context, the V-Dem freedom of expression index captures the extent to which a government respects freedom of press and media, freedom of people to discuss political matters at home or in public, as well as the freedom of academic and cultural expression. Countries with laws upholding the freedom of expression, may curtail freedom in practice and vice versa, we nevertheless draw on this as a preliminary indicator in the absence of more nuanced data.

When people have agency to participate in food systems governance and decision-making in meaningful ways, they can shape their food systems to make them more just. Multiple possibilities for civil society and citizen engagement exist in democracies, including on matters related to food systems, such as elections, public debates, and consultations on keys laws and policies.[4] However, where these opportunities to engage are lacking due to discrimination, exclusion or in many cases, lack of freedom of expression (table 3), people are more likely to be marginalised and exposed to harm, and may take action through protests or other forms of movements.[15]

With the growing concentration of power - financial, technological, economic, and political – across many food systems, citizen agency is increasingly claimed or manifested through diverse forms of food activism. These forms of food activism span rights-based movements for justice, reactive street protests, alternative food systems governance structures, initiatives safeguarding the quality and cultural significance of food, and other modes of individual and collective advocacy.[341] Movements for food justice and protests often involve marginalised groups – farmers, women, Indigenous and rural peoples – and are motivated by concerns about food and nutrition security, prices and affordability, and livelihoods, and seek the

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implementation of the basic right to food. At times however, as in Europe more recently, farmers' protests, though challenging the growing concentration of power within the food system, may go against more ambitious state policies to address climate change or food systems transformations.[342] Nevertheless citizens' freedom of expression and other aspects of agency remain central to addressing structural inequalities and discrimination within the food system.[341,343]

The nature of state response to citizen agency varies, ranging from neglect or repression to concessions and even policy change, and widespread citizen consultation in processes of decision-making cannot be taken for granted.[341] States appear responsive to movements for food justice, often to avoid political conflict or public critique, though at times also driven by the global push for sustainability.[342] Different forms of citizen agency and their associated state responses give voice to diverse groups of stakeholders affected by food system changes and are key to representational justice.[341]

In sum, agency is a social foundation for the rights to food, decent work and a healthy environment, and is independently important from a justice perspective. Freedom of expression and other civil and political freedoms support agency within food systems, while corporate concentration and discrimination undermine it. When people lack agency, they may assert it with protests and other forms of activism. For all these reasons, it is important to try and characterize, quantify and track agency.

A Safe and Just Space

A just transformation should look to keep everyone within a safe and just space, below the boundary that provides planetary stability, and above the foundation that supports justice (shown in green in **Figure 8**). However, the social harms associated with falling below the social foundations defined here are not evenly distributed, leaving far too many people with unmet human rights (to the left of the dashed vertical line in **Figure 8**). Meanwhile, people are not equally responsible for the extent to which the food system boundaries are already transgressed; far too many people's dietary habits, if adopted globally, would cause the global food system to exceed the planetary boundaries (e.g. dietary patterns of countries that lie above the dashed horizontal line in **Figure 8**). Moving the global population to a safe and just space requires everyone to take reasonable responsibility for keeping the food systems within planetary boundaries, by minimising the pressures they exert on the planet and supporting efforts to ensure the benefits from food systems are distributed fairly and everyone's human rights are met (**Figure 8**).

Decisions regarding what constitutes 'reasonable responsibility' for keeping the food systems within planetary boundaries involve considerations of fair allocation. These decisions should be reached through deliberative processes that take current capabilities and past responsibilities into account, including where lasting legacies (e.g. colonial histories) continue to produce unjust outcomes for many marginalised communities. These processes can draw on existing principles and mechanisms that support equitable burden-sharing in international processes and negotiations (e.g. climate change and trade), such as common but differentiated responsibilities and differentiated capabilities.[344]

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Here, we apply the simplest principle as a starting point, which assumes an equal share of the planetary boundaries but makes no accommodation for differentiated capabilities or needs (e.g. more efficient technologies).[344] For each country, and for five planetary boundaries where combined data is available (GHG emissions, land use, water use, nitrogen, phosphorus), we calculate if and how the food systems share of the planetary boundary values would be exceeded if the dietary consumption patterns of that one nation were to be adopted globally. We contrasted this with estimates of a country's distance from three social foundations, which had the most comprehensive data (diet affordability, agricultural wages, and nitrogen leaching) (Appendix 3). We used Kobe plots to visualize associations between the social foundations and planetary boundaries.

On average 3.7 billion people, predominantly in low-income and lower-middle countries in Sub Saharan Africa and South Asia do not benefit from the social foundations (countries whose foundation <100). In these contexts, key barriers limit citizens abilities to meet their human rights. At the same time, 6.9 billion people, from all income groupings, lie above the planetary boundaries (countries with average boundary >100%) (**Figure 8**). These are countries whose dietary patterns, if adopted globally, would transgress all planetary boundaries. Therefore, policies that look to secure social foundations, must simultaneously ensure that changes to dietary patterns will not put disproportionate pressure on planetary boundaries. Meanwhile only 115 million people are currently in the safe and just space. Efforts to support justice have not succeeded in protecting the planet, and conversely conditions that support a safe planet, do not necessarily guarantee justice. Policies are therefore needed to simultaneously protect the planet and address justice, because currently, almost every country in the world is outside (or on the edge) of the Safe and Just corridor, with places least responsible for destabilising the planet falling the furthest below the social foundations. Similarly, those furthest above the planetary boundaries tend also to be the wealthiest, with the diets of the top third of the global population, from High-Income and Upper Middle-income nations, amounting to over 70% of the food system share of the planetary pressure.

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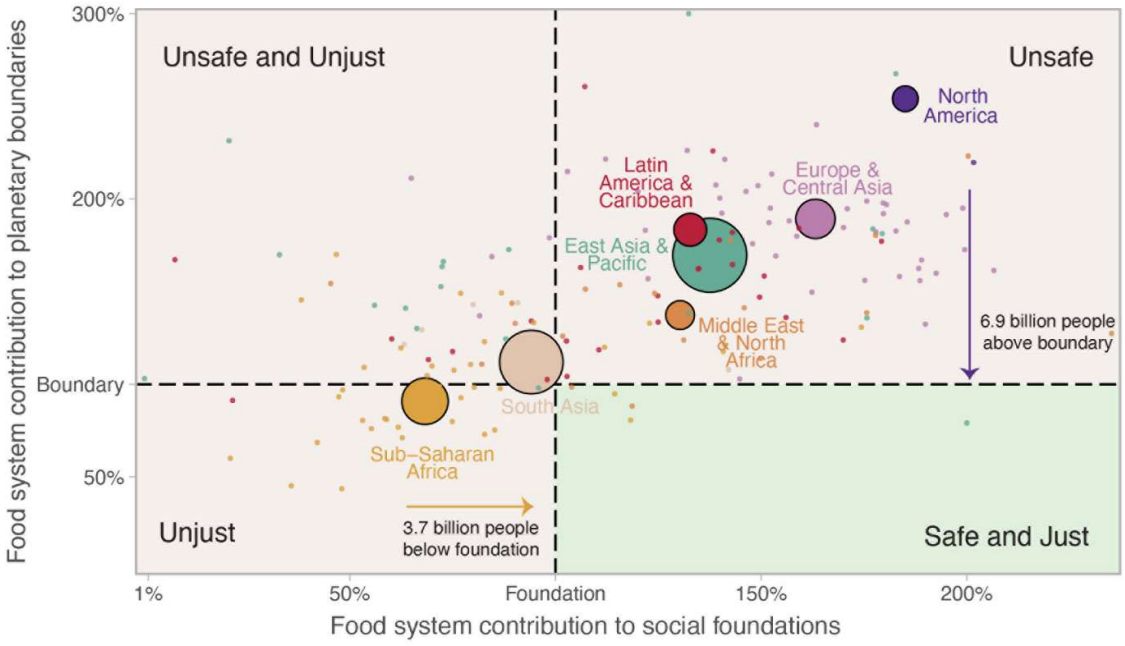


Figure 8: Global population distribution among planetary boundaries and social foundations. Kobe plot contrasts each country's food system contribution to five planetary boundaries (y-axis, average % for GHG emissions, land, nitrogen, phosphorus, and water, where 100% is the boundary) by their status of three social foundations (x-axis, average status for diet affordability, agricultural wages, and nitrogen exceedance to groundwater, where 0% is the foundation). Large circles are regional averages, sized by total population. We estimated the total number of people in countries that fell below social foundations (3.7 billion people) or transgressed planetary boundaries (6.9 billion people). Countries above social foundations and below planetary boundaries would be in the Safe and Just corridor. Kobe plots comparing each social foundation and planetary boundary are shown in **Figure A3.4**. Each country's social foundations status was normalized to have each social foundation = 100%, where countries would fall below (<100%) or above (>100%) the foundation. Values above the foundation were capped at a maximum of 300%.

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Section 4: Assessing potential environmental and socioeconomic consequences of a food systems transformation

Exploring what food systems that are more aligned with health, environmental, and justice objectives could look like, requires assessing the potential consequences of how food systems would be restructured by dietary change, increased productivity, and reduced food loss and waste (FLW). We use two complementary modelling approaches for that purpose.

First, we assembled a multi-model ensemble of ten global economic models used in high-level assessments of climate change, land use and food security[345–350] and involved in the Agricultural Model Intercomparison and Improvement Project (AgMIP).[350–352] The ensemble of economic models includes a mix of partial equilibrium models (agricultural sector only), with more detailed biophysical and sectoral representation, and general equilibrium models (whole of economy), which can simulate interactions across non-agricultural sectors (e.g., energy). All simulate important system dynamics that would drive changes across a transforming food system, including, for example, the ability of producers to substitute inputs based on their availability and cost.

Second, we used DIA-GIO (the Global Input-Output module of the Dietary Impact Assessment model), an updated version of the static input-output food model developed for the 2019 EAT-*Lancet* Commission (See modelling description in **Appendix 4** for summary of updates).[194] This was done to improve comparability with the modelling methodology used by the 2019 Commission, and recognizing there is uncertainty to the capacity of economic systems to adapt to rapid large-scale changes. Delays to a food systems transformation, for example, would constrain the scope of food systems to adapt, limiting the possibility to efficiently reallocate resources across alternate uses such as energy or fibre production. Therefore, we used DIA-GIO as an accounting tool to scope the biophysical option space based on the current and projected supply, demand, and trade relationships, but without the effects of economic feedback. This allowed us to consider potential implications of a food system with constrained capacity for, or dedicated policies (e.g., on land-use changes) that would regulate, resource reallocation.

There is substantial uncertainty in how food systems would transform, and using a range of models and modelling approaches allows us to engage with this uncertainty, which we will do by reporting ensemble median, and where appropriate the full ensemble range (i.e., min to max) as well as comparing to DIA-GIO. See supplementary materials (**Appendix 4**) for more detailed documentation on models, and modelling approaches applied in this analysis.

Defining alternative future food systems

In addition to updating and extending the modelling suite, this analysis has updated the scenario framework used to assess global and regional changes across food systems. We constructed three core scenarios described below (**Table A4.3**).

The business-as-usual scenario (BAU) projects how food systems could look by 2050 assuming a continuation of current trends and policies. This scenario assumes population and economic growth based on the “Middle-of-the-Road" scenario (SSP2) of the Shared Socioeconomic Pathways, a scenario

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framework designed for the IPCC to model the consequences of climate change in the 21st century.[353–356] This scenario projects global population and GDP to grow by 23% to 9.6 billion people and 127% to 282 trillion US$ between 2020 and 2050 respectively (**Figure A4.2**, **Table A4.9**).[357–359] To simulate the consequences of climate change in the BAU, we applied a representative concentration pathway (RCP 7.0) which assumes limited mitigation efforts and temperature increases of around 2°C by 2050. The biophysical consequences of this future climate were represented using published estimated changes in crop yields,[360] livestock yields,[361] and agricultural labour productivity.[362] Following model parameterization in the 2019 Commission,[1,194] DIA-GIO BAU projections to 2050 were informed by projections from IMPACT[363], one of the participating global economic models.

The EL scenario (EAT-*Lancet* style food systems transformation) starting in 2020 deviates from BAU along three key dimensions. In EL, we assume that by 2050: (1) Healthy diets (**Table 1**) are adopted by all; (2) a 7-10 percent increase on top of global BAU agricultural productivity based on projections quantified as a part of previous model intercomparisons[350,364] for SSP1,[350,364] a more sustainable shared-socioeconomic pathway (**Table A4.10**); and (3) a halving of BAU food loss and waste (FLW), consistent with SDG 12.3. Finally, an additional scenario, ELM (EAT-*Lancet* Mitigation) combines EL with ambitious mitigation. [347,350] Ambitious mitigation was based on previous modelling efforts to assess determinants of land-use across SSP projections[350] and land-use policies and decarbonization pathways to achieve 1.5°C warming by the end of the century.[347,350] Ambitious mitigation includes a range of policies (emissions pricing and land-use regulations), which define market conditions that determine the mix of technologies and practices (e.g., afforestation, renewables, and bioenergy) adopted to maintain carbon budgets. Each economic model has somewhat different capacity to model decarbonization pathways, see Table A4.17 for a summary of each model's implementation of mitigation. This scenario was run recognising that a transition towards more sustainable food systems cannot be achieved without a wider societal transition towards greater sustainability. This scenario also allowed us to assess potential synergies and trade-offs between a food systems transformation and ambitious economy-wide mitigation efforts, particularly through potential competition for land-use. While mitigation efforts would be expected to reduce climate impacts by end-of-century, we keep BAU climate impacts (RCP 7.0) in ELM, recognising the uncertainty of these efforts translating to reductions in climate impacts by 2050.

We emphasise that these scenarios aim to explore end points of a food systems transformation, and do not explore possible pathways that could lead to these outcomes by 2050. Assessing the implication of these endpoints is an important first step in understanding the potential benefits and costs of the changes simulated in these scenarios. Future work is needed to explore the pathways of change under varying assumptions of global development.

Comparing alternative food systems projections across modelling approaches

Across the model ensemble, the BAU scenario, compared to 2020, shows a 37% increase in global agricultural production by 2050 (**Figure 9a**). Livestock production increases by around 33% and crops by 37%. All regions see increased overall agricultural production from 2020, with the largest increases in Sub-Saharan Africa (around 100%) and the smallest increases in China (11% for ensemble, 18% for DIA-GIO) and Europe (18% for ensemble, 16% for DIA-GIO) (**Figure 9b**).

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Model results suggest that by 2050, the combined effects in an EL scenario could result in total agricultural production (AGR) near 2020 levels, but with important changes to the composition of production (**Figure 9c**). Compared to 2020, livestock production declines by 22% (27% for DIA-GIO). Driven primarily by reductions in demand for crop production for animal feed which would decline substantially from BAU 2050 levels. While the models agree on the direction of change (i.e., declining crop production compared to BAU) there is less agreement on the magnitude of this reduction, with some models suggesting 2050 crop production would remain above 2020 levels, whereas others suggesting it could fall slightly below 2020 levels.

A sectoral analysis demonstrates that the largest declines are in ruminant (RUM) production (cattle, goats, sheep) with a 55% (75% for DIA-GIO) reduction compared to BAU 2050 levels, or a 33% (63% for DIA-GIO) decline on 2020 levels across the ensemble (**Figure 9c, Figure A4.3**). This is accompanied by a decline in global ruminant animal numbers of 26% (result reported by IMPACT and GLOBIOM). Non-ruminant production saw a smaller decline of 24% (-46% in DIA-GIO), with larger declines for pork (-48% based on three ensemble models reporting, -83% in DIA-GIO) than poultry (-14% for both DIA-GIO and the mean of two reporting ensemble models) production (**Figure A4.4**). The economic models generally show smaller declines in production compared to DIA-GIO, as other sectors (e.g., for pet food, bone meal) increase their demand for animal sourced foods (See **Figure A4.10** for changes in food, feed, and other demand). EL demand for animal feed declines (-3%) from around 2.5 billion tonnes in 2020 to 2.4 billion tonnes by 2050. This compares to a 39% increase in feed production to around 3.5 billion tonnes in BAU.

There is less ensemble model agreement on changes in cereals, but the median results show modest production declines in rice (-13%), wheat (-4%), and coarse grains (all other grains) (-3%). Sugar crop production also shows absolute declines (-7% for ensemble, -30% for DIA-GIO) on 2020 levels in EL.

The modelling approaches differ in the projections of vegetables, fruits, nuts and seeds, legumes, roots and tubers, primarily due to different commodity aggregations methods (VFN in **Figure 9**). When we disaggregate the food group, we see much greater agreement between the ensemble and DIA-GIO, with vegetable production increasing by 42% (48% for DIA-GIO), fruit by 61% (36% for DIA-GIO), nuts by 172% (155% for DIA-GIO), legumes by 187% (56% for DIA-GIO), with roots and tubers declining by 9% (-42% for DIA-GIO). Differences in legumes can be attributed to ensemble models reporting soybeans (accounting for the bulk of legume production) as oilseeds (OSD) rather than legumes, highlighting differences in how different disciplines (i.e., nutrition vs production) analyse food production and consumption. When we combine OSD and legumes across the ensemble the median production by 2050 for EL is 1.07 billion tonnes compared to 1.08 billion for DIA-GIO.

Considering the impacts of individual drivers, if we only include improved productivity the median projection for production across the ensemble is similar to BAU (38% vs 37% for BAU), but the range of model projections is somewhat higher (31%-53% min-max vs 25%-41% in BAU) (**Figure A4.5**). The use of global economic models highlights that, in isolation (and without dedicated policies), efficiency gains may not translate to lower overall production and may even increase it. Reducing FLW or dietary change in isolation leads to a smaller increase in production of 29% (17% for DIA-GIO) and 15% (18% for DIA-GIO) respectively compared to 2020 (**Figure A4.5**). Reduced FLW achieves this by shrinking the gap between what is consumed and what is purchased, signalling a need for less production to meet

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demand, whereas a shift to healthy diets would avoid overconsumption and reduce the demand for more resource intensive animal sourced foods and animal feed.

ELM shows larger declines in production compared to EL across livestock sectors, with RUM, NRM, and DRY declining by 37, 35, and 15 percent compared to 33, 24, and 7 percent respectively. These larger declines are the consequence of increased production costs from the pricing of emissions. On the other hand, ELM has slightly larger increases across crop production, due to increased demand for crops from a growing bioeconomy (e.g., biofuels, biomass, bioplastics) to facilitate a transition away from fossil fuels (**Figure 9e, Figure A4.10**).

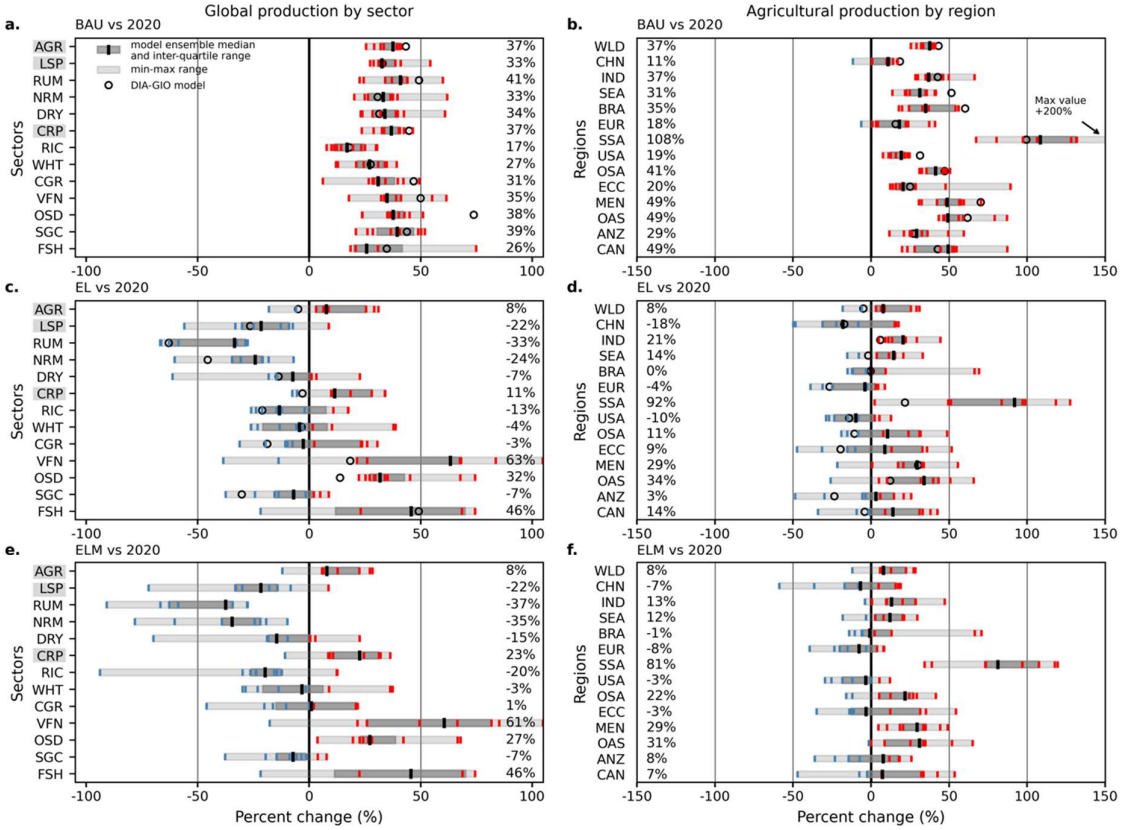


Figure 9: Projecting 2050 agricultural production by sector and region. a. global production by sector for BAU vs 2020. **b.** agricultural production by region for BAU vs 2020. **c.** global production by sector for EL vs 2020. **d.** agricultural production by region for EL vs 2020. **e.** global production by sector for ELM vs 2020. **f.** agricultural production by region for ELM vs 2020. All scenario results are reported as the percent change between 2050 and 2020. Individual model results in the ensemble are given by vertical lines within the grey shaded range of results (dark grey = inter-quartile range, light grey = min-max range). Black vertical lines indicate median values which are also expressed numerically in each figure. Results are coloured blue for a percentage decrease and red for a percentage increase. The DIA-GIO model results are given by the unfilled black circle and only include BAU and EL scenarios. Sectors are grouped by crop and livestock commodities. Sectors: AGR = all agricultural products (excluding FSH), LSP = all livestock products (excluding FSH), RUM = ruminant meat, NRM = nonruminant meat (poultry, pork, eggs), DRY = dairy, CRP = all crops, RIC = rice, WHT = wheat, CGR = coarse grains, VFN = vegetables, fruits, and nuts (and legumes, roots and tubers), OSD = oilseeds, SGC = sugar crops., FSH = fisheries and aquaculture. Regions are ordered in terms of size of total agricultural production in 2020 based on FAO data[365]. Regions: WLD = World, ANZ = Australia and New Zealand; BRA = Brazil; CAN = Canada; CHN = China; EUR = Europe; ECC = Eastern Europe, Caucasus, Central Asia; IND = India; MEN = Middle East and North Africa; OAS = Other Asia;

OSA = Other South and Central America; SEA = Southeast Asia; SSA = Sub-Saharan Africa; USA = United States of America.

Exploring the biophysical option space of a food systems transformation

We estimated the consequences of an EAT-*Lancet* food systems transformation on the Earth system. Where possible, we align the control variables with the food system boundaries defined in Section 3 (land, GHG, blue water). However, where models cannot currently report against these variables (Nitrogen surplus and Phosphorus loss) we have used control variables from the 2019 Commission (Nitrogen use and Phosphorus use) as proxy indicators.

Assessing potential impact on Climate, Land, Water, Nitrogen, and Phosphorous Boundaries

The modelling results show that in BAU, the environmental impact of agricultural production is projected to increase compared to 2020, where agricultural production is already above the food share of multiple planetary boundaries, with animal products responsible for the majority of emissions, and grains for the majority of nitrogen, phosphorous, and water use (**Figure 10a**). Agricultural emissions are expected to rise by 33% (20 to 50%; 51% for DIA-GIO) in the model ensemble, primarily driven by a 22% (18 to 25%) increase in ruminant animal numbers. The model ensemble projects agricultural crop yields to increase by 24% (17 to 46%), slowing but not preventing agricultural land expansion, which increases by 4% (1 to 7%; 16% for DIA-GIO) or ~200 Mha, with cropland expanding by 10% (4 to 25%). Resource use for producing crops increases in BAU according to ensemble results, with blue water use increasing by 13% (-10 to 43%; 1% for DIA-GIO), suggesting uncertainty on future increases on water-use efficiency (i.e., adoption of irrigation technologies, planting of more water efficient crops) and rates of expansion of irrigated area to 2050. Nitrogen and phosphorous application increasing by 41% (22 to 55%; 31% for DIA-GIO) and 41% (36 to 46%; 26% for DIA-GIO) respectively. BAU results suggest food systems could exceed the resource-use boundaries by more than 100% for nitrogen-use and by 55-75% for land, water, and phosphorous use (**Figure 10b**).

All three components of EL (dietary change, increased productivity, reduced FLW) contribute to more efficient and less resource-intensive food systems by 2050. To achieve the agricultural emissions target of 5 $GtCO_2e\ yr^{-1}$ from CH_4 and N_2O from biological processes, non-CO_2 emissions at the farm-gate would need to decrease by more than 30% from current estimates of 7.1 $GtCO_2e\ yr^{-1}$.[172] Under EL, agricultural non-CO_2 emissions decline, primarily due to fewer ruminants, with the ensemble median and DIA-GIO showing a 20% and 32% decline compared to 2020 respectively. However, there is low agreement across models on whether these reductions are sufficient to meet the food system boundary (–48 to 13% from 2020 across models). All regions show emissions reductions in EL compared to BAU by 2050, with the largest decreases occurring in Sub-Saharan Africa, Brazil, and the rest of Latin America (**Figure A4.6**). When EL is coupled with emissions pricing and land-use policies in ELM, the model ensemble shows agricultural emissions declining further to 34% (-84 to -18%) of 2020 levels, and below the food system boundary.

Ensemble results suggest total global agricultural land use (cropland + grazing land) could fall by 7% (-26% to 1%) below 2020 levels (decrease of ~340 Mha) in EL, a substantial departure from BAU projections described above. Most of this decline comes from reductions in grazing land (-11%, -59% to 1%). Latin America accounts for 30% of the decline in grazing land from 2020 (with Brazil alone

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accounting for 16%), while Sub-Saharan Africa accounts for 22%. Such a reduction in future agricultural land-use could provide room for conservation or restoration of natural ecosystems, particularly in these regions. The ensemble results suggest an increase in cropland (10%, -3% to 42%) from 2020, whereas DIA-GIO suggests that cropland area could decrease to 22% below 2020 levels without other uses of land (**Figure A4.9**). Coupling ambitious mitigation with a shift to healthy diets under ELM shows even greater reductions in future agricultural area, with agricultural land declining globally by 14% (-28 to -4%) compared to 2020. This larger reduction is due to both drivers reducing the demand for and production of animal products, and in particular ruminant production, the main users of grazing land.

Current estimates indicate that global blue water use remains below the food system boundary. However, regional water scarcity remains a critical concern, and additional efforts may be needed to increase water use efficiency and manage water-use, particularly in areas already experiencing water stress (e.g., Indo-Gangetic plains, Mediterranean, etc.). EL lowers water use compared to BAU 2050 levels, but there is low agreement across the ensemble in terms of whether this reduction is sufficient to fall below 2020 levels (4%, -25 to 39%; -8% for DIA-GIO). Ensemble results suggest similar blue water use in ELM compared to EL (3%, -40 to 45%), but with results showing a wider range of outcomes. While EL reduces both N- and P- use compared to BAU, usage levels are still projected to increase compared to 2020 (15%, -17 to 32%; and 15%, 5 to 25%, respectively), and remain above the planetary boundaries. DIA-GIO results suggest that under EL, nitrogen and phosphorus inputs could decline substantially compared to current levels (-35 and -53%, respectively) and near or below planetary boundaries, when demand from non-food sectors does not increase.

There are important complementarities across the three drivers of EL, which in combination achieved better environmental outcomes than any individual driver in isolation.[366] Dietary change alone could substantially contribute to improvements along land and emissions boundaries, but there is greater uncertainty on the outcome across water, N- and P-use by 2050, as many commodities growing in demand also require these inputs. DIA-GIO showed greater environmental gains from increased productivity and reduced FLW, than did the economic models, where rebound effects in demand limit the environmental gains from these drivers. For example, increased productivity in ruminant production lowers the cost of ruminant products, which in turn leads to lower consumer prices and stimulates increased consumer demand. This increase in demand leads to a larger ruminant herd leading to similar emissions under the increased productivity scenario compared to BAU (Fig 10b). A shift to healthy diets would avoid this outcome as it would reduce demand for ruminant products. A shift to healthy diets, on the other hand, would increase demand for more perishable fruits and vegetables and could increase the volume of FLW, highlighting the increased importance of interventions to reduce FLW in an EL future.

The range of environmental results (cropland extent, and blue water, N, and P use) highlights substantial uncertainty in how agri-food systems could respond to a food system transformation. A transition to a healthy diet would include reductions in demand for some agricultural commodities (e.g., animal-sourced foods, and sugar), accompanied by reductions in intermediate demand from these sectors for inputs (e.g., animal feed). However, this transition would also increase the demand for other agricultural commodities (e.g., fruits, vegetables, legumes, and nuts).

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Whether this transition would lead to a net reduction in resource use by agriculture depends on a variety of factors. First is whether resources (cropland, water, fertilizers) dedicated to producing crops no longer demanded can easily be converted to producing agricultural commodities that are increasing in demand. For example, not all cropland dedicated to feed crops would be suitable (agro-climatically or economically) to produce fruits, vegetables, legumes, and nuts. Second, are the crops increasing in demand less resource intensive than those that are declining in demand. While animal-sourced foods are generally resource intensive, many of the crops increasing in demand can also be relatively resource intensive, particularly with respect to water and fertilizer use. Third, many crops that are important animal feeds (e.g., cereals and oilseeds) are also inputs to a variety of industrial uses (e.g., cosmetics, bioplastics, biofuels, etc.). Less demand for animal feeds would make these agricultural commodities cheaper, which could spur additional demand from outside the food system, limiting environmental gains. Models with larger reductions in resource use (i.e. DIA-GIO), assume limited rebounds in demand and less competition for reallocating resources to producing a healthy diet, whereas many of the economic models suggest there could be a wider range of potential uses for resources that could lead to smaller environmental gains without additional economic incentives (e.g., true cost accounting) or policies (land-use regulation). Potential increased competition for resource use is more evident in ELM, where there is increased demand for agricultural products from the bioeconomy (i.e., biofuels, biomass, bioplastics) as a part of transitioning away from fossil fuels, and land-use policies that restricts land expansion leading to increased agricultural intensification of existing cropland.

This suggests that the modelled changes could contribute substantially to reducing environmental pressure across many dimensions compared to remaining on a BAU trajectory. However, there is uncertainty with respect to reducing environmental impact compared to today or fully remaining within a safe operating space. Much of this uncertainty depends on how broad the scope is for alternative uses for natural resources and agricultural commodities, emphasising the need to couple supply- and demand-side changes to avoid undesired consequences and rebound effects. The model results present a critical foundation for a food system transformation, even as additional policies and innovations[367,368] that promote improved food system efficiency and resource use (e.g., precision ag, fertilizer management, improved production allocation), further reductions in FLW, applications of sustainable intensification approaches (**Panels 5** and **6** and **Appendix 2**), or circularity[369–371] (**Panel 4**) may be required to ensure a complete transition to a safe operating space.

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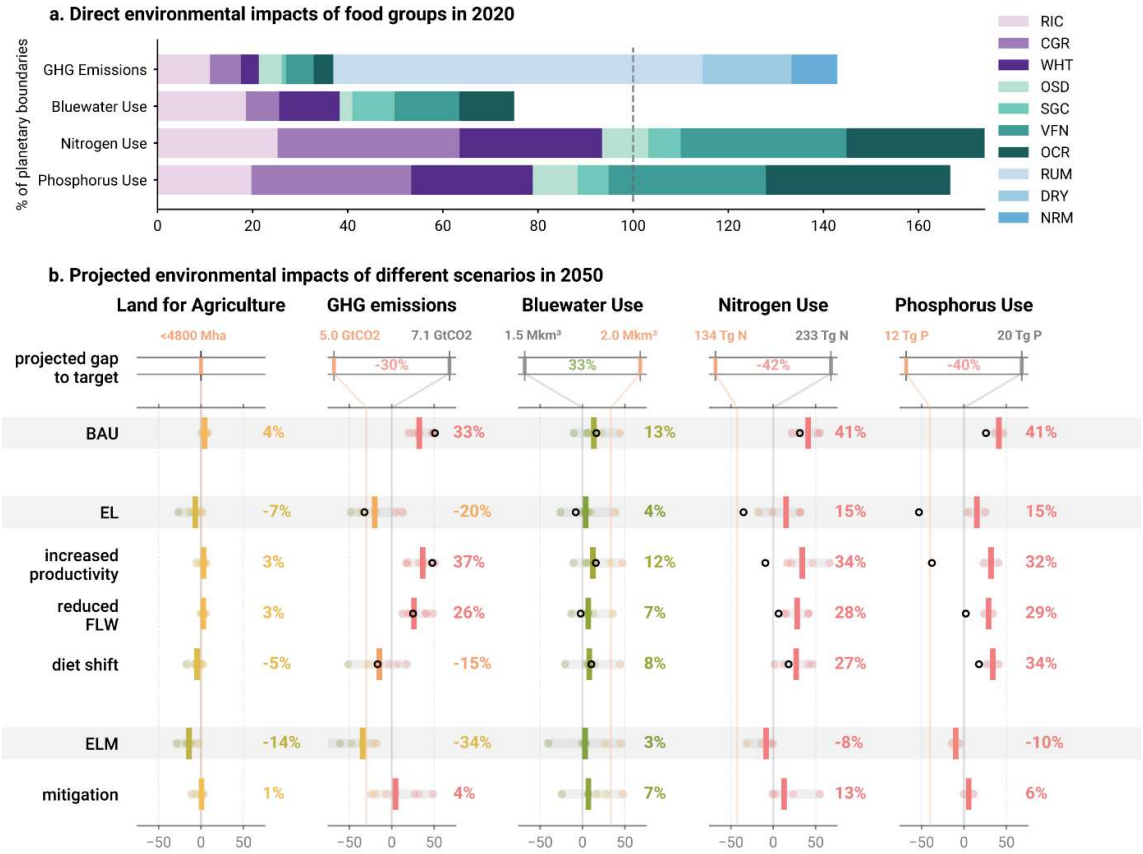


Figure 10: Environmental impacts of food systems. a. Direct environmental contribution towards planetary boundaries of food groups in 2020 (i.e., nitrogen use for animal feed production appears in crop production). Source: DIA-GIO. Food groups: (grains in violet) RIC = rice, CGR = coarse grains, WHT = wheat, (crops in teal) OSD = oilseeds, SGC = sugar crops, VFN = vegetables, fruits, and nuts (and legumes, roots and tubers), OCR = other crops, (livestock products in blue) RUM = ruminant meat, DRY = dairy, NRM = nonruminant meat (poultry, pork, eggs) **b. Projected environmental impacts of different scenarios in 2050**. The first row shows the current state (grey line) of the food system for five environmental variables —Land for Agriculture, Non-CO_2 Emissions from Agriculture, Water Withdrawals for Crops, Nitrogen Use for Crops, and Phosphorus Use for Crops—and their food system boundaries (orange line). The percentage change needed from the current level to reach the boundary is indicated between the two lines. The lines continue from the first row and are translated to percentage change from the current state in the subsequent rows. Each subsequent row represents percentage changes relative to the current state for different scenarios in 2050: the core scenarios (highlighted in grey) BAU (Business-As-Usual), EL (EAT-*Lancet*), and ELM (EAT-*Lancet* with mitigation), and their drivers (increased productivity, reduced food loss and waste (FLW), diet shift, and climate mitigation). The thicker vertical lines represent the multi-model median, with the lighter dots indicating individual model results. Colours indicate whether results are below (green), between (orange), or exceeding (red) the food system boundary. Open black circles indicate results from the DIA-GIO model.

Socioeconomic and justice implications of food systems transformation

Assessing agricultural labour and livelihood implications

Changes in labour demand can have implications for production costs and income, as well as ultimately production and total demand.[372] Across all scenarios (BAU, EL, ELM), assumed economic development and increasing urbanization leads to an agriculture sector that contributes a smaller share of total economic output and employment by 2050.[373,374] While the structural change in demand suggested by a dietary change in EL (Figure 9) would have important consequences on which sectors are increasing

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or decreasing their demand for labour, globally, we see modest additional reductions in labour demand under EL or ELM compared to BAU (**Figure 11a, and Appendix 4 Table A4.22**). These results are consistent with recent analyses using current sectoral and regional labour requirements, which found a shift to a healthy diet would lead to a less labour-intensive global food system.[375] All of which suggests that a shift to a healthy diet would not only be less resource-intensive, as highlighted in the previous section; but also modestly less labour-intensive to produce. The global reduction in labour intensity is driven by various factors, including a reduction in the production of animal feeds, and a reduction in output from more labour-intensive sectors like industrial pork, poultry, and dairy production offsetting increased labour demand in expanding crop sectors like vegetable, fruits and nuts.

Livestock sectors would face particular economic challenges, with the livestock share of total agricultural value of production declining from ~40% in 2020 to around 15% by 2050 in EL and ELM (**Figure 11b**). This is due to a 41% decline in global production, coupled with a 31% decline in producer prices for livestock products,[376] which contributes to a 36% reduction in livestock labour demand by 2050 compared to BAU. The increased demand for some plant-based foods, especially vegetables, fruits, and nuts, would drive increased demand for labour in these expanding sectors, which globally across all of agriculture offset most of the declines in livestock labour demand. These ensemble results are broadly consistent with DIA-GIO results, which suggest the shifts in sectoral demand for labour would result in a modest reduction in overall agricultural labour demand (<5%) globally.

The agricultural sector contributes a larger share of GDP and employment in lower-income regions (up to 40%) compared to higher-income regions (<5%).[377] Despite a decline in the contribution of agriculture to the economy compared to current levels, by 2050 agriculture would remain a relatively large source of GDP and employment in many regions (e.g., India, and Sub-Saharan Africa). The labour demands by sector also vary substantially across region and food system. As such, the challenges of restructuring agriculture and food sectors would vary regionally.[378] The restructuring of food systems could be relatively more challenging in regions with large agricultural labour forces (e.g., India, Sub-Saharan Africa, and China), or large livestock sectors (e.g., Latin America). Regions with larger vegetable, fruit and nut sectors (e.g., China), may benefit from changes in demand without the need for substantial reallocation of resources across agricultural sectors. **Figure 11** shows the size of agricultural labour force by region (panel a) and the relative importance of the livestock sector and the VFN sectors (panel b) to highlight regions where restructuring of labour demand could present greater challenges.

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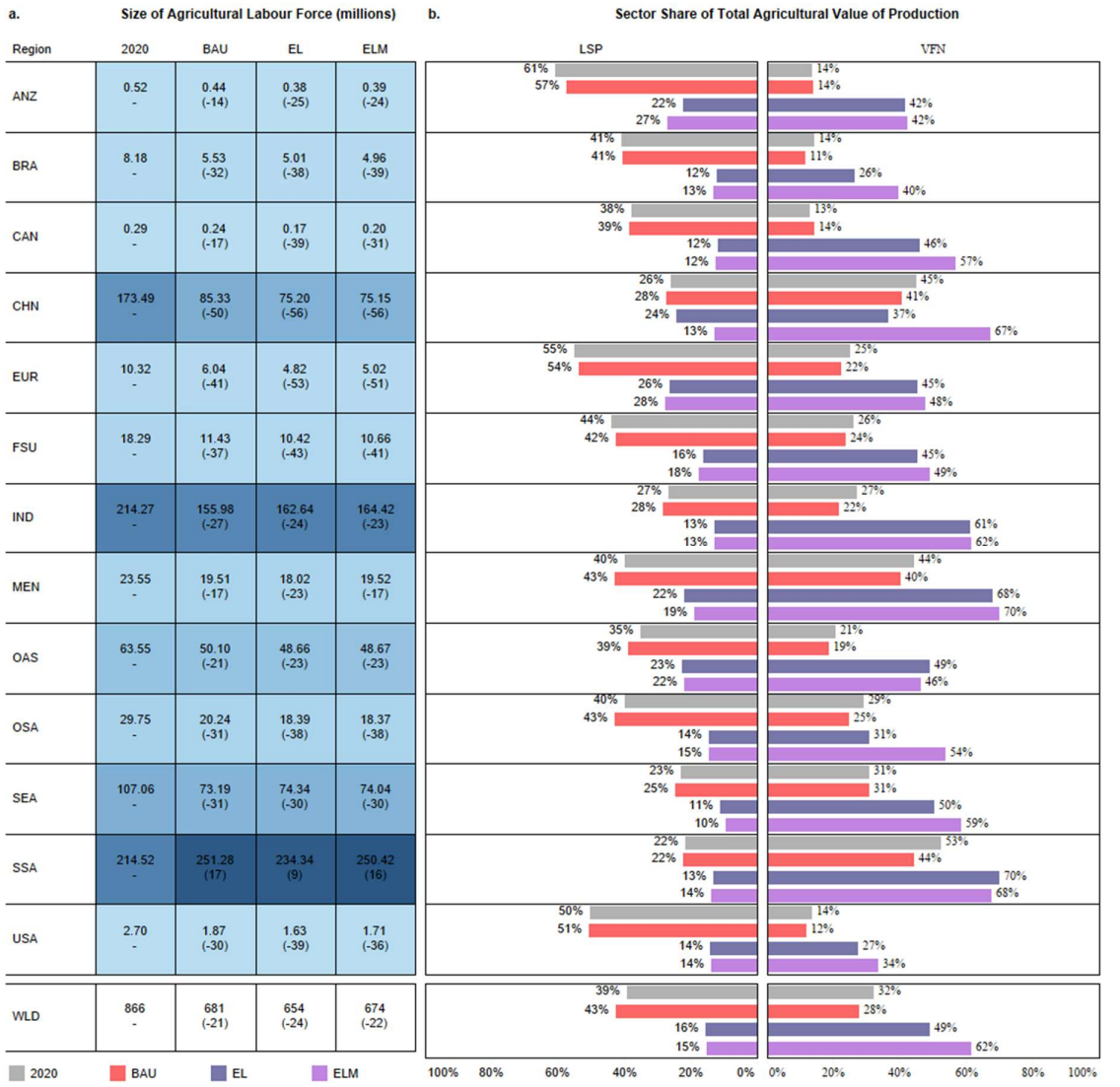


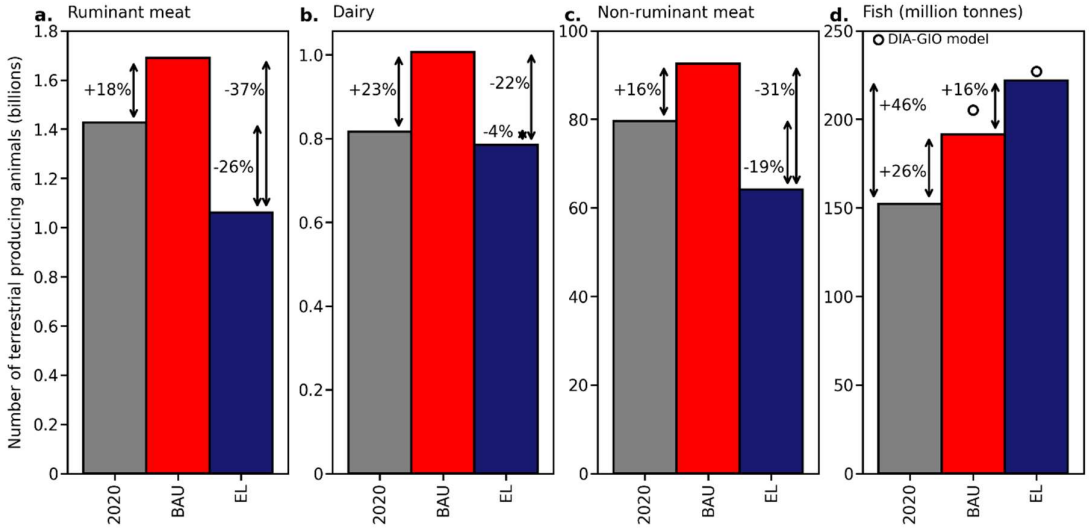
Figure 11: Summary of regional disaggregation of agricultural labour and value of production. a. agricultural labour force (millions) for the world and 13 regions by 2050 under BAU, EL and ELM. Intensity of shading reflects regional share of global agricultural employment. Employment numbers are derived from benchmarking the percentage change (2050 vs 2020) of the median model to agricultural employment in 2020.[365] Percentage change from 2020 by scenario shown in parentheses. Full model results are given in Table A4.22**. b.** the share of value for livestock (LSP) and vegetables, fruits, legumes and nuts (VFN) in total agricultural value of production for 2020 (grey), BAU (red), EL (blue), ELM (purple). Agricultural value of production is given in current prices.

Changes in labour demand would impact livelihoods beyond employment levels. Model ensemble results suggest that agricultural wages could keep pace with the overall economy, with average agricultural wages increasing by 81%, 74%, and 73% by 2050 for BAU, EL, and ELM respectively. However, substantial restructuring across agricultural sectors (i.e., reductions in animal production, expansion of fruits and vegetables) would have important justice implications. These results assume a smooth transition to 2050 across all three scenarios. For this to occur in the EL scenario, there would need to be clear and consistent market signals to discourage new entrants (e.g., producers newly entering a specific sector) into contracting sectors (i.e., ruminants), while encouraging entry into

2099 expanding sectors (i.e., VFN), along with the necessary investments in human and physical capital to
2100 facilitate labour transitions both within and outside of food systems.
2101

Panel 8: Challenges and changes in livestock production

An EAT-*Lancet* aligned food systems transformation would 'mark a paradigm shift in our relationship with farmed animals',[P66] with a considerably transformed and smaller livestock system globally (**Panel Figure**). To match nutritionally healthy meat consumption from the human diet point of view, we estimate that the producer animal numbers would decline globally to 1.1 billion (-26%) ruminants for meat (cattle, sheep, goats), 785 million (-4%) dairy animals, 66 billion (-19%) non-ruminants (of which >95% poultry, <5% pigs). Conversely, fish production would increase to 220 million tonnes (+46% on 2020 levels). From the perspective of value of production, we see an absolute contraction from 2020 levels, with a 43% decline across the global terrestrial livestock sector (-US$650 billion) by 2050. Proportionally this is more marked for ruminant meat (-71%), than non-ruminants (-46%) or dairy (-20%). It also represents a 50% decline in terrestrial livestock sector employment by 2050, noting that in a BAU scenario we see a decline of around 25%.



Panel Figure: Projected changes in the number of livestock producing animals and fish production under BAU and EL scenarios. a. Global animal numbers for ruminant meat (cattle, sheep, goats). **b.** Global animal numbers for dairy. **c.** Global animal numbers for non-ruminants (poultry, pigs). **d.** Global fish production (million tonnes). The grey bar gives current animal numbers based on FAO data.[P67] The red and blue bars give projected numbers from modelling for the Commission in a BAU and EL scenario respectively. The unfilled black marker in d. gives results for the DIA-GIO model. Note that different units of measure are applied for each category.

Change in livestock animal numbers indicate reductions in CH_4 and N_2O emissions (-22% versus 2020), and grazing land (-11% versus 2020, ~340Mha). Further improvements and innovations in practices can and should be developed and applied to further reduce emissions and both increase and capture environmental benefits of livestock production. For example, some of the methane emissions linked to ruminant management can potentially be mitigated in the future[P68] (**Figure 5**).

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The meat and dairy sectors are the most impacted by shifts to healthy diets, which must critically take into account livelihoods, culture, and power dynamics. While we recognise the contentious and complex nature of animal-sourced foods production and consumption, a smaller livestock sector creates opportunities to give greater consideration to animal health and wellbeing, environmental outcomes, and labour quality. We flag six important opportunities and considerations to navigate this transition which we recommend considering in combination, rather than in isolation:

Gains through Efficiency and Technology: There are significant efficiency gains in production, notably in the global south, that can markedly reduce anticipated environmental and health impacts of production. Emissions intensity can be improved so that per unit production, less GHG would be emitted.[P69] Caution is urged around densely occupied confined systems notably around other environmental effects such as concentrated nutrient pollution, and disease risk, over-use of antimicrobials, animal health and welfare and labour conditions. The assumed conservation gains of improved efficiency are only attained with complementary policies and actions that limit, for example, continued expansion into intact lands.

Zero Conversion of Intact Forests, and Grasslands: The additional conversion of forests for pasture or feed systems is antagonistic to achieve both human and environmental goals. Often forgotten are intact grasslands, which are even more threatened than forest globally. Only 30% of intact grasslands are remaining, making them the most converted, but also least protected ecosystems globally.[P70]

Gains through Nature Positive Rangeland Management: While intensive (over)grazing contributes to land degradation,[P71,P72] integrating grazing livestock to maintain grasslands is also a possibility for conserving and restoring grassland ecosystems[P73] including carbon sequestration. Bai et al. estimate increases in SOC of 2.3 to 7.3 $GtCO_2e\ year^{-1}$ for grassland restoration in general, with Improved grazing management providing 0.15 to 0.7 $GTCO_2e\ year^{-1}$.[P74] Improving grazing management ranges from complete removal of grazing livestock to different ways of reducing grazing intensity, highlighting the need to balance the management with the agroecosystem conditions.[P73] Importantly, the production of supplementary feeds needs to be internalised into the overall effects of the livestock production systems, due to e.g. deforestation.[P75] In forest biomes, silvo-pastoral systems present some opportunity to mitigate effects of livestock while contributing to productivity gains.[P76]

Gains Through Integration: Modern agriculture has often separated animal and plant productions systems. Methods reconnecting these systems, whether integrated in landscapes or connected through circular production such as insect-based feed offer promise.[P77-79] Feeding livestock with byproducts in circular systems has potential, but the number of animals that could be reared is limited by the availability of such feed, resulting in substantially lower production levels than what is currently produced.[P79]

Gains in Animal Welfare: Perspectives emphasising the welfare and wellbeing of animals in agriculture have risen due to a growing concern related to intensive, confined, industrialised farming systems, or 'factory farming'. For instance high stocking densities,[P81,P82] long transportation times,[P83] restricting natural behaviour[P84] pose animal welfare concerns, and also extensive systems come with

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their own challenges.[P85] Animal welfare concerns have also been shown to influence consumer choice, along with the produce quality, even outranking environmental concerns.[P86] Importantly, discussion on animal welfare and wellbeing should reflect current, multidisciplinary knowledge, bringing together advancing research on animal cognition and behaviour, veterinary science and ethics.[P87]

Non-ruminant Animal Sourced Foods: In some regions beef consumption is flat or declining (e.g. USA, Europe), largely replaced by poultry and pork production. Blue foods, or aquatic foods are common to many cultures and traditions. In general, animal sourced foods will have higher environmental footprints than plant sourced foods because of lost energy conversion between trophic levels. This loss is lowest for aquatic and avian animal sourced foods and can be further mitigated by more circular systems. However, most livestock production systems share similar disease, and pollution risks at scale, notably in dense highly confined systems and all have concerns related to animal health and welfare.

Assessing production costs and food expenditure implications

Using various modelling approaches, we observe a smaller and less resource intensive food system with EL compared to BAU. It is one that would require fewer natural resources (i.e., land and water), chemical (N and P), and labour inputs. Across the ensemble, these changes could amount to a moderate reduction in average agricultural producer prices of 8% for EL by 2050 compared to BAU **(Figure 12a**). Assuming current input requirements and prices, DIA-GIO projected a similar reduction in costs (10%). This suggests that transformed food systems by 2050 could produce healthy diets for all while reducing input costs, natural resource use, as well as environmental pressures compared to BAU. However, whether this potential is realized will ultimately depend on the transition pathway (i.e., the mix of policies, technologies, and cultural changes) followed to foster an EL compatible food system transformation.

Across food systems, lower production costs could increase average food affordability if passed along to consumers. That said, it is important to note that lower producer prices can contribute to lower agricultural wages and income with negative consequences on food affordability, particularly in rural areas. Ensemble results suggest that average agricultural prices would not change substantially from 2020 levels for both BAU and EL. This contrasts with ELM, where increases in producer prices contribute to a 10% increase in consumer prices compared to 2020. Food expenditure (reported by AIM, ENVISAGE, and MAGNET), which is a factor of consumer prices and food demand, is projected to grow in all three scenarios, but at a slower rate than per capita income, with the share of global income spent on food falling from 7% to 5%, 4%, and 4% by 2050 for BAU, EL, and ELM respectively (**Figure 12b**). Globally, changes in food expenditure between BAU and EL are driven by two offsetting shifts in the consumption bundle. First, a decline in the demand for, and the prices of, relatively more expensive animal sourced foods. For example, demand for, and consumer prices of, ruminant meat fall by 62% and 16% respectively compared to 2020, even as ruminant prices remain substantially higher than prices of all other commodities (**Figure 12a**). Second, demand for and prices of VFN increase substantially, which at the global level mostly offset decreased spending on animal products.

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While globally, by 2050, these two shifts mostly offset each other, some regions currently consuming relatively low levels of animal sourced foods (e.g., India), or would require relatively large increases in VFN demand (e.g., Eastern Europe, Caucasus, and Central Asia) to achieve a healthy diet could see increased food expenditure in 2050 compared to BAU. By contrast, regions that are currently overconsuming animal sourced foods (e.g. USA) could see declining food expenditures. This result is consistent with recent analysis using DIA-GIO that found that for individual consumers today, healthy diets could already be more affordable than current unhealthy diets in high- and upper middle-income countries, even as they remain more expensive in low- and lower middle-income countries[8].

Even as the share of income spent on food is declining for all regions and scenarios compared to 2020, the affordability of diverse healthy diets remains a concern. Lower income regions that import a substantial share of their VFN (e.g., Other Asia), could have additional concerns for increased vulnerability to international price shocks on domestic food affordability and availability. And while progress is made, Sub-Saharan Africa continues to spend a larger share of income (21%) on food in EL than any other region. This suggests lower income regions (bottom of list of regions in **Figure 12b**) could remain relatively more vulnerable to food poverty, and that targeted interventions to account for higher VFN prices and social protections to ensure consumers can afford a healthy diet may be needed.

These results highlight that a food systems transformation, if achieved, could contribute towards social and environmental goals. However, the mechanisms for getting there (e.g., taxes, repurposing of subsidies, incorporation of true cost of food approaches) will be critical to informing and incentivizing behaviour change towards more sustainable production practices and healthier consumption patterns. The cost of these actions will ultimately determine whether a food system transformation increases or decreases the cost of individual foods and the overall diet.

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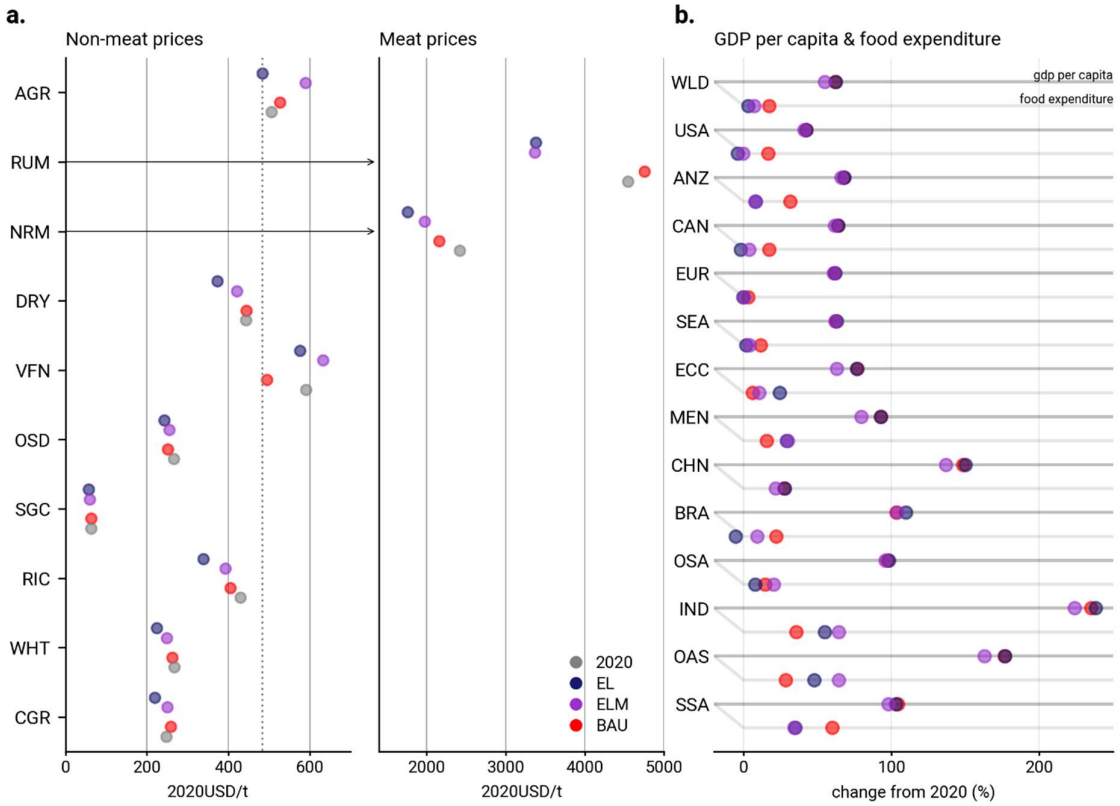


Figure 12. Changes in agricultural producer prices and food expenditure implications. a. global average prices by sector for 2020 (grey), BAU in 2050 (red), EL in 2050 (blue), and ELM in 2050 (purple). Global prices are expressed in 2020 US$/t, note the different scale for non-meat and meat prices. Prices for 2020 were obtained from FAOSTAT [365]. Percentage change in prices (from 2020 to 2050) given by model results were applied to FAO 2020 prices. **b.** GDP per capita and food expenditure by region for BAU, EL, ELM expressed as a percentage change from 2020. Median GDP per capita for 3 reporting models (AIM, ENVISAGE, and MAGNET) is located at the region's first row followed by food expenditure results in the second row, which are expressed as percentage change from BAU 2020. Sectors: AGR = all agricultural products, RUM = ruminant meat, NRM = non-ruminant meat (poultry, pork, eggs), DRY = dairy, VFN = vegetables, fruits, and nuts (and legumes, roots and tubers), OSD = oilseeds, SGC = sugar crops, RIC = rice, WHT = wheat, CGR = coarse grains. Regions: WLD = World, ANZ = Australia and New Zealand; BRA = Brazil; CAN = Canada; CHN = China; EUR = Europe; ECC = Eastern Europe, Caucasus, Central Asia; IND = India; MEN = Middle East and North Africa; OAS = Other Asia; OSA = Other South and Central America; SEA = Southeast Asia; SSA = Sub-Saharan Africa; USA = United States of America.

Mitigation efforts (**Figure A4.7)** could increase the cost of agricultural production by limiting land supply and pricing emissions. Across the ensemble, mitigation efforts in isolation would increase consumer prices by 17% (0 to 40%) compared to BAU 2050 prices. This is broadly consistent with past studies suggesting that mitigation efforts could increase food prices.[349] This increased risk can be explained by multiple factors that raise the price of producing and consuming food. First, land use and mitigation policies increase the cost of key agricultural inputs (e.g., land, fertilizers) raising the cost of production. Second, emissions pricing raises the cost of agricultural products, particularly of emission intensive commodities like ruminant meat. Vulnerability to changes in food prices varies, with lower income regions already at higher risk of food insecurity, like Sub-Saharan Africa, the most vulnerable to price increases. **Panel 9** explores how the EL components contribute to changes in producer and consumer prices, and their potential policy implications.

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2185 Low- and middle-income regions contribute the largest reductions in emissions and agricultural land-
2186 use in EL and ELM (e.g., China, Brazil, Sub-Saharan Africa), and predominantly are regions where
2187 dietary change risks increasing food prices. These are also the regions that historically have
2188 experienced large changes in land-use or had the least access to novel technologies and affordable
2189 reliable energy. This highlights the importance of increased productivity to reduce agricultural yield
2190 gaps, as well as reducing FLW, both of which could play a critical role in alleviating price pressures
2191 caused by a shift to healthy diets and/or ambitious mitigation. There are potential complementarities
2192 between a shift to a healthy diet and ambitious mitigation, both alleviates pressure on land, and
2193 globally, reduces GHG-intensive foods in the consumption bundle. Further demand-side interventions
2194 could also play a role in managing food affordability concerns. Modelling suggests that targeted food
2195 subsidies bundled with mitigation policies[379,380] or full cost efforts[381] could help manage these price
2196 increases, as discussed in the following section.
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Panel 9: Understanding the drivers of price changes to inform policy priorities

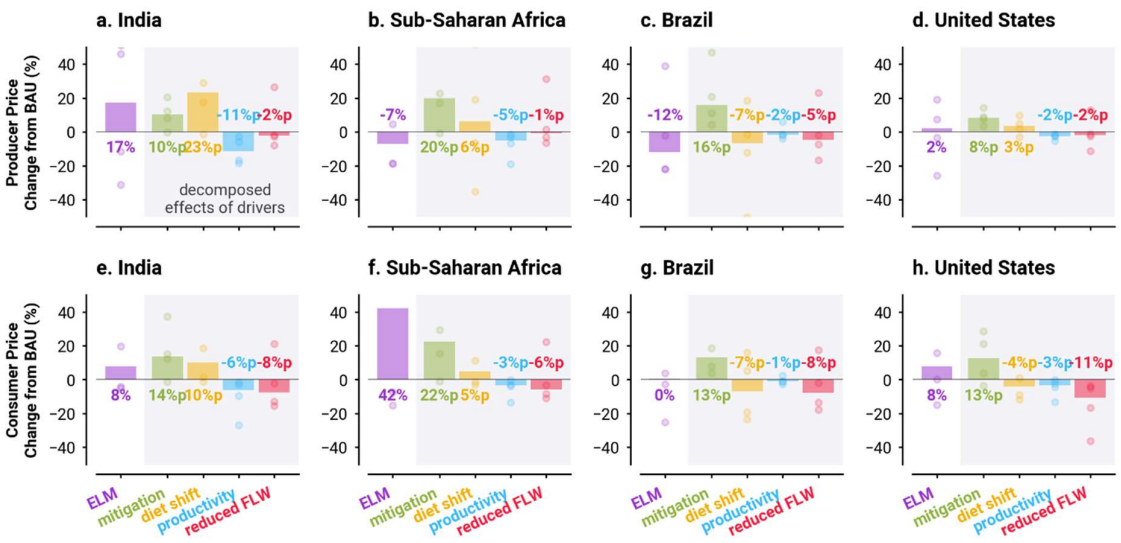
To assess which scenario drivers (dietary change, increased productivity, reduced food loss and waste, and ambitious mitigation) were most responsible for changes in agricultural prices we conducted a decomposition analysis using four models from the ensemble (AIM, CAPRI, ENVISAGE, and MAGNET) that reported regional consumer and producer (e.g., farm gate) prices (See **Appendix 4 Fig A4.7** for full ensemble results of producer prices).

Ambitious mitigation could increase the cost of production in all regions by limiting agricultural land expansion and pricing emissions. Increased producer prices translate to higher consumer prices, posing a risk to food security. Dietary change on the other hand has more varied impact on prices. In Brazil and the USA, regions with high animal-sourced food consumption, adoption of healthy diets could reduce average consumer prices by 7% and 4% respectively (**Panel figure g** and **h**, yellow bar). However, in India, where there is low red meat consumption, increased demand for vegetables, fruits, and nuts could contribute to a 10% increase in average consumer prices (**Panel figure e**, yellow bar)

Increased productivity and reduced FLW contribute to more efficient food systems, reducing the cost of production and leading to lower consumer prices in all regions. The potential to mitigate price increases is particularly critical in lower income regions with greater food security challenges. For example, in India and Sub-Saharan Africa reduced FLW and increased productivity partially offset the price increases due to ambitious mitigation and dietary change (**Panel figure** blue and red bars). FLW reductions contribute more to reductions in consumer prices than producer prices, with the biggest gains in regions with relatively high consumer waste (e.g., USA **Panel figure h**). Broadly, these results suggest the importance of supply-side interventions that increase the efficiency of food systems, particularly in low-income settings where price rises pose immediate food security risks.

Previous modelling[P88–91] has suggested supply-side measures (investments in resource use efficiency, agricultural R&D, improved extension services), would be insufficient to alleviate food insecurity. As such, policies and interventions that improve infrastructure and functioning of markets, as well as demand-side interventions, such as price subsidies and poverty alleviations measures, would be needed to manage higher diet costs in lower income regions.

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Panel figure: The key drivers of price changes in ELM. Regional impact of ELM (purple) on producer (a-d) and consumer (e-h) prices as percent change (%) from the business-as-usual (BAU) scenario, decomposed into four key drivers shown as percentage points (%p): mitigation (green), diet shift (yellow), improved productivity (blue), and reduced food loss and waste (FLW) (red). Note that decomposition values are not additive, as there are interactions between the four scenario drivers, see SI for explanation of decomposition.

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Section 5: Solutions and actions to improve health, environmental sustainability, and justice

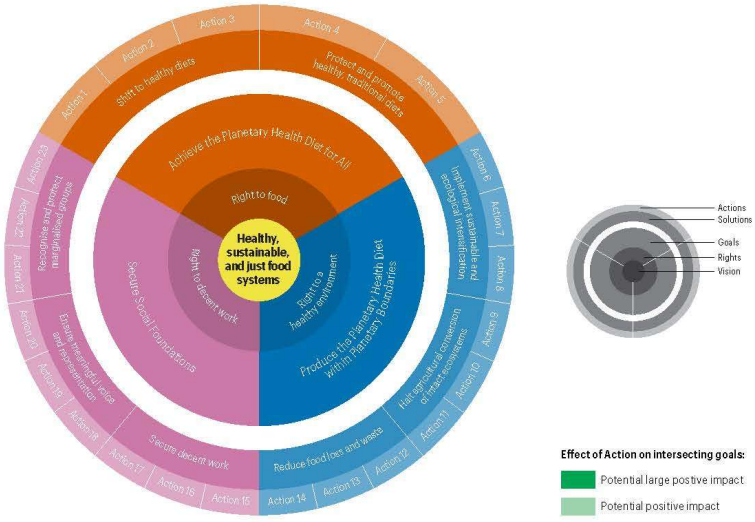
A "great food transformation"[1] is required if the world is to align with the EAT-*Lancet*'s vision by 2050. This transformation must operate across multiple leverage points, including profound shifts in the underlying objectives of food systems outcomes.[382,383] The focus must move beyond simply maximizing profit and volume in agriculture to achieving food security in ways that prioritize diet quality and advance health, sustainability, and social justice. Equally essential is interventions that change underlying rules and incentives of the food system, such as taxes, subsidies, and regulations,[382,383] as these form the conditions under which deeper shifts in values, norms, and governance can emerge.

This section focuses on these underlying rules and incentives through the lens of eight domain-specific solutions aimed at advancing health, environment, and/or justice goals simultaneously. For every solution, we identify two to three actions that the Commission has evaluated, based on synthesis of existing literature, as critical for transforming food systems. These actions are grounded in available scientific evidence demonstrating their potential to deliver meaningful impacts across health, environment, and justice outcomes, while also creating the enabling environment for more profound systems change. **Figure 13** summarizes these solutions and their associated actions.

Several analyses have shown that individual policies and interventions, on their own, are insufficient to drive multi-goal transformative change. Instead, bundled or integrated approaches are needed—for example, to keep global warming below 1.5 degrees[384] or to reduce the hidden costs of current food systems (estimated to be 15 trillion US$/year).[9] This is because the drivers and outcomes of food systems are highly interconnected, interacting in both direct and indirect ways.[385] Investing in coordinated sets or packages of solutions is therefore essential to steer food systems transformation in positive directions.

We highlight some of these dynamics in actions 3 and 15-23. The domain-specific actions presented in this section are not isolated; rather, they are deeply interconnected and can produce synergistic effects across goals, while also navigating potential trade-offs. For example, introducing regulations to limit land use expansion may promote health and environmental sustainability but could risk undermining justice if it restricts access for marginalized or indigenous people's access to that land. However, if such regulations are implemented alongside efforts that recognise and protect the resource use of these groups, both sustainability and justice can be enhanced. By implementing actions as part of carefully designed 'bundles,' it becomes possible to advance multiple goals simultaneously (see **Section 6: Transformation**).

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Solution	Action	Health	Envir.	Justice
1 Shift to healthy diets	1 Use taxes and subsidies to shift affordability of unhealthier foods towards the affordability of healthier foods			
	2 Combine restricting advertising and availability with mandatory warning labels on unhealthy foods			
	3 Increase purchasing power for households in the lowest quintile through different social protection measures			
2 Protect and promote healthy, traditional diets	4 Recognize and include traditional healthy foods and diets in food-based dietary guidelines and public procurement programmes (e.g. school food programmes)			
	5 Support local markets, including the development of value chains to promote consumer demand of underutilised healthy locally produced crops			
3 Implement sustainable and ecological intensification	6 Ensure producers' access to and enhanced governance over land, sea, production inputs, agricultural training and extension, peer-knowledge networks, and markets			
	7 Mitigate power-imbalances between producers and corporations, by supporting producer coalitions, subsidies to sustainable practices, and regulating corporate control, global trade and financialization			
	8 Public and private sector investments to cover the transition costs, research and development of SI/EI relevant innovations			
4 Halt agricultural conversion of intact ecosystems	9 Combine regulatory measures such as protection of natural ecosystems, suspension of logging concessions, and implementation of land-use zoning with coordination mechanisms to reduce 'land expansion leakage'			
	10 Invest in community management of local ecosystems, including indigenous communities, to promote stewardship of land and water, and balance conservation and use of ecosystems.			
	11 Increase multi-sector commitments to zero deforestation commitments across supply chains			
5 Reduce food loss and waste	Use fiscal and regulatory policy incentives as well as circular economy mechanisms, and technologies, to:			
	12 Improve storage, logistics and supply chain data/analytics - especially in low-income settings			
	13 Reduce retail and consumer waste through awareness raising, education, skills - especially in high income settings			
	14 Recycle nutrients and energy, prioritizing animal feed and on-farm waste recovery			
6 Secure decent work	15 Guarantee payment of updated living wages for all and close the gender pay gap			
	16 Provide training in skills that can enhance redeployment in the context of food system transitions (especially for youth, women and current labour force)			
	17 Improve enforcement of legislation, in society in general and food system workplace specifically, against • Gender-based violence and sexual harassment • Occupational health conditions • Child labour			
7 Ensure meaningful voice and representation	18 Ensure the existence of enabling mechanisms for collective bargaining by agri-food system workers and farmers			
	19 Develop legal and regulatory framework to limit market concentration and ensure transparency in lobbying			
	20 Improve transparency, accountability, representation, and access to information through, e.g., supporting civil society, enabling social audits to hold actors accountable, and increasing women's representation in positions of influence			
8 Recognise and protect marginalised groups	21 Implement a range of social protection policies that can provide benefits for those at risk, including mothers, the poor, elderly, and disabled			
	22 Procure and implement healthy and sustainable meals in schools and other institutions			
	23 Protect basic human rights of people in conflict areas			

Figure 13: Goals, solutions, and actions to achieve healthy, sustainable, and just food systems. Depending on how they are implemented, all actions have the potential to contribute positively to other goals. The suggested strength of positive impact is developed based on dialogue with the Commissioners.

Goal 1: Achieve the Planetary Health Diet for All

Solution 1: Shift to healthy diets

To shift diets towards The Planetary Health Diet, it should ideally be more available, affordable, convenient, aspirational, and delicious than unhealthy alternatives. Two sets of feasible interventions emerged from a scoping review of systematic reviews.[386] Both sets of interventions focus on food environments—the physical, economic, political, and sociocultural settings in which people engage with the food system to acquire food[387] —most often considered more cost-effective and equitable than those targeting individuals or households.[387–389] The first set includes price-based interventions, which are likely to reduce the purchase and consumption of unhealthy foods.[390–392] The second set involves non-price-based interventions that restrict advertising and availability of unhealthy foods and mandate warning labels on them.

Taxes on foods and beverages with high content of added sugar, salt, or saturated fats (or a combination thereof) are particularly impactful when combined with subsidies on nutritious foods that decrease their relative price.[392,393] Modelling studies suggest optimal price levels for mitigating health and environmental impacts of unhealthy foods and meat that would require calibration by context.[379,380] By contrast, restricting advertising and marketing of unhealthy foods could shift populations towards healthier foods.[394,395] Labelling foods to denote higher energy content and those high in fat, sugar, and salt decreases purchasing and consumption[396,397] using either mandatory front-of-pack warning labels as in several Latin American countries or traffic light systems as is common in Europe.[398] Reducing the proportion of unhealthy foods that are available in the market in parallel with increasing the proportion of healthier foods[399,400] can reduce purchasing and consumption, as can reducing portion, package, and serving sizes of energy dense and unhealthier foods.[401,402]

Affordability of food is determined by supply and demand side dynamics as well as by purchasing power.[8,287] When making the PHD affordable for all, increasing purchasing power for lower income consumers is more important than 'reducing the price' of foods.[403] Social protection measures (see also Solution 8) including, providing nutritious school meals (**Panel 11**), public procurement and distribution systems, employment guarantee schemes, and government investments in health-promoting insurance systems, all have the potential to contribute to increased affordability for low-income households. Living wages, universal basic income, income growth, and targeted income transfers, especially for economically disadvantaged people,[404] and more equitable distribution of the benefits of national economic growth through fiscal policies, would also support increased purchasing power. Previous modelling studies suggest that the relative cost of a healthy diet can be substantially reduced, even in LMICs, through combinations of pro-poor income growth, reduced food loss and waste, and a cost accounting that includes the cost of diet related climate and health.[8]

Solution 2: Protect and promote healthy, traditional diets

In some regions, traditional diets are closely aligned with the principles of the Planetary Health Diet.[147,405,406] While it is important to acknowledge that not all traditional diets are inherently healthy or sustainable in their current form, they frequently embody a deep connection to the local environment, biological diversity, agricultural practices, cultural beliefs, and long-standing adaptations to available resources.[149,407] However, revitalizing traditional diets pose significant challenges. Efforts

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such as the promotion of millets in India and anchovetas in Peru illustrate the difficulty and resistance such initiatives can face, often due to opposition from entrenched commercial or political interests.[408] Amid ongoing nutrition transitions and the rapid rise in the supply and demand of ultra-processed foods, it is increasingly urgent to identify, protect, and promote healthy, traditional dietary patterns that are at risk of erosion.[145]

Various approaches exist that recognise and enhance the cultural, environmental, and nutritional value of Indigenous and traditional diets. These approaches aim to make such diets more desirable, accessible, and affordable.[148,409] Cultural valorisation, including the celebration of traditional foods, can elevate their social status and render them more aspirational.[148] For example, the Food and Agriculture Organization's designation of the "International Year of Millets" sought to raise awareness of the environmental, climate resilience, and health benefits associated with these crops.[410] Incorporating traditional, healthy foods into national food-based dietary guidelines and nutrition education programs can help safeguard local knowledge and culinary practices.[409] Moreover, linking these efforts to public procurement policies—such as school feeding programmes— and social protection schemes can magnify their reach and impact.

Public investment in local and territorial markets can further strengthen value chains and stimulate demand for underutilized, nutritious, and locally produced foods.[411–414] Similarly, the development and support of local seed systems can play a critical role in preserving and scaling up agrobiodiversity, particularly under-consumed fruits, nuts, legumes and vegetables.[415] These species and their wide range of varieties within species have often been displaced by dominant staples like wheat and rice. Yet, they offer potentially climate resilience and nutrition benefits, and merit renewed attention.[416]

Goal 2: Produce the Planetary Health Diet within Planetary Boundaries

Solution 3: Implement sustainable and ecological intensification

In regions characterized by significant yield gaps, policies aimed at increasing productivity through sustainable and ecological intensification (SEI) practices can increase resource use efficiency by lowering the environmental impact per unit of production.[417] Conversely, in areas where agricultural productivity is already high, policy efforts should prioritize reducing environmental degradation and pollution associated with intensive farming systems and practices.

Securing long-term access to land and water resources is essential to enabling farmers to adopt and implement SEI practices, many of which entail substantial up-front costs and/or require longer time horizons to yield benefits—particularly when used to rehabilitate or recover exhausted or degraded lands.[418] Access to land is especially critical for women, who frequently face additional and entrenched legal and sociocultural barriers to ownership and control.[419] Despite their pivotal role in supporting marginal groups and remote communities, public advisory (extension) services have suffered from chronic underfunding.[420] Revitalizing and redesigning these services, with coordinated support from public, private and civil society actors, is essential to assist farmers in transitioning and adopting new methods towards sustainable practices.[420] Strategic investments in farmer networks—facilitating knowledge exchange, equipment sharing, and improved market access—can also lower adoption barriers. Brazil's success in promoting diversified and organic farming through the integration of farmer networks with supportive public policies offers a compelling model.[421]

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Addressing the structural imbalances between producers and dominant agribusiness corporations is critical. Strengthening anti-trust legislation and implementing policies to reduce excessive market concentration can reduce systemic barriers to SEI adoption and practices.[421] Robust competition policies can foster more equitable pricing for producers, support diversified market structures, and stimulate innovation,[14] all while contributing to the resilience of food systems.[422,423] In parallel, tighter regulation of food commodity speculation could stabilise producer incomes and create more favourable conditions for long-term investments.[424]

Both public and private sector investments are needed to support the transition to SEI practices, particularly in offsetting initial costs to advance the research and development of innovations and appropriate technologies.[425] Investment in labour-saving technologies can reduce the burden of otherwise labour-intensive practices, while crop breeding for high-yielding or climate resilient varieties suited to low chemical input conditions can improve the productivity and profitability for SEI. Financial mechanisms such as payments for ecosystem services,[426] cost-share payments,[421] and similar instruments could provide crucial support to farmers shifting towards sustainable practices. Historically, most agricultural subsidies have been directed toward a narrow set of staple crops—wheat, rice, maize, soy (for feed), and dairy.[417] To realign agricultural production to dietary recommendations that emphasize increased consumption of legumes, nuts, fruits, and vegetables, subsidies must reform.[427] Targeted investment in under-supported foods, alongside research to improve their yield, resilience, and regional adaptability, is essential to building more sustainable, health promoting agriculture systems.

Solution 4: Halt agricultural conversion of intact ecosystems

The multi-model ensemble results indicate a projected 7% decline in agricultural land by 2050 relative to 2020 driven by dietary shifts, increased agricultural productivity, and reductions in food loss and waste. However, to limit the expansion of agriculture and aquatic systems into intact systems, a combination of regulatory policies, community management, and multi-sectoral commitments and coordination are necessary. This may include the strict protection of natural ecosystems, and the suspension or limiting of logging concessions and commercial fishing licenses in protected areas. It is essential that these regulations are implemented in ways that minimise leakage, i.e. ensuring that the protection of land and water in one region does not inadvertently result in increased exploitation elsewhere.[428] Attention should be given to populations inhabiting or using resources in protected areas. This includes ensuring meaningful stakeholder engagement and where appropriate, empowering leadership by Indigenous communities.[429] Recognizing and securing land and sea tenure rights for these communities is essential. Retaining biodiversity intactness can also be compatible with certain forms of sustainable land/water use, such as wild harvesting, selective logging with native species, or extensive rangeland management that maintains native biodiversity. In such cases, sustainable uses are those that are well below the 10% Human Appropriation of Net Primary Productivity (**Table 2**), and where biodiversity intactness index values stay well above 95, thereby minimizing impact on species composition.[157]

Both regional policies and voluntary initiatives in the EU and the UK have introduced zero deforestation commitments across supply chains.[432] While a few region- and commodity-specific commitments have contributed to small reductions in deforestation,[433] the evidence of effectiveness of these efforts is

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limited, as they are still understudied and relatively new.[434,435] Yet, these initiatives have spurred progress in monitoring, traceability, and awareness of deforestation, and expanding their implementation to cover a larger share of the market could greatly increase their impact on global deforestation reduction.[435]

Solution 5: Reduce food loss and waste

The ensemble scenario results indicate that halving food loss and waste (FLW), in alignment with SDG target 12.3, yields moderate benefits across all five modelled Planetary Boundaries. Some level of loss or waste is inevitable for food safety and reliability of supply. Food losses and waste can be reduced, so that there is less demand on food production, or else recycled into the circular economy (see **Panel 4**). The 'Food Waste Pyramid'[436] outlines a hierarchy of recycling management options based on financial and environmental returns: depending on context, the highest priority is usually to feed waste to livestock (though livestock numbers are reduced in one of the EAT-*Lancet* scenarios), followed by industrial uses—including anaerobic digestion for biogas and other products—then composting, incineration, and finally, landfill disposal.

In lower-income contexts, food loss predominantly occurs at the production and post-harvest stages, whereas in higher-income contexts, consumer-level food waste is the main contributor.[437] Reducing food loss depends on improving storage, transportation logistics, and access to labour and equipment to ensure timely harvests and transformation of crops into food products sought after by the consumer. In some cases, shortening supply chains may reduce food loss by reducing the need for extended storage and distribution. Circular economy opportunities—such as the production of low-cost high-quality animal feed, renewable energy usage, and improved food safety—can provide demonstrable benefits (see **Panel 4**).[438]

To address food waste in households, food service, and retail, education initiatives, awareness campaigns, and skill-building remain the primary institutional tools. Technical interventions focus on leveraging data and analytics to improve the efficiency of food supply chains. To raise effectiveness of these soft tools, they should be complemented by regulatory measures, taxes and subsidies.[439] More systemic resolution of food waste must confront underlying drivers, institutional lock-ins, and rebound effects.[440] For example, aesthetic standards and preferences (e.g., size, colour, blemishes) imposed by markets contribute to supply chain losses and consumer waste. Similarly, current food safety laws and regulations, combined with existing investments in infrastructure, often favour incineration or landfill over alternative uses such as feeding waste to animals.

Goal 3: Secure Social Foundations

Solution 6: Secure decent work

There are several measures that can be implemented to ensure that work within food systems is safe, dignified, and equitable without discrimination based on gender, race, or other forms of difference. Securing decent work requires, among other actions, raising wages for food system workers to living wage levels[4] and promoting gender equitability across all roles and sectors.[441] Current workers may be affected by the changes in production and consumption patterns that are essential for food systems transformation. For example, a reduction in livestock production could impact employment across local, regional, and national scales, depending on how and where such transitions occur.[442] Therefore, improving working conditions and preventing exploitation should include more robust implementation

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and enforcement of legislation against child labour and forced labour,[443] protection from exposure to agricultural pollutants,[444] and prevention of gender-based violence and sexual harassment in the workplace.[445] Governments should also prioritize educational initiatives and legal support mechanisms for workers to strengthen the enforcement and uptake of such protections.

Solution 7: Ensure meaningful voice and representation

Securing meaningful voice and representation is critical to ensuring that decision-making processes in food systems are more democratic and inclusive. Collective bargaining mechanisms, supported and implemented through unions and civil society organizations, can advocate effectively for the rights and interests of food systems workers and small-scale producers and actors. For policies concerning both production and consumption, the proactive engagement of diverse coalitions and perspectives — including unions, civil society actors, and marginalised populations—can foster more democratic and participatory decision-making governance.[330] Although these processes may be slowed by disagreements and trade-offs, expert facilitation and the establishment of clear procedural guidelines can help ensure momentum and constructive progress.[330] Importantly, such inclusive platforms can contribute to improved food systems governance by enabling interaction among actors across sectors and scales,[446] while empowering local institutions and promoting decentralised decision-making authority.[447]

Power imbalances similarly affect consumers, who often have limited influence over the terms of food access, affordability, and quality.[423] Ensuring consumer representation through regulatory mechanisms, participatory food policy councils, and consumer advocacy groups can help rebalance these asymmetries and strengthen individual and collective agency within food system governance.[448]

Additional measures to democratize food systems include the allocation of reserved seats in policy forums for marginalised groups,[449] the institutionalisation of citizens' assemblies and consultations.[450] Efforts to counter corporate influence and concentration should involve stricter regulations on political donations, mechanisms to mitigate conflicts of interest, and greater transparency in lobbying and the funding of scientific research.[14] Policies to address corporate concentration should include strengthened national and international competition frameworks,[14] alongside regulatory mechanisms to identify, monitor, and mitigate undue corporate influence on policy and governance processes.

Deliberate efforts to build inclusive coalitions that include marginalised groups while also increasing transparency and accountability and expanding access to information can create new spaces for dialogue.

Solution 8: Recognise and protect marginalised groups

Embedding justice into decision-making processes ensures that the responsibility for advocacy does not fall disproportionately on marginalised groups. The implementation of a comprehensive set of social protection policies can improve access to, and affordability of, healthy and sustainable diets. Social protection measures—including school meals (**Panel 11**), unconditional cash transfers, maternity entitlements, old age pension, and disability benefits—are broad-based interventions that directly or indirectly improve food security and nutrition.[4,451]

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Additional strategies include targeting financial support for women farmers, crop and livestock insurance to buffer against shocks, subsidies for farm inputs and technologies, and food price stabilisation mechanisms such as internationally coordinated food storage policies.[452] Ensuring that solutions are co-created with marginalised communities can help create context-specific solutions that are socially acceptable.[453] Co-creation should be facilitated through improved representation, as previously discussed, and by engaging directly with affected groups—especially early in the transformation process.[454] This also requires sustained support, including funding for inclusive initiatives and training programs that build capacities within marginalised populations. Finally, NGOs play a vital role in safeguarding basic human rights for people in conflict-affected areas, and this role should be supported by multilateral organisations and national governments. Interventions may include establishing safe zones as a short-term measure, rebuilding food supply chains with international assistance in the medium term, and creating dedicated funding mechanisms to prevent and alleviate famines in conflict areas over the longterm.[327]

Adopt responsible, equitable technology and innovation across solutions

While none of the solutions explicitly focus on emerging technologies, technological innovation is relevant across food system transformation. Emerging technologies—such as artificial intelligence, cellular agriculture, nanotechnology, and robotics—have the potential to significantly reshape and disrupt agriculture and food systems.[367,455] These innovations could enhance agricultural productivity without expanding land use, thereby contributing to reduced deforestation and habitat loss. They may also facilitate precision farming, reduce waste, and optimize the use of key inputs like water and fertilizers.[367]

The effectiveness of these technologies will depend on balanced and strategic investments that align their development, deployment, and use with principles of equity, responsible innovation, and coherent policy frameworks,[456,457] as well as the broader transition to renewable energy sources. Redirecting public and private funding toward near-ready technologies that support the solutions described in this report will be critical. Comprehensive evaluation of emerging technologies—considering their impacts across different geographical and cultural contexts—is essential to ensure they contribute to just food systems transformations.[458] This includes recognizing that technologies can have both positive and negative effects, many of which remain uncertain—particularly in the case of rapidly advancing tools like artificial intelligence. To avoid and or mitigate unintended environmental and social trade-offs, investments should be carefully targeted to ensure broad accessibility and fair distribution of the technologies.[455,457] Among the most discussed technologies relevant to dietary shifts are novel alternatives to replacing conventional meat. **Panel 10** explores their potential implications for health, environment, and justice.

Panel 10: The potential role of meat alternatives in meeting EAT-*Lancet* targets

The Commission recommends a plant-rich diet with large shares of protein coming from minimally processed plant foods, such as legumes (**Section Healthy Diets**). We also find that globally, and in most regions, consumption of red meat and other meats is above healthy and sustainable levels. As consumer studies have revealed several barriers to replacing animal protein sources with traditional plant protein sources, including convenience, taste, and cultural values,[P92] a range of meat alternatives are emerging across several regions, particularly in HICs. They include plant-based alternatives (PBAs),

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fermentation-derived products (using microorganisms to produce protein-rich foods), and cultivated meat from animal cells designed to replicate the sensory properties of animal-source foods.[P92] Previous systematic reviews[P94,P95] and modelling studies[P96,P97] suggest that replacing conventional meat with these alternatives could have both positive and negative implications on health, environment, and justice. The potential impacts are context-dependent and vary based on the specific ingredients, processing levels, and what they replace within the diet.

Environmental Implications

It is well established that whole high-protein plant foods and traditional products prepared from these foods (tofu, tempeh) have lower environmental impacts than animal foods. Meta-analyses and modelling studies indicate that PBAs can also have substantially lower environmental impacts compared to meat, particularly regarding greenhouse gas (GHG) emissions and land use, but greater impacts than minimally processed plant foods.[P94,P95,P97] Cultivated meat and fermentation-derived products are anticipated to have higher GHG emissions than PBAs and minimally processed plant foods, and lower to similar GHG emissions, land and water use compared to conventional meat, with its impact reduction potential being largely dependent on the transition to renewable energy sources.[P93,P98]

Health Implications

Replacing red meat with legumes and other plant protein sources can provide several health benefits. The nutritional performance of emerging meat alternatives varies widely based on each product´s specific formulation, levels of processing, nutritional composition and density, and what they are replacing in the diet. PBAs that contain substantial amounts of legumes, vegetables, and nuts are found to have favourable nutritional profiles,[P95] contributing to higher intake of fibre and folate, and lower saturated fat intake.[P94,P97] However, some PBAs are highly processed, high in added sugar, salt, and saturated fat. Further research is required on the bioavailability of vitamins and minerals as well as the protein quality of PBAs and fermentation-based alternatives for a better understanding of the nutritional effects of integrating them into diets. Cultivated meat is expected to have a similar nutritional profile as conventional meat and might therefore be similarly associated with colorectal cancer and other diet-related diseases.[P97] The recommended consumption levels of processed meat alternatives remain similar to those of conventional meat in **Table 1**.

Justice Implications

There is less understanding of the role of emerging meat alternatives on socio-economic consequences including food and nutrition security. Price is a key driver of purchase and consumption. While unprocessed legumes are least expensive, PBAs are currently often more expensive than the products they aim to replace.[P97] Cultivated meats are currently not widely available, but despite high uncertainties, the existing peer-reviewed assessments not related to industry interests suggest it will not be a cost-competitive product even with substantial investment and improved production methods.[P99–101] The alternative meat industry could have additional implications for the labour market, e.g., by generating and shifting employment from rural areas to cities.[P93,P102] As many large transnational food corporations enter the emerging market for meat alternatives, there are concerns regarding further market concentration/consolidation in the form of protein companies.[P102,P103] Emerging alternatives may mitigate animal welfare concerns, although cultivated meat still involves some animal use through tissue biopsy removal.[P104]

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Section 6: A Just Food Systems Transformation is possible

The magnitude of changes needed to shift from an unsustainable '*status quo*' to the outcomes advocated for in this Commission are admittedly enormous. **Figure 14** illustrates the differences between the present state, the projected trajectory under business-as-usual (BAU) scenarios for environmental and dietary patterns from the DIA-GIO model, and the projected trajectory needed for desired future state aligned with global adoption of the Planetary Health Diet, food system boundaries, and social foundations by 2050. For all the variables where we have modelled current trends (a-i), is shown how substantially different the future trajectory needs to be compared to the current one.

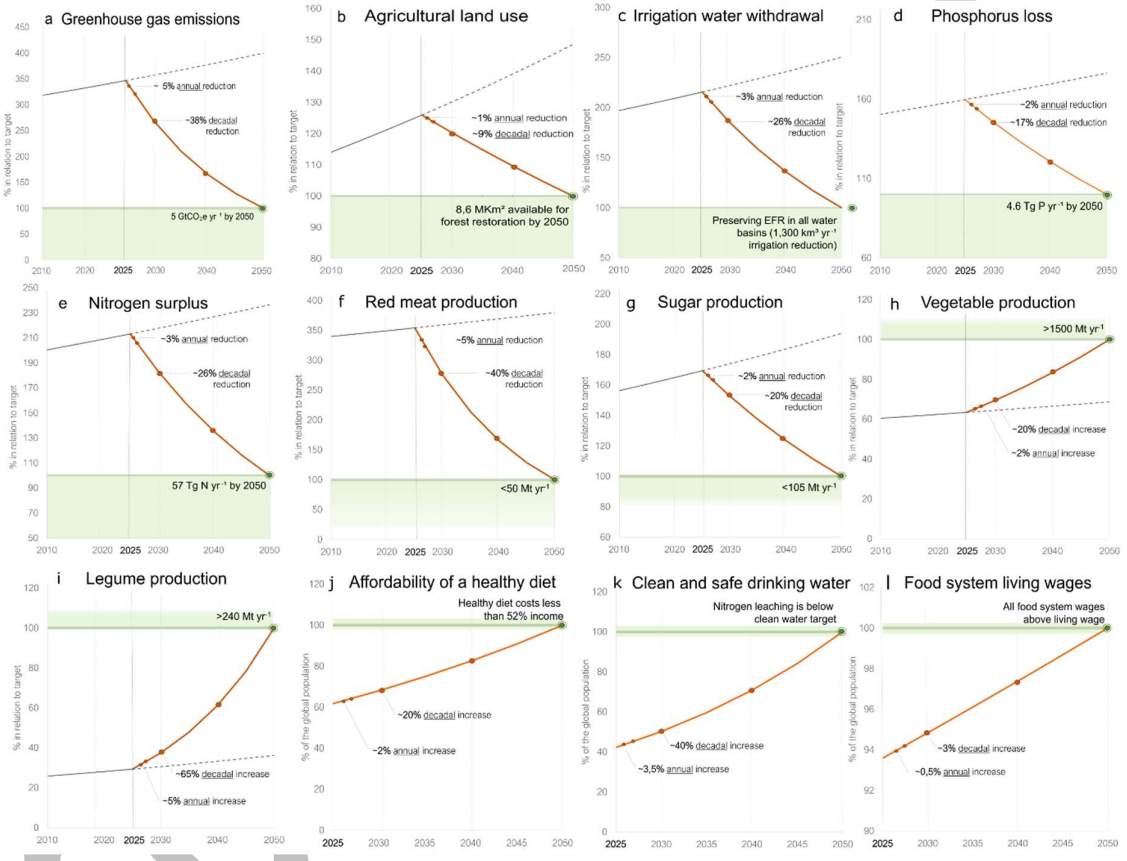


Figure 14. The development trajectories needed to meet the Commission's suggested targets for production of food groups to support the Planetary Health Diet, impacts on Food Planetary Boundaries, and associated annual and decadal rate of change required to meet targets in 2050. Environment targets (a,b,c,d,e) are based on the food system boundaries (**Table 2**). Note that irrigation water withdrawal required is based on aggregated *regional* overshoot of ecological flow requirements in water basins. Global production targets (f,g,h,i) are based on food demand following Planetary Health Diet implementation and halving of FLW under SSP2 based on DIA-GIO model results. BAU trajectories for the production and environmental targets are also based on DIA-GIO model results (**Modelling section**). Social foundations (j,k,l) are based on ensuring everyone is above the social foundation (i.e. 100% of the global population), where trajectories show the current global population (%) that is below each social foundation, based on recent estimates (**Justice section**).

To accelerate progress, the Commission calls for the development of transformative roadmaps to ensure that, by 2050, all individuals have access to healthy diets that are equitably produced, processed, and distributed within planetary boundaries. These roadmaps should be tailored to different sectors, scales, actors, and geographies. We propose five steps to guide their development:

(1) establish context-specific bundles of actions and policies; (2) set and track targets that enable collective action and transparent accountability; (3) build coalitions of diverse actors; (4) identify and address barriers to change; and (5) unlock financial resources for transformation. These steps broadly align with prior work to develop implementation roadmaps for food systems,[161,367,459,460] climate, and biodiversity.[27] In the sections that follow, we elaborate on each step, highlighting its rationale and the enabling conditions for its success.

Establish context-specific bundles of actions and policies

All solutions identified earlier (**Figure 13**) contribute to a specific goal (health, sustainability, or justice), with potential positive or negative additional contributions to other goals. For example, fiscal policies aimed at promoting healthy diets (Action 1) can yield co-benefits for both public health and environmental sustainability. However, such policies may generate trade-offs with justice unless accompanied by public investments in social protection that increase purchasing power for low-income households (Action 3, 15 and 22-23). While these interventions may independently contribute to shifts in production management and consumption patterns toward more sustainable and equitable outcomes, their transformative potential is fully realized only when implemented as contextually appropriate bundles of mutually reinforcing actions.

Bundling is the implementation of multiple actions simultaneously or in an intentionally staggered manner. We refer to bundles as '*a coherent set of interventions designed explicitly to achieve a single or multiple objectives of interest*'.[9] An example of an action bundle is the UK initiative 'A blue print to halve obesity' in five years, which comprises more than 30 intentionally integrated policies spanning different domains.[462] Bundling has been proposed as a necessary condition for food systems transformation.[27,461]

Identifying and bundling actions is an inherently social process that requires cooperation and coordination beyond the implementation of singular policy or technical measures.[461] It extends beyond policy coherence by addressing both short- and long-term objectives, demanding attention to the governance of transition.[463] Resistance to change, often mobilized by actors adversely affected by specific measures, can constrain implementation.[461] Systematic bundling offers a means to mitigate trade-offs between political feasibility and policy effectiveness.[27,464] It can also increase the acceptability of measures by, for example, combining actions that increase costs for consumers (e.g., taxes on meat), with those that offer discounts on low-emission food alternatives.[464] Integrating social protection mechanisms or retraining opportunities with prioritized interventions can help mitigate resistance by addressing short-term vulnerabilities associated with structural transitions.[461] For instance, combining actions to shift dietary patterns (Solution 1) and improve sustainable and ecological intensification of healthy food groups (Solution 3) with the provision of training in skills to support redeployment (Action 16) can support the broader goal of securing decent work (Solution 6).

Well-sequenced and gradually enacted policies can generate positive tipping points,[465] whereby early successful interventions build public trust and facilitate broader acceptance of subsequent reforms. In contexts where interventions are met with scepticism or bias, combining interventions with robust evaluations can foster support over time, allowing citizens to engage with the interventions directly and observe its effects.[466] Careful policy sequencing is therefore critical: poorly timed or misaligned reforms can erode confidence in government abilities, undermining legitimacy for future initiatives.

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For example, changes in agricultural management require time to build the necessary skills and conditions to adopt sustainable and ecological practices. In Sri Lanka, the abrupt ban on agrochemicals in pursuit of organic agriculture failed to account for the time required to train farmers in organic techniques, build soil organic matter, and develop integrated pest management practices.[467] This led to collapsing yields, which could have been avoided with a more phased and strategically sequenced policy roll out. Similar challenges have arisen in the Netherlands with the implementation of nitrogen regulations,[468] and in France, where the fuel tax contributed to the emergence of the Yellow Vest movement.[469]

Governments can enhance their ability to effectively bundle, sequence, and prioritise interventions through institutional mechanisms that foster cross-sectoral collaboration—such as inter-ministerial coordination—and by partnering more closely with research organisations. A compelling example of this type of partnership is Brazil's Fome Zero (Zero Hunger) Program[470], which integrated efforts across Ministries of Health, Education, and Social Development, in collaboration with research organisations. The program strategically bundled policies including cash transfers for poor households, support for small-scale farmers, and nutrition education to address food insecurity and promote sustainable agriculture.[470,471]

Prioritizing different actions in different regions

Bundles of actions for food system transformation will vary significantly across contexts. For example, consumption side actions to achieve the PHD (Solution 1) need to be a high priority in HICs and upper MICs, as per capita consumption contributes disproportionately to transgressing planetary boundaries. The per capita externality costs to human health and ecosystems are nearly four times higher in North America and Oceania than in Sub-Saharan Africa,[472] despite the relative burden of these costs (as a share of GDP) being greater in LICs. HICs[8] also bear a greater responsibility for reducing energy-related emissions and supporting food systems improvements in LMICs,[473] efforts that are essential to achieving the mitigation pathway modelled in this Commission (ELM). Accordingly, the societal benefits of dietary shifts towards the PHD would be especially high in HICs and upper MICs.[8]

In many LICs and MICs, priorities should instead include maintaining existing healthy dietary patterns (especially among youth), addressing hunger and undernutrition, and preventing expansion of unhealthy diets (Solution 2).

MICs, in particular, have the greatest overall potential to reduce food systems-related climate emissions on the production side by shifting toward more sustainable agricultural practices (e.g. Solution 3) and adopting cleaner, more circular processing systems (incl. Solution 5).[473]

Others[474] work that includes stakeholder consultations on regional food systems priorities have highlighted the following prioritization focal areas: increasing food availability in East and Southern Africa; promoting income growth in West and Central Africa; improving the nutritional quality of diets in the Pacific; and protecting against deforestation in Latin America.

Set and track targets to enable collective action and accountability

Target-setting has emerged as a strategy to align diverse actors around shared ambitions and responsibilities, improve policy integration, and help overcome barriers to transformation.[463] Global

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targets can shape international agendas and catalyse bold policies across multiple scales. For example, net-zero emissions targets aligned with the Paris Agreement—while insufficient on their own—have nonetheless accelerated progress in carbon markets (e.g., the EU Emissions Trading System TS) and spurred rapid expansion of renewable energy development.

The identification of PHD reference values and ranges, food system boundaries, and social foundations represents an initial step toward establishing science-based targets for food systems. While global targets can foster a shared vision and ambition, their translation into concrete actions across scales and sectors is essential for achieving meaningful impact.[475] Such target setting should be grounded in independent scientific assessments, be attainable and actionable, and supported by a transparent analytical rationale. Their achievement must be measurable.[476] Science-based targets are most effective when developed and implemented through inclusive dialogues with diverse stakeholders.[477] There is a critical need for methodological advancements to enable disaggregation of targets (and their indicators) across geographic scales (local, municipal, national, global) and across sectors.[476]

Recently, there has been a growing uptake of voluntary science-based target commitments by companies, cities (see e.g. **Panel 12**), and national governments—such as wide adoption of the '*Voluntary Guidelines on Food Systems and Nutrition*', established by the Committee on World Food Security.[478] Voluntary commitments have corresponded with increased action,[479] especially in the climate domain. Corporate initiatives can drive transformation by leveraging their leadership positions, enabling mutual learning among adopters of science-based targets, and fostering trust and competitiveness through engagement with expert groups and accountability mechanisms.[480]

However, research on voluntary science-based target setting remains nascent. Emerging evidence suggests that without effective implementation, monitoring and evaluation, such commitments may risk hindering transformative change—e.g., by legitimising powerful corporate actors and insulating them from democratic oversight.[479] To accelerate progress and ensure measurable improvements, transitioning science-based targets from voluntary frameworks to regulatory mechanisms is essential.[478]

Ensure monitoring and evaluation of targets and actions

Improved monitoring across food systems is essential for monitoring progress towards proposed targets, and informing adaptive, evidence-based decision-making. Recent calls from the scientific community have emphasized the need for monitoring frameworks that move beyond tracking isolated indicators and instead integrated, multi-layered, cross-sectoral data—bridging analyses that have traditionally been treated in silos.[482,483] Such approaches enhance compliance and accountability.[482]

One example is the Food System Countdown to 2030 Initiative[29,460] which promotes greater accountability and transparency through comprehensive global monitoring of food systems across five domains: diets, nutrition, and health; environment, natural resources, and production; livelihoods, poverty, and equity; governance; and resilience.[29,484] Robust monitoring and evaluation (M&E) systems are also important for supporting learnings about what works, particularly given the limited context-specific evidence on the effectiveness of food system interventions, particularly when bundled.[27] M&E

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frameworks must therefore facilitate iterative refinement of strategies and actions in response to emerging evidence and shifting conditions.[486]

The current evidence gaps, combined with the urgent need for action, underscore the need to improve science-policy interfaces through greater integration, iteration, and interaction among researchers, policy actors and stakeholders across society[487,488]. Effective M&E frameworks should be co-developed by multiple stakeholders—including government, industry, civil society, and research institutions.[367,457] While scientific assessments play a key role in synthesising existing knowledge, novel tools are required to evaluate the impacts of bundled and sequenced interventions rather than isolated actions.[489]

Stronger alignment between global and sub-global assessments—such as those from the *Lancet* Commissions, the Food System Economic Commission, the High-Level Panel of Experts on Food Security and Nutrition, and IPES-Food—and corresponding assessments on climate, environment, biodiversity health, and justice (e.g., with IPCC, IPBES, and the Earth Commission to name a few) would enhance the capacity to integrate and leverage collective knowledge across domains.[483] National food system pathways, supported by the UN Food Systems Summit, offer a timely opportunity to develop integrated roadmaps that connect food system transformation with climate, biodiversity, health, and economic objectives.

Build coalitions of diverse actors

Effective bundling of actions requires coalitions of actors to negotiate between contending interests, navigate difficult choices,[367,461] and ensure that the necessary capacities are deployed for transformation.[490] The recent UN Food Systems Summit highlighted coalitions as essential for addressing food systems' multi-sectoral and multi-scalar challenges, leading to over 20 coalitions being formed to deal with issues like school meals (**Panel 11**), deforestation, agroecology, blue foods, data transparency, and fair wages.[491]

Coalitions can bring a variety actors with divergent interests and perspectives to the table to negotiate more inclusive, viable, and realistic pathways.[487] Food policies will have different winners and losers, and tensions will need to be managed.[9] For instance, fear of job losses in certain sectors can paralyse reforms towards sustainability. In such cases, coalitions could negotiate ways to compensate those who stand to lose or invest in new opportunities that would benefit them.[9]

Different food system actors have varying capacities to enact change. Interventions that could enable system shifts have sometimes stalled, often due to delays and bottlenecks in regulatory processes.[4] Communities, International NGOs, and other stakeholders can deploy different capabilities to support transformation in different ways. By forming stronger alliances and coalitions, these actors can implement more coordinated and timely interventions for transformative change.[492] Realizing food systems transformation will require novel forms of partnership among inter-governmental and global institutions, national governments, sub-national public authorities (e.g., cities, states, and municipalities), and inter-ministerial committees can align policies across sectors. Engagement from the private sector, civil society, and social movements is equally critical.[473] Different actors bring distinct capacities and mandates, each playing a unique role in shaping systemic change.[458] Transformation cannot occur without forging coalitions that span boundaries, reconcile divergent interests, and build broad-based legitimacy for new policy pathways.[490,493] Initiatives such as the UN Zero Hunger coalition,

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the EU Farm to Fork policy framework, and the School Meals Coalition (**Panel 11**) illustrate how diverse competencies and agendas can be integrated to advance health, environmental sustainability, and justice in tandem.

Identify and address barriers to change

Coalitions aiming to advance food systems transformation involve actors and stakeholders with different interests and tactics to preserve such interests, sometimes designed to maintain the status quo.[494,495] These competing interests shape the incentives and constraints surrounding transformative efforts.[461] For coalitions to function effectively, three key barriers must be addressed: (1) lack of political leadership; (2) corporate interests; and (3) weak and fragmented demand for action.

Lack of political leadership and appropriate governance framework

Political leadership has been notably absent in driving transformative food policy agendas and committing resources to long-term structural change to food systems.[423] Short electoral cycles often discourage support for policies whose benefits, such as improvements in population health, are realized beyond a single political term. This hesitancy is compounded by substantial upfront investments required for transformation, and the perceived risks these pose to, for example, employment and food prices.[9,496] Moreover, government subsidies often favour large corporate actors over broader public welfare and public goods.[497]

Effective transformation requires coordinated, intersectoral policy actions that extend beyond food systems themselves. Yet current governance arrangements often fall short to systematically address and integrate agriculture and the environment, health and nutrition, infrastructure, energy, growth, and equity.[484]

Corporate interests used against public interests

The second major barrier is the exercise of corporate power in ways that undermine public interests. The high degree of corporate concentration across food systems remains an intractable governance issue.[333,498] This is partly due to the out-sized influence of large transnational food and beverage companies who have considerable power and resources at their disposal to block initiatives.[17] Concentrated market structures, with a few dominant firms, are common in food systems from production (agricultural inputs), trade (commodity trade), and consumption (food processing and retail),[14,499] that impact people's access to food e.g. through manipulative pricing, as well as advertising and packaging that shapes consumers' preferences.[500] Corporate actors employ tactics such as direct lobbying of governmental officials to undermine political priorities, including dietary guidelines and regulatory interventions.[501] Another avenue of influence by corporate interests is in the sponsorship of scientific studies that aligns with commercial interests and the dissemination of misinformation aimed at discrediting independent scientific evidence—such as in cases involving meat industry-sponsored scientists.[502,503] Furthermore, public-private partnerships are increasingly co-opted by corporate actors to shape discourses, particularly in the area of sustainability, in ways that reinforce their legitimacy and market power.[504,505]

Weak and fragmented demand for action

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A perceived lack of effective public demand and acceptance for transformative change is frequently cited by policymakers and private sector actors as justification for deprioritising ambitious reforms. Citizens may resist policies that ultimately serve the public due to the difficulty of weighing short-term costs, particularly in terms of employment in affected sectors, against long-term benefits.[466,486]

While grassroot actors play a critical role in building public engagement and political momentum for more equitable and sustainable food systems,[506] their efforts are often fragmented and constrained by entrenched power dynamics and the structural inequities of food systems.[499,507] In some repressive political contexts, civil society and grassroot organisations are deliberately excluded or marginalized by authoritarian regimes, further silencing calls for change. In other contexts, grassroot mobilisation can itself become a source of polarisation with some backing policies that might not promote public good over the long term.

Fragmentation in public demand can also stem from a lack of consensus on priorities and insufficient space for dialogue—particularly facilitated, inclusive processes that can clarify areas of disagreement and forge common ground.[477] These challenges are especially pronounced with global commitment mechanisms—such as the Paris Agreement or the Kunming-Montreal Global Biodiversity Framework—into local or national actions.[21] Misinformation further compounds public disengagement, especially when systemic challenges like public health are framed as matters of individual responsibility. This framing distorts public understanding of the structural determinants and diminishes support for necessary reforms.[508] The absence of transparent monitoring systems exacerbates the problem by undermining public trust in transformational policies and fostering uncertainty or misconceptions about their potential for delivering broad-based benefits.[509]

Unlock financial resources for transformation

It has been suggested that financial resources, averaging US$500 billion each year between now and 2050, are needed to enable necessary food systems transformations.[9] However, benefits could amount to more than 5 trillion a year.[9] Importantly, not all actions require large amounts of financial resources to be successful. Some can be implemented at relatively low cost or can even be cost neutral. However, they require willingness to reprioritize current resource spending. Here, we first look at the potential to unlock resources within the food system, primarily through bundling of different activities that already happens in the food system. We then explore how to unlock resources by bundling with broader policy agendas.

Repurposing subsidies, and other food systems investments

Subsidies to the agriculture sector represent a significant resource estimated at roughly US$851 billion in the 2020-2022 period (for the 54 countries that report to the Organization for Economic Cooperation and Development). The Food Systems Economic Commission has estimated that the cost of food systems transformation is between US$200-500 billion per year.[9] Without changing the degree of financing provided to food production, setting clear conditions for the use of these currently earmarked public funds in favour of public goods such as public health, and environmental security would be a major first step towards transformation.[417] At least a third of agricultural subsidies have no public benefit and could be repurposed.[510] In the EU, 82% of the European Union's agricultural subsidies favour animal-based agriculture.[510] Farm sector subsidies could be used to incentivize or invest in

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sustainable/ecological intensification, focusing on management of opportunity crops that are currently neglected in relation to healthy diet, while promoting dietary change.[427] Fisheries subsidies of around US$35 billion each year, could be used to support sustainable aquatic production practices rather than contribute to falling fish stocks and declining profitability, which in turn fuels more over-fishing as well as environmentally damaging forms land-based aquaculture.[511]

Shifts in agricultural and other subsidies, or value-added tax (VAT) can reduce health costs and increase health benefits, while lowering climate impacts.[380] Health directed taxation of meat products could yield a 9% decrease in premature deaths associated with red and processed meat consumption, with an estimated 14% decrease in attributable health costs globally, notably in high and middle-income countries.[380]

Measures that seek to distribute income more equitably (via e.g. social protection measures or progressive tax policies), combined with a serious public and private sector commitment to reducing food loss and waste along all food value chains, can together improve the relative affordability of healthy dietary patterns. When these and other measures were combined in a previous modelling effort, the cost of Planetary Health Diet aligned diets fell by 25-29% in low-income to lower middle-income countries.[8] However, the substantial restructuring of any sector, including the 'repurposing' of any kind of subsidy should be handled with care, since the potential unintended effects of shifting resources from one targeted purpose to another can be as significant as the intended effects.[512]

Alignment of investments with the climate-, nature/biodiversity-, and economic agendas

Another way to unlock resources for food systems transformation is to align approaches and financial priorities with other critically and mutually interdependent policy and investment agendas. A share of climate or biodiversity finance funding could be turned towards food systems transformation. For example, at the Conference of Parties (COP) climate summit in Egypt in 2022 (COP27), the COP Presidency and World Health Organization launched the Initiative on Climate Action and Nutrition (I-CAN), to better integrate the global delivery of climate change adaptation and mitigation goals and the policy action necessary to meet nutrition and sustainable food systems goals.[513] This alignment requires future summit agendas, focused on climate, fossil fuels, renewable energy, employment growth, food systems, and more, to work towards integration of targets and investment modalities. However, many initiatives currently lack coherence and alignment with agriculture and other policies at different levels. This is the case, for instance, of the many initiatives on tree planting which, if showing considerable benefits for food security, nutrition and the environment, remain largely uncoordinated (Vansant 2024.[514,515] By ramping up these efforts, governments can work more strategically to integrate and coordinate these multiple agendas to repurpose fiscal incentives away from economic "bads" (e.g. carbon emissions, biodiversity destruction, consumption of excessive sugar, salt or trans-fats, etc.) towards public goods.[516]

In 2022, subsidies to the energy sector (currently driven by fossil fuels) were estimated to be around US$7 trillion.[517] Ending subsidy support to polluting energy production would allow for a repurposing of resources to alternative public sector investments.[518] The latter would include regenerative energy to support diet quality through, for example, solar-powered drying and chilling of perishable foods, and other innovations in cold chain technologies that significantly reduce nutrient-rich food loss and waste. However, project-level climate financing for food systems stands at only 4.3%, or US$28 billion, of global

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climate finance for mitigation and adaptation in all sectors, with specific mitigation finance in the food sector being only 2.2% of total climate finance.[473] In their "Recipes for a Liveable Planet Report", the World Bank estimates that annual investments in reducing food systems emissions will need to increase by 18 times, to US$260 billion, to reduce current food system emissions by half by 2030.[473]

Different ways to unlock finance for food systems transformation could work if banks, investors, and large businesses adopt and report against the Taskforce on Climate Related Financial Disclosures (TCFD), help develop the Taskforce on Nature-related Financial Disclosure (TNFD), and set Science-Based Targets (SBTs), targeting Paris-aligned/net zero portfolios.[519] Through these agendas, financial institutions can commit to a variety of portfolios to shift towards more sustainable food systems, such as deforestation-free portfolios (e.g., deforestation-free pension funds). Public spending should also create mechanisms for private investment in food systems transformation. Central banks can for example introduce stress testing for financial institutions based on their viability in a future economy that fully accounts for negative externalities.

The cost of food systems transformation for lower-income groups and countries are beyond their current financing capacity. Lifting their financing constraints is critical to unlock the global benefits of transformation.[473] Countries with limited fiscal capacity need international support to invest in food systems sustainability.[517]

Wealthy countries and other donors should increase Overseas Development Assistance (ODA) from current low levels (relative to their actual and projected national wealth), as well as climate finance for food systems adaptation through multilateral development finance institutions. Wealthy governments can introduce targeted debt relief to facilitate the flow of capital to food systems transformations, including debt for food swaps. This could be supported by innovative financial instruments, such as guarantees for a new type of perpetual/long-dated social and environmental bond, with capped adjustable rates.

Conclusions: accelerating meaningful action

The Commission calls for an urgent, comprehensive approach to food systems transformation, centred on the development of context-specific roadmaps that lay out viable evidence-based solution sets. Such roadmaps should focus on bundling actions, setting science-based targets, building inclusive coalitions, establishing and building on already existing monitoring and accountability mechanisms, and mobilising financial resources at scale. At the core of the Commission's framework are three foundational elements: (1) recommended food group intake values for the Planetary Health Diet to advance human health; (2) food system planetary boundaries to ensure achieve environmental sustainability; and (3) social foundations to guide the creation of just food systems. These values, boundaries, and foundations can provide the guide for target-setting and collective action, adaptable across geographies and sectors.

The Commission has identified eight solutions and 23 actions to enable food systems transformation. These can be organized into coherent 'bundles' of interventions that simultaneously advance health, environmental and justice goals. Bundling enhances political feasibility and policy effectiveness, particularly when designed to prioritise the needs of marginalised and disadvantaged populations. The most suitable and effective bundles will vary by context and should be tailored to the specific challenges and opportunities of each region and sector.

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Cross-sectoral coalitions—including actors from public institutions, private sector, and civil society—are essential to achieve synergistic governance. These coalitions must align with existing and emerging global frameworks, such as the Paris Agreement, the Convention on Biological Diversity, and the post-2030 SDG agenda. Ensuring accountability within such coalitions is critical. Mechanisms must be established to insulate policymaking from undue corporate influence, while civil society and social movements play a vital role in promoting transparency and oversight.

The Commission also underscores the need for actions beyond the food system. Its modelling indicates that the PHD can only be achieved within GHG and land-use planetary boundaries if mitigation efforts in other sectors are also scaled up. Similarly, shifting diets among low-income and vulnerable groups requires coupling dietary interventions with broader social protection measures. Affordability must be achieved not only by lowering food prices but also by addressing structural poverty and inequities. Financing for food systems transformation must draw from broader funding streams—such as those targeting climate mitigation and biodiversity conservation and protection—rather than relying solely on current food systems financing.

Finally, the Commission positions justice as both a central goal and a driving force for food systems transformation. Food systems cannot be just without ensuring the PHD is affordable and accessible to all, and without significantly reducing transgressions of planetary boundaries. At the same time, justice is necessary to overcome the deeply entrenched structural barriers that currently impede transformative change. In this sense, justice is not only an outcome of food systems transformation, but a prerequisite for enabling it.

Panel 11: School meals

School meals are increasingly recognised as a cost-efficient investment for governments to advance multiple policy objectives, including health and nutrition, education, social protection, and agriculture.[P105] Well-designed and strategically implemented school meal programmes throughout the next 7,000 days – the period of development between the first 1,000 days of life and adulthood – can make a lasting impact, particularly on the most vulnerable children and adolescents, by improving attendance and academic performance, and reducing dropout rates.[P106]

Moreover, school meals programmes make up one of the largest outputs of the global food system, feeding 420 million children daily. Sustainable school meals coupled with consistent and action-oriented food education can empower future generations by fostering healthier and more sustainable food habits at a critical age when life-long dietary preferences and social attitudes are formed and carried into adulthood.

In 2021, in recognition of the unique potential of school meals for improving child health, wellbeing, and education following the COVID-19 pandemic, national governments formed the global School Meals Coalition (SMC), declaring their commitment to scaling up and strengthening their national school meals programmes to ensure every child has access to a nutritious meal at school by 2030. To support the (now) 105 SMC member states to achieve this ambitious mission, the independent Research Consortium for School Health and Nutrition, with the input of 160 global experts from more

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than 80 organisations, identified evidence-based policy approaches to support the delivery of diverse, balanced, and sustainably produced school meals.

Since these programmes are overwhelmingly domestically financed and managed, the policy levers lie in the hands of national governments, allowing for significant change to be made at pace. Incorporating sustainable school meal policies can lower environmental impact, improve climate resilience and leverage food system transformation in both high- and low-income settings. Key policy strategies to support positive change in this area include providing nutrient-rich menus, that are predominantly plant-based; sourcing production from local farms using sustainable and ecological intensification practices that support agrobiodiversity and climate resilience, as well as structured demand and stable markets to smallholder farmers and processors; shifting to efficient cooking solutions to reduce negative health and environmental impacts; reducing food loss and waste; and ensuring action-oriented food and climate education to enable future generations to make sustainable choices. With increased awareness, children also serve as powerful agents of change among their families and broader communities.[P107]

Countries and regional bodies are already demonstrating that these actions are possible. Europe, for example, now requires a minimum share of organic foods in school menus,[P108] and approximately 40% of national school meals programmes currently have agriculture policy objectives such as agrobiodiversity, food sovereignty, and climate-smart foods.[P109] The national school meals programme in Brazil legislates that at least 30% of the food used in the preparation of school meals is locally sourced from family farms.[P110] Like Brazil, many countries in Africa and Asia have implemented a food systems approach to school meals, often involving public-private partnerships.

While financing is often the barrier to scale-up, food-related costs of providing healthy and sustainable school meals to every child could amount to up to 1% of GDP in low-income countries where school meal coverage is low.[P111] When weighing the long-term costs of inaction—such as the treatment of diet-related health issues and the impact of greenhouse gas emissions—the case for investing in school meals becomes undeniably compelling. The study identified savings of US$ 120-200 billion in treating diet-related illnesses (including US$ 7-13 billion in low-income countries), and a reduction in climate change costs of US$ 18-70 billion (including US$ 1-5 billion in low-income countries). The savings were greatest, in each case, for meal compositions in line with recommendations for healthy and sustainable dietary patterns.

In summary, sustainable school meals policies can positively influence dietary preferences of the next generation, and promote the adoption of sustainable production practices, broaden the local food basket and stimulate crop diversity, along with other social and economic development outcomes. The inclusion of school meals on the climate finance agenda, as well as in Nationally Determined Contributions for both health and the environment are critical steps to more resilient, sustainable, and equitable food systems.

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Panel 12: 40 Cities Initiative to achieve the Planetary Health Diet for All by 2030

Launched in October 2019 by *C40*, a global network of almost 100 mayors of leading cities committed to addressing climate change, 16 cities signed up to an ambitious initiative aiming to achieve the Planetary Health Diet for all by 2030 in ways that are "reflective of the culture, geography, and demography of their residents". Seven of the cities are in Europe, five in North America, one in South America, two in East Asia and one in South-East Asia.

The cities signing up pledged to implement four important measures by 2030:

- Aligning their food procurement to the Planetary Health Diet.
- Supporting an overall increase of healthy plant-based food consumption by shifting away from unsustainable, unhealthy diets.
- Reducing food loss and waste by 50% from a 2015 baseline.
- Working with residents, businesses, public institutions and other organizations to develop a joint strategy for implementing these measures and achieving these goals inclusively and equitably and incorporating this strategy into Climate Action Plans, including incorporation into nationally determined contributions to climate goals.

Interim evaluation

In September 2023, 15 of the 16 participating cities submitted interim reports on their progress. Sufficient data were provided by seven cities to quantify progress towards the first two measures. Between them, these seven cities serve over 400 million meals a year for different groups and establishments including schools and hospitals. Measured against different baseline years from between 2015 and 2022, cities reported an increase in their purchasing of plant-sourced protein of 44% (from a mean of 6,356 to 8,667 tonnes) and a decline in their meat purchasing of 19% (from a mean of 16,648 to 12,765 tonnes). In recognition of its significant potential in shifting millions of meals in major cities to be healthier and more sustainable, this initiative won the prestigious US$2-million Food Planet Prize awarded by *The Curt Bergfors Foundation*, in June 2024.

Many examples of progress towards all four measures were described by cities in the interim evaluation in 2023 including engaging with citizens, restaurants, store owners and town planners to change food environments so healthier and sustainable options are readily available and offering training for businesses on how to reduce food waste.

But while excellent examples abound, the extent of progress for each of the four measures across all 16 cities remains unknown at the time of writing because monitoring systems using similar robust metrics across all cities have yet to be put in place.

Barriers to progress reported by cities

Two barriers to progress were commonly reported by participating cities:

Misaligned national procurement standards: Procurement standards don't include consideration of the environmental impact of foods purchased. To achieve the PHD for all, cities are having to make the case for, and then implement this change throughout the entire public food supply chain on their own.

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Insufficient resources for evaluation: Budgetary restrictions, coupled with increasing food prices are curtailing cities' capacity to gather data on their progress towards each of the four aims of this initiative.

Maximising the impact of the *C40* Good Food Cities Initiative

Providing additional resources to *C40 Good Food Cities* at this juncture is vital to maximise its impact and value as a global exemplar of transitioning food systems, by achieving the following:

- **Data collection**: setting up and running monitoring mechanisms to assess progress and adjust if off-track for achieving its 2030 goal.
- **Coalitions**: setting up multi-level platforms to engage different authorities and citizens to create a shared vision.
- **Advocacy**: support for campaigns and other forms of advocacy to inspire national governments and international partners to increase ambition and action at the scale needed to achieve PHD for all.

Lessons from *C40* all initiatives needed to achieve the Planetary Health Diet for all

Mayors from 16 cities around the world are leading the way in transforming the food in their cities. Similar ambitious initiatives are now needed in every city, town and village on our planet to achieve the *Planetary Health Diet* for all.

But these pioneering cities highlight that realizing these ambitions will require each initiative to be matched - at its inception - by sufficient resources for two core activities:

- implementing a programme of interventions built on existing evidence;
- Robust evaluation, built in from inception as part of the implementation plan, so that progress is monitored in real time. This will allow interventions showing promise to be optimized and those that are ineffective to be stopped, and others started.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the corresponding author (FDC) used ChatGTP to produce an initial executive draft of the summary by uploading a pdf of the Commission to the tool. After using this service, FDC reviewed and edited the content as needed and takes full responsibility for the content of the publication.

References

1 Willett W, Rockström J, Loken B, *et al.* Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* 2019; **393**: 447–92.

2 Van Vuuren D, Stehfest E, Gernaat D, *et al.* The 2021 SSP scenarios of the IMAGE 3.2 model. 2021; published online Oct 11. DOI:10.31223/X5CG92.

3 Mason-D'Croz D, Bogard JR, Sulser TB, *et al.* Gaps between fruit and vegetable production, demand, and recommended consumption at global and national levels: an integrated modelling study. *Lancet Planet Health* 2019; **3**: e318–29.

4 HLPE. Reducing inequalities for food security and nutrition. Rome: CFS HLPE-FSN, 2023 https://www.fao.org/3/cc6536en/cc6536en.pdf.

5 Huang J, Neufeld LM, Badiane O, Caron P, Forsse LS. Equitable livelihoods must underpin food systems transformation. *Nat Food* 2022; **3**: 394–6.

6 Afshin A, Sur PJ, Fay KA, *et al.* Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet* 2019; **393**: 1958–72.

7 Bai Y, Herforth A, Masters WA. Global variation in the cost of a nutrient-adequate diet by population group: an observational study. *Lancet Planet Health* 2022; **6**: e19–28.

8 Springmann M, Clark MA, Rayner M, Scarborough P, Webb P. The global and regional costs of healthy and sustainable dietary patterns: a modelling study. *Lancet Planet Health* 2021; **5**: e797–807.

9 Ruggeri Laderchi, C., Lotze-Campen, H., DeClerck, F., *et al.* The Economics of the Food System Transformation. Food System Economics Commission (FSEC), Global Policy Report. The Food System Economics Commission, 2024 https://foodsystemeconomics.org/wp-content/uploads/FSEC-Global_Policy_Report.pdf (accessed Jan 29, 2024).

10 FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2024. FAO; IFAD; UNICEF; WFP; WHO;, 2024 DOI:10.4060/cd1254en.

11 Selig ER, Nakayama S, Wabnitz CCC, *et al.* Revealing global risks of labor abuse and illegal, unreported, and unregulated fishing. *Nat Commun* 2022; **13**: 1612.

12 Kurtz J, Blackstone NT, Decker Sparks JL, Rodriguez R, Pinto C. The true cost of labour must be worker-defined. *Nat Food* 2021; **2**: 630–1.

CONFIDENTIAL

13 ILO. Global wage report 2020-21: wages and minimum wages in the time of COVID-19. Geneva: INTL LABOUR OFFICE, 2020.

14 Clapp J. The problem with growing corporate concentration and power in the global food system. *Nat Food* 2021; **2**: 404–8.

15 ILO. ILO declaration on fundamental principles and rights at work and its follow-up. 2022 https://www.ilo.org/sites/default/files/2024-04/ILO_1998_Declaration_EN.pdf (accessed Nov 19, 2024).

16 Khan I. Disinformation and freedom of opinion and expression: report of the Special Rapporteur on the Promotion and Protection of the Right to Freedom of Opinion and Expression, Irene Khan. Geneva: UN, 2021 https://digitallibrary.un.org/record/3925306 (accessed Nov 7, 2024).

17 Wood B, Williams O, Nagarajan V, Sacks G. Market strategies used by processed food manufacturers to increase and consolidate their power: a systematic review and document analysis. *Glob Health* 2021; **17**: 17.

18 Bui LP, Pham TT, Wang F, *et al.* Planetary Health Diet Index and risk of total and cause-specific mortality in three prospective cohorts. *Am J Clin Nutr* 2024; **120**: 80–91.

19 Cacau LT, De Carli E, de Carvalho AM, *et al.* Development and Validation of an Index Based on EAT-Lancet Recommendations: The Planetary Health Diet Index. *Nutrients* 2021; **13**: 1698.

20 Mosnier A, Javalera-Rincon V, Jones SK, *et al.* A decentralized approach to model national and global food and land use systems. *Environ Res Lett* 2023; **18**: 045001.

21 Mosnier A, Schmidt-Traub G, Obersteiner M, *et al.* How can diverse national food and land-use priorities be reconciled with global sustainability targets? Lessons from the FABLE initiative. *Sustain Sci* 2023; **18**: 335–45.

22 Mazac R, Järviö N, Tuomisto HL. Environmental and nutritional Life Cycle Assessment of novel foods in meals as transformative food for the future. *Sci Total Environ* 2023; **876**: 162796.

23 Mazac R, Meinilä J, Korkalo L, Järviö N, Jalava M, Tuomisto HL. Incorporation of novel foods in European diets can reduce global warming potential, water use and land use by over 80%. *Nat Food* 2022; **3**: 286–93.

24 Kelly L, Kebreab E. Recent advances in feed additives with the potential to mitigate enteric methane emissions from ruminant livestock. *J Soil Water Conserv* 2023; **78**: 111–23.

25 Tulloch AIT, Borthwick F, Bogueva D, *et al.* How the EAT–Lancet Commission on food in the Anthropocene influenced discourse and research on food systems: a systematic review covering the first 2 years post-publication. *Lancet Glob Health* 2023; **11**: e1125–36.

26 IPCC. Summary for Policymakers. In: Shukla PR, Skea J, Calvo Buendia E, *et al.*, eds. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. 2019. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf.

27 IPBES. IPBES Nexus Assessment on Biodiversity, Water, Food, Health and Climate. Bonn, Germany: IPBES, 2024.

CONFIDENTIAL

28 Singh BK, Fraser EDG, Arnold T, *et al.* Food systems transformation requires science–policy–society interfaces that integrate existing global networks and new knowledge hubs. *Nat Food 2022* 2022; : 1–3.

29 Schneider KR, Fanzo J, Haddad L, *et al.* The state of food systems worldwide in the countdown to 2030. *Nat Food* 2023; **4**: 1090–110.

30 Caron P, Ferrero y de Loma-Osorio G, Nabarro D, *et al.* Food systems for sustainable development: proposals for a profound four-part transformation. *Agron Sustain Dev* 2018; **38**: 41.

31 DeClerck FAJ, Koziell I, Benton T, *et al.* A Whole Earth Approach to Nature-Positive Food: Biodiversity and Agriculture. In: von Braun J, Afsana K, Fresco LO, Hassan MHA, eds. Science and Innovations for Food Systems Transformation. Cham: Springer International Publishing, 2023: 469–96.

32 DeClerck F, Barrios E, Benton TG, *et al.* Biodiversity, agriculture and sustainable production: GBF Target 10. *PLOS Sustain Transform* 2023; **2**: e0000048.

33 Gupta J, Bai X, Liverman DM, *et al.* A just world on a safe planet: a Lancet Planetary Health–Earth Commission report on Earth-system boundaries, translations, and transformations. *Lancet Planet Health* 2024; **8**: e813–73.

34 Rockström J, Gupta J, Qin D, *et al.* Safe and just Earth system boundaries. *Nature* 2023; **619**: 102–11.

35 FAO, WHO. What are healthy diets? Joint statement by the Food and Agriculture Organization of the United Nations and the World Health Organization. Rome, Italy: WHO; FAO;, 2024 DOI:10.4060/cd2223en.

36 Rhee JJ, Mattei J, Hughes MD, Hu FB, Willett WC. Dietary diabetes risk reduction score, race and ethnicity, and risk of type 2 diabetes in women. *Diabetes Care* 2015; **38**: 596–603.

37 Li C, Bishop TRP, Imamura F, *et al.* Meat consumption and incident type 2 diabetes: an individual-participant federated meta-analysis of 1.97 million adults with 100 000 incident cases from 31 cohorts in 20 countries. *Lancet Diabetes Endocrinol* 2024; **12**: 619–30.

38 Springmann M. Estimates of energy intake, requirements, and imbalances based on anthropometric measurements at global, regional, and national levels and for sociodemographic groups. *Submitt Manuscr* submitted manuscript.

39 Schwingshackl L, Hoffmann G, Iqbal K, Schwedhelm C, Boeing H. Food groups and intermediate disease markers: a systematic review and network meta-analysis of randomized trials. *Am J Clin Nutr* 2018; **108**: 576–86.

40 Schlesinger S, Neuenschwander M, Schwedhelm C, *et al.* Food Groups and Risk of Overweight, Obesity, and Weight Gain: A Systematic Review and Dose-Response Meta-Analysis of Prospective Studies. *Adv Nutr* 2019; **10**: 205–18.

41 Wan Y, Tobias DK, Dennis KK, *et al.* Association between changes in carbohydrate intake and long term weight changes: prospective cohort study. *BMJ* 2023; **382**: e073939.

CONFIDENTIAL

42 Yu J, Balaji B, Tinajero M, *et al.* White rice, brown rice and the risk of type 2 diabetes: a systematic review and meta-analysis. *BMJ Open* 2022; **12**: e065426.

43 Reynolds A, Mann J, Cummings J, Winter N, Mete E, Te Morenga L. Carbohydrate quality and human health: a series of systematic reviews and meta-analyses. *Lancet* 2019; **393**: 434–45.

44 Aune D, Keum N, Giovannucci E, *et al.* Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: systematic review and dose-response meta-analysis of prospective studies. *BMJ* 2016; **353**: i2716.

45 Hu H, Zhao Y, Feng Y, *et al.* Consumption of whole grains and refined grains and associated risk of cardiovascular disease events and all-cause mortality: a systematic review and dose-response meta-analysis of prospective cohort studies. *Am J Clin Nutr* 2023; **117**: 149–59.

46 Mozaffarian D, Hao T, Rimm EB, Willett WC, Hu FB. Changes in diet and lifestyle and long-term weight gain in women and men. *N Engl J Med* 2011; **364**: 2392–404.

47 Schwingshackl L, Schwedhelm C, Hoffmann G, Boeing H. Potatoes and risk of chronic disease: a systematic review and dose-response meta-analysis. *Eur J Nutr* 2019; **58**: 2243–51.

48 Mousavi SM, Gu X, Imamura F, *et al.* Total and type of potato intake and risk of type 2 diabetes: Results from three US cohort studies and a substitution meta-analysis. *Submitt Manuscr* submitted manuscript.

49 Bertoia ML, Mukamal KJ, Cahill LE, *et al.* Changes in Intake of Fruits and Vegetables and Weight Change in United States Men and Women Followed for Up to 24 Years: Analysis from Three Prospective Cohort Studies. *PLoS Med* 2015; **12**: e1001878.

50 Muraki I, Imamura F, Manson JE, *et al.* Fruit consumption and risk of type 2 diabetes: results from three prospective longitudinal cohort studies. *BMJ* 2013; **347**: f5001.

51 Miller V, Micha R, Choi E, Karageorgou D, Webb P, Mozaffarian D. Evaluation of the Quality of Evidence of the Association of Foods and Nutrients With Cardiovascular Disease and Diabetes: A Systematic Review. *JAMA Netw Open* 2022; **5**: e2146705.

52 Aune D, Giovannucci E, Boffetta P, *et al.* Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality-a systematic review and dose-response meta-analysis of prospective studies. *Int J Epidemiol* 2017; **46**: 1029–56.

53 Farvid MS, Barnett JB, Spence ND. Fruit and vegetable consumption and incident breast cancer: a systematic review and meta-analysis of prospective studies. *Br J Cancer* 2021; **125**: 284–98.

54 Wang DD, Li Y, Bhupathiraju SN, *et al.* Fruit and Vegetable Intake and Mortality: Results From 2 Prospective Cohort Studies of US Men and Women and a Meta-Analysis of 26 Cohort Studies. *Circulation* 2021; **143**: 1642–54.

55 Mottaghi T, Amirabdollahian F, Haghighatdoost F. Fruit and vegetable intake and cognitive impairment: a systematic review and meta-analysis of observational studies. *Eur J Clin Nutr* 2018; **72**: 1336–44.

56 Grodstein F, Kang JH, Glynn RJ, Cook NR, Gaziano JM. A randomized trial of beta carotene supplementation and cognitive function in men: the Physicians' Health Study II. *Arch Intern Med* 2007; **167**: 2184–90.

CONFIDENTIAL

57 Yeh TS, Yuan C, Ascherio A, Rosner BA, Willett WC, Blacker D. Long-term Dietary Flavonoid Intake and Subjective Cognitive Decline in US Men and Women. *Neurology* 2021; **97**: e1041–56.

58 Guasch-Ferre M, Tessier AJ, Petersen KS, *et al.* Effects of Nut Consumption on Blood Lipids and Lipoproteins: A Comprehensive Literature Update. *Nutrients* 2023; **15**. DOI:10.3390/nu15030596.

59 Arnesen EK, Thorisdottir B, Barebring L, *et al.* Nuts and seeds consumption and risk of cardiovascular disease, type 2 diabetes and their risk factors: a systematic review and meta-analysis. *Food Nutr Res* 2023; **67**. DOI:10.29219/fnr.v67.8961.

60 De Souza RJ, Dehghan M, Mente A, *et al.* Association of nut intake with risk factors, cardiovascular disease, and mortality in 16 countries from 5 continents: analysis from the Prospective Urban and Rural Epidemiology (PURE) study. *Am J Clin Nutr* 2020; **112**: 208–19.

61 Zargarzadeh N, Mousavi SM, Santos HO, *et al.* Legume Consumption and Risk of All-Cause and Cause-Specific Mortality: A Systematic Review and Dose-Response Meta-Analysis of Prospective Studies. *Adv Nutr* 2023; **14**: 64–76.

62 Zuo X, Zhao R, Wu M, Wan Q, Li T. Soy Consumption and the Risk of Type 2 Diabetes and Cardiovascular Diseases: A Systematic Review and Meta-Analysis. *Nutrients* 2023; **15**: 1358.

63 Al-Shaar L, Satija A, Wang DD, *et al.* Red meat intake and risk of coronary heart disease among US men: prospective cohort study. *BMJ* 2020; **371**: m4141.

64 Nagata C, Mizoue T, Tanaka K, *et al.* Soy intake and breast cancer risk: an evaluation based on a systematic review of epidemiologic evidence among the Japanese population. *Jpn J Clin Oncol* 2014; **44**: 282–95.

65 Guasch-Ferre M, Satija A, Blondin SA, *et al.* Meta-Analysis of Randomized Controlled Trials of Red Meat Consumption in Comparison With Various Comparison Diets on Cardiovascular Risk Factors. *Circulation* 2019; **139**: 1828–45.

66 Zeraatkar D, Johnston BC, Bartoszko J, *et al.* Effect of Lower Versus Higher Red Meat Intake on Cardiometabolic and Cancer Outcomes: A Systematic Review of Randomized Trials. *Ann Intern Med* 2019; **171**: 721–31.

67 Shi W, Huang X, Schooling CM, Zhao JV. Red meat consumption, cardiovascular diseases, and diabetes: a systematic review and meta-analysis. *Eur Heart J* 2023; **44**: 2626–35.

68 World Cancer Research Fund/American Institute for Cancer Research. Diet, nutrition, physical activity and colorectal cancer. 2018 dietandcancerreport.org.

69 Struijk EA, Fung TT, Sotos-Prieto M, *et al.* Red meat consumption and risk of frailty in older women. *J Cachexia Sarcopenia Muscle* 2022; **13**: 210–9.

70 Zhang H, Greenwood DC, Risch HA, Bunce D, Hardie LJ, Cade JE. Meat consumption and risk of incident dementia: cohort study of 493,888 UK Biobank participants. *Am J Clin Nutr* 2021; **114**: 175–84.

71 Li Y, Li Y, Gu X, *et al.* A Prospective Study of Long-Term Red Meat Intake, Risk of Dementia, and Cognitive Function in US Adults. *Neurology* in press.

CONFIDENTIAL

72 Iqbal R, Dehghan M, Mente A, *et al.* Associations of unprocessed and processed meat intake with mortality and cardiovascular disease in 21 countries [Prospective Urban Rural Epidemiology (PURE) Study]: a prospective cohort study. *Am J Clin Nutr* 2021; **114**: 1049–58.

73 Hill ER, O'Connor LE, Wang Y, *et al.* Red and processed meat intakes and cardiovascular disease and type 2 diabetes mellitus: An umbrella systematic review and assessment of causal relations using Bradford Hill's criteria. *Crit Rev Food Sci Nutr* 2022; : 1–18.

74 Lescinsky H, Afshin A, Ashbaugh C, *et al.* Health effects associated with consumption of unprocessed red meat: a Burden of Proof study. *Nat Med* 2022; **28**: 2075–82.

75 Yu H, Zhang J, Xie J, *et al.* Dose-Response Meta-Analysis on Risk of Diabetes in Relation to Red and Processed Meat Consumption - Asian Populations, 2006-2021. *China CDC Wkly* 2023; **5**: 1012–6.

76 Gu X, Drouin-Chartier JP, Sacks FM, Hu FB, Rosner B, Willett WC. Red meat intake and risk of type 2 diabetes in a prospective cohort study of United States females and males. *Am J Clin Nutr* 2023; **118**: 1153–63.

77 Zhong VW, Van Horn L, Greenland P, *et al.* Associations of Processed Meat, Unprocessed Red Meat, Poultry, or Fish Intake With Incident Cardiovascular Disease and All-Cause Mortality. *JAMA Intern Med* 2020; **180**: 503–12.

78 Papier K, Knuppel A, Syam N, Jebb SA, Key TJ. Meat consumption and risk of ischemic heart disease: A systematic review and meta-analysis. *Crit Rev Food Sci Nutr* 2023; **63**: 426–37.

79 Drouin-Chartier J-P, Schwab AL, Chen S, *et al.* Egg consumption and risk of type 2 diabetes: findings from 3 large US cohort studies of men and women and a systematic review and meta-analysis of prospective cohort studies. *Am J Clin Nutr* 2020; **112**: 619–30.

80 Dehghan M, Mente A, Rangarajan S, *et al.* Association of egg intake with blood lipids, cardiovascular disease, and mortality in 177,000 people in 50 countries. *Am J Clin Nutr* 2020; **111**: 795–803.

81 Tang H, Cao Y, Yang X, Zhang Y. Egg Consumption and Stroke Risk: A Systematic Review and Dose-Response Meta-Analysis of Prospective Studies. *Front Nutr* 2020; **7**: 153.

82 Tong TYN, Appleby PN, Key TJ, *et al.* The associations of major foods and fibre with risks of ischaemic and haemorrhagic stroke: a prospective study of 418 329 participants in the EPIC cohort across nine European countries. *Eur Heart J* 2020; **41**: 2632–40.

83 Willett WC, Ludwig DS. Milk and Health. *N Engl J Med* 2020; **382**: 644–54.

84 Brassard D, Tessier-Grenier M, Allaire J, *et al.* Comparison of the impact of SFAs from cheese and butter on cardiometabolic risk factors: a randomized controlled trial. *Am J Clin Nutr* 2017; **105**: 800–9.

85 Zhao B, Gan L, Graubard BI, *et al.* Plant and Animal Fat Intake and Overall and Cardiovascular Disease Mortality. *JAMA Intern Med* 2024; **184**: 1234–45.

86 Dehghan M, Mente A, Rangarajan S, *et al.* Association of dairy intake with cardiovascular disease and mortality in 21 countries from five continents (PURE): a prospective cohort study. *The Lancet* 2018; **392**: 2288–97.

CONFIDENTIAL

87 Farvid MS, Malekshah AF, Pourshams A, *et al.* Dairy Food Intake and All-Cause, Cardiovascular Disease, and Cancer Mortality: The Golestan Cohort Study. *Am J Epidemiol* 2017; **185**: 697–711.

88 Vieira AR, Abar L, Chan DSM, *et al.* Foods and beverages and colorectal cancer risk: a systematic review and meta-analysis of cohort studies, an update of the evidence of the WCRF-AICR Continuous Update Project. *Ann Oncol* 2017; **28**: 1788–802.

89 Zhao Z, Wu D, Gao S, *et al.* The association between dairy products consumption and prostate cancer risk: a systematic review and meta-analysis. *Br J Nutr* 2023; **129**: 1714–31.

90 Schwingshackl L, Hoffmann G, Schwedhelm C, *et al.* Consumption of Dairy Products in Relation to Changes in Anthropometric Variables in Adult Populations: A Systematic Review and Meta-Analysis of Cohort Studies. *PLOS ONE* 2016; **11**: e0157461.

91 Zhuang P, Liu X, Li Y, *et al.* A global analysis of dairy consumption and incident cardiovascular disease. *Nat Commun* 2025; **16**: 437.

92 Campoy C, Escolano-Margarit MV, Anjos T, Szajewska H, Uauy R. Omega 3 fatty acids on child growth, visual acuity and neurodevelopment. *Br J Nutr* 2012; **107**: S85–106.

93 Wei B-Z, Li L, Dong C-W, Tan C-C, Alzheimer's Disease Neuroimaging Initiative, Xu W. The Relationship of Omega-3 Fatty Acids with Dementia and Cognitive Decline: Evidence from Prospective Cohort Studies of Supplementation, Dietary Intake, and Blood Markers. *Am J Clin Nutr* 2023; **117**: 1096–109.

94 Manson JE, Cook NR, Lee IM, *et al.* Marine n-3 Fatty Acids and Prevention of Cardiovascular Disease and Cancer. *N Engl J Med* 2019; **380**: 23–32.

95 Abdelhamid AS, Brown TJ, Brainard JS, *et al.* Omega-3 fatty acids for the primary and secondary prevention of cardiovascular disease. *Cochrane Database Syst Rev* 2020; **2020**. DOI:10.1002/14651858.CD003177.pub5.

96 Prentice RL, Aragaki AK, Van Horn L, *et al.* Low-fat dietary pattern and cardiovascular disease: results from the Women's Health Initiative randomized controlled trial. *Am J Clin Nutr* 2017; **106**: 35–43.

97 Prentice RL, Caan B, Chlebowski RT, *et al.* Low-fat dietary pattern and risk of invasive breast cancer: the Women's Health Initiative Randomized Controlled Dietary Modification Trial. *JAMA* 2006; **295**: 629–42.

98 Mozaffarian D, Katan MB, Ascherio A, Stampfer MJ, Willett WC. Trans fatty acids and cardiovascular disease. *N Engl J Med* 2006; **354**: 1601–13.

99 Kim Y, Je Y, Giovannucci EL. Association between dietary fat intake and mortality from all-causes, cardiovascular disease, and cancer: A systematic review and meta-analysis of prospective cohort studies. *Clin Nutr* 2021; **40**: 1060–70.

100 WHO. Saturated Fatty Acid and Trans-Fatty Acid Intake for Adults and Children: WHO Guideline. Geneva, 2023.

101 Schoeneck M, Iggman D. The effects of foods on LDL cholesterol levels: A systematic review of the accumulated evidence from systematic reviews and meta-analyses of randomized controlled trials. *Nutr Metab Cardiovasc Dis* 2021; **31**: 1325–38.

CONFIDENTIAL

102 Martínez-González MA, Sayón-Orea C, Bullón-Vela V, *et al.* Effect of olive oil consumption on cardiovascular disease, cancer, type 2 diabetes, and all-cause mortality: A systematic review and meta-analysis. *Clin Nutr* 2022; **41**: 2659–82.

103 Sun Y, Neelakantan N, Wu Y, Lote-Oke R, Pan A, van Dam RM. Palm Oil Consumption Increases LDL Cholesterol Compared with Vegetable Oils Low in Saturated Fat in a Meta-Analysis of Clinical Trials. *J Nutr* 2015; **145**: 1549–58.

104 Estruch R, Ros E, Salas-Salvado J, *et al.* Primary Prevention of Cardiovascular Disease with a Mediterranean Diet Supplemented with Extra-Virgin Olive Oil or Nuts. *N Engl J Med* 2018; **378**: e34.

105 Te Morenga L, Mallard S, Mann J. Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ* 2012; **346**: e7492.

106 Qin P, Li Q, Zhao Y, *et al.* Sugar and artificially sweetened beverages and risk of obesity, type 2 diabetes mellitus, hypertension, and all-cause mortality: a dose-response meta-analysis of prospective cohort studies. *Eur J Epidemiol* 2020; **35**: 655–71.

107 Te Morenga LA, Howatson AJ, Jones RM, Mann J. Dietary sugars and cardiometabolic risk: systematic review and meta-analyses of randomized controlled trials of the effects on blood pressure and lipids. *Am J Clin Nutr* 2014; **100**: 65–79.

108 WHO. Guideline: sugars intake for adults and children. Geneva: World Health Organization, 2015 https://iris.who.int/handle/10665/149782 (accessed Nov 5, 2024).

109 Ma Y, He FJ, Sun Q, *et al.* 24-Hour Urinary Sodium and Potassium Excretion and Cardiovascular Risk. *N Engl J Med* 2022; **386**: 252–63.

110 Monteiro CA, Cannon G, Moubarac JC, Levy RB, Louzada MLC, Jaime PC. The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutr* 2018; **21**: 5–17.

111 Lane MM, Gamage E, Du S, *et al.* Ultra-processed food exposure and adverse health outcomes: umbrella review of epidemiological meta-analyses. *BMJ* 2024; **384**: e077310.

112 Tsugane S. Why has Japan become the world's most long-lived country: insights from a food and nutrition perspective. *Eur J Clin Nutr* 2021; **75**: 921–8.

113 Hu FB, Drescher G, Trichopoulou A, Willett WC, Martínez-González MA. Three decades of the Mediterranean diet pyramid: A narrative review of its history, evolution, and advances. *Am J Clin Nutr* 2025; published online May 13. DOI:10.1016/j.ajcnut.2025.04.036.

114 Zhang C, Schulze MB, Solomon CG, Hu FB. A prospective study of dietary patterns, meat intake and the risk of gestational diabetes mellitus. *Diabetologia* 2006; **49**: 2604–13.

115 English LK, Ard JD, Bailey RL, *et al.* Evaluation of Dietary Patterns and All-Cause Mortality: A Systematic Review. *JAMA Netw Open* 2021; **4**: e2122277.

116 Schwingshackl L, Bogensberger B, Hoffmann G. Diet Quality as Assessed by the Healthy Eating Index, Alternate Healthy Eating Index, Dietary Approaches to Stop Hypertension Score, and Health Outcomes: An Updated Systematic Review and Meta-Analysis of Cohort Studies. *J Acad Nutr Diet* 2018; **118**: 74-100 e11.

CONFIDENTIAL

117 Wang P, Song M, Eliassen AH, *et al.* Optimal dietary patterns for prevention of chronic disease. *Nat Med* 2023; **29**: 719–28.

118 Sotos-Prieto M, Bhupathiraju SN, Mattei J, *et al.* Association of Changes in Diet Quality with Total and Cause-Specific Mortality. *N Engl J Med* 2017; **377**: 143–53.

119 Lai JS, Hiles S, Bisquera A, Hure AJ, McEvoy M, Attia J. A systematic review and meta-analysis of dietary patterns and depression in community-dwelling adults. *Am J Clin Nutr* 2014; **99**: 181–97.

120 Liu YH, Gao X, Na M, Kris-Etherton PM, Mitchell DC, Jensen GL. Dietary Pattern, Diet Quality, and Dementia: A Systematic Review and Meta-Analysis of Prospective Cohort Studies. *J Alzheimers Dis* 2020; **78**: 151–68.

121 Stubbendorff A, Stern D, Ericson U, *et al.* A systematic evaluation of seven different scores representing the EAT-Lancet reference diet and mortality, stroke, and greenhouse gas emissions in three cohorts. *Lancet Planet Health* 2024; **8**: e391–401.

122 Berthy F, Brunin J, Alles B, *et al.* Association between adherence to the EAT-Lancet diet and risk of cancer and cardiovascular outcomes in the prospective NutriNet-Sante cohort. *Am J Clin Nutr* 2022; **116**: 980–91.

123 Mente A, Dehghan M, Rangarajan S, *et al.* Diet, cardiovascular disease, and mortality in 80 countries. *Eur Heart J* 2023; **44**: 2560–79.

124 Willett WC, Hu FB, Forouhi NG. A healthy diet should consider environmental impact. *Eur Heart J* 2024; **45**: 1375.

125 Ye YX, Geng TT, Zhou YF, *et al.* Adherence to a Planetary Health Diet, Environmental Impacts, and Mortality in Chinese Adults. *JAMA Netw Open* 2023; **6**: e2339468.

126 Chen H, Wang X, Ji JS, *et al.* Plant-based and planetary-health diets, environmental burden, and risk of mortality: a prospective cohort study of middle-aged and older adults in China. *Lancet Planet Health* 2024; **8**: e545–53.

127 Bajaj S, Springmann M. A review of the quality of evidence of nutrient reference values. *Lancet Planet Health*; **Submitted**.

128 Springmann M, Auclair O, Bajaj S, *et al.* Many diets for many people: planetary health diets and their health and environmental impacts at global, regional, national, and demographic levels. *Nature*; **Submitted**.

129 Smith AD, Refsum H. Homocysteine, B Vitamins, and Cognitive Impairment. *Annu Rev Nutr* 2016; **36**: 211–39.

130 Mariotti F, Gardner CD. Dietary Protein and Amino Acids in Vegetarian Diets-A Review. *Nutrients* 2019; **11**. DOI:10.3390/nu11112661.

131 Chen Z, Glisic M, Song M, *et al.* Dietary protein intake and all-cause and cause-specific mortality: results from the Rotterdam Study and a meta-analysis of prospective cohort studies. *Eur J Epidemiol* 2020; **35**: 411–29.

132 Baum JI, Kim IY, Wolfe RR. Protein Consumption and the Elderly: What Is the Optimal Level of Intake? *Nutrients* 2016; **8**. DOI:10.3390/nu8060359.

CONFIDENTIAL

133 Ardisson Korat AV, Shea MK, Jacques PF, *et al.* Dietary protein intake in midlife in relation to healthy aging - results from the prospective Nurses' Health Study cohort. *Am J Clin Nutr* 2024; **119**: 271–82.

134 UNICEF. Undernourished and overlooked: a global nutrition crisis in adolescent girls and women: executive Summary. 2023.

135 Fleming TP, Watkins AJ, Velazquez MA, *et al.* Origins of lifetime health around the time of conception: causes and consequences. *Lancet* 2018; **391**: 1842–52.

136 WHO. Nutrition counselling during pregnancy. E-Libr. Evid. Nutr. Actions ELENA. 2023.

137 WHO. WHO recommendations on antenatal care for a positive pregnancy experience. World Health Organization, 2016.

138 Piccoli GB, Clari R, Vigotti FN, *et al.* Vegan-vegetarian diets in pregnancy: danger or panacea? A systematic narrative review. *BJOG* 2015; **122**: 623–33.

139 Dewey KG, Zlotkin SH. Antenatal multiple micronutrient supplements: time for alignment to support country action. *The Lancet* 2025; **405**: 1033–5.

140 Santos-Guzmán A, Unar-Munguía M, Rivera JA, Ramírez-Silva I. Addressing infant and young child feeding recommendations from a planetary health perspective. *Adv Nutr* 2024. DOI:https://doi.org/10.1016/j.advnut.2024.100303.

141 Hagan JF SJ. Bright Futures: Guidelines for Health Supervision of Infants, Children, and Adolescents. Elk Grove Village, IL: American Academy of Pediatrics, 2017.

142 Kvestad I, Hysing M, Shrestha M, *et al.* Vitamin B-12 status in infancy is positively associated with development and cognitive functioning 5 y later in Nepalese children. *Am J Clin Nutr* 2017; **105**: 1122–31.

143 Ulak M, Kvestad I, Chandyo RK, *et al.* The effect of infant vitamin B(12) supplementation on neurodevelopment: a follow-up of a randomised placebo-controlled trial in Nepal. *Br J Nutr* 2023; **129**: 41–8.

144 Krebs NF. Food Based Complementary Feeding Strategies for Breastfed Infants: What's the Evidence that it Matters? *Nutr Today* 2014; **49**: 271–7.

145 FAO. The White/Wiphala Paper on Indigenous Peoples' food systems. FAO, 2021 DOI:10.4060/cb4932en.

146 Armes S, Bhanjdeo A, Chakraborty D, Kaur H, Ray S, Rao N. Aligning Santal Tribe Menu Templates with EAT-Lancet Commission's Dietary Guidelines for Sustainable and Healthy Diets: A Comparative Analysis. *Nutrients* 2024; **16**: 447.

147 Guasch-Ferre M, Willett WC. The Mediterranean diet and health: a comprehensive overview. *J Intern Med* 2021; **290**: 549–66.

148 Argumedo A, Song Y, Khoury CK, *et al.* Biocultural Diversity for Food System Transformation Under Global Environmental Change. *Front Sustain Food Syst* 2021; **5**: 685299.

CONFIDENTIAL

149 LeBlanc KE, Baer-Sinnott S, Lancaster KJ, *et al.* Perspective: Beyond the Mediterranean Diet-Exploring Latin American, Asian, and African Heritage Diets as Cultural Models of Healthy Eating. *Adv Nutr* 2024; **15**: 100221.

150 Pan W-H, Wu S-Y, Chang P-C. Is Nutrient Quality of the Locally-Existing, EAT-Lancet-like Plant-Based Diet Better or Worse than the Average Diet in Taiwan? An Example of Local Translation. *Nutrients* 2024; **16**: 2775.

151 UNICEF. Improving Young Children's Diets During the Complementary Feeding Period. New York: UNICEF, 2020.

152 Dewey K. Guiding principles for complementary feeding of the breastfed child. 2003.

153 Guasch-Ferre M, Li Y, Willett WC, *et al.* Consumption of Olive Oil and Risk of Total and Cause-Specific Mortality Among U.S. Adults. *J Am Coll Cardiol* 2022; **79**: 101–12.

154 Schwingshackl L, Bogensberger B, Benčič A, Knüppel S, Boeing H, Hoffmann G. Effects of oils and solid fats on blood lipids: a systematic review and network meta-analysis. *J Lipid Res* 2018; **59**: 1771–82.

155 Dennis KK, Wang F, Li Y, *et al.* Associations of dietary sugar types with coronary heart disease risk: a prospective cohort study. *Am J Clin Nutr* 2023; **118**: 1000–9.

156 Huang Y, Chen Z, Chen B, *et al.* Dietary sugar consumption and health: umbrella review. *BMJ* 2023; **381**: e071609.

157 Rockström J, Steffen W, Noone K, *et al.* A safe operating space for humanity. *Nature* 2009; **461**: 472–5.

158 Richardson K, Steffen W, Lucht W, *et al.* Earth beyond six of nine planetary boundaries. *Sci Adv* 2023; **9**: eadh2458.

159 Te Wierik S, Rockström J, Norberg A, *et al.* Food system boundaries: identifying the safe operating space for food. *Manuscr Submitt Publ* 2025.

160 Garnett T, Appleby MC, Balmford A, *et al.* Sustainable Intensification in Agriculture: Premises and Policies. *Science* 2013; **341**: 33–4.

161 Rockström J, Williams J, Daily G, *et al.* Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio* 2017; **46**: 4–17.

162 Pretty J, Benton TG, Bharucha ZP, *et al.* Global assessment of agricultural system redesign for sustainable intensification. *Nat Sustain* 2018; **1**: 441–6.

163 Tamburini G, Bommarco R, Wanger TC, *et al.* Agricultural diversification promotes multiple ecosystem services without compromising yield. *Sci Adv* 2020; **6**. DOI:10.1126/sciadv.aba1715.

164 Beillouin D, Cardinael R, Berre D, *et al.* A global overview of studies about land management, land-use change, and climate change effects on soil organic carbon. *Glob Change Biol* 2022; **28**: 1690–702.

CONFIDENTIAL

165 Jones SK, Monjeau A, Perez-Guzman K, Harrison PA. Integrated modeling to achieve global goals: lessons from the Food, Agriculture, Biodiversity, Land-use, and Energy (FABLE) initiative. *Sustain Sci* 2023; **18**: 323–33.

166 Beusen AHW, Doelman JC, Van Beek LPH, *et al.* Exploring river nitrogen and phosphorus loading and export to global coastal waters in the Shared Socio-economic pathways. *Glob Environ Change* 2022; **72**: 102426.

167 Schulte-Uebbing LF, Beusen AHW, Bouwman AF, de Vries W. From planetary to regional boundaries for agricultural nitrogen pollution. *Nature* 2022; **610**: 507–12.

168 Maggi F, Tang FHM, Tubiello FN. Agricultural pesticide land budget and river discharge to oceans. *Nature* 2023; **620**: 1013–7.

169 Van Boeckel TP, Brower C, Gilbert M, *et al.* Global trends in antimicrobial use in food animals. *Proc Natl Acad Sci* 2015; **112**: 5649–54.

170 Nabuurs G-J, Mrabet R, Abu Hatab A, *et al.* Agriculture, Forestry and Other Land Uses (Chapter 7). In: Shukla AR, Skea J, Slade R, *et al.*, eds. . Cambridge, UK and New York, NY, USA: Cambridge University Press, 2022: 747–860.

171 Caleffi S, Mozaffarian D, Micha R, Springmann M. The socio-demographic characteristics of food-related environmental impacts. *Prep*.

172 Tubiello FN, Rosenzweig C, Conchedda G, *et al.* Greenhouse gas emissions from food systems: building the evidence base. *Environ Res Lett* 2021; **16**: 065007.

173 Gatto A, Chepeliev M. Global food loss and waste estimates show increasing nutritional and environmental pressures. *Nat Food* 2024; **5**: 136–47.

174 Roe S, Streck C, Obersteiner M, *et al.* Contribution of the land sector to a 1.5 °C world. *Nat Clim Change* 2019; **9**: 817–28.

175 Lessmann M, Ros GH, Young MD, de Vries W. Global variation in soil carbon sequestration potential through improved cropland management. *Glob Change Biol* 2021; **28**: 1162–77.

176 Zhao X, Mignone BK, Wise MA, McJeon HC. Trade-offs in land-based carbon removal measures under 1.5 °C and 2 °C futures. *Nat Commun* 2024; **15**: 2297.

177 Lade SJ, Steffen W, de Vries W, *et al.* Human impacts on planetary boundaries amplified by Earth system interactions. *Nat Sustain* 2020; **3**: 119–28.

178 FAO. Land statistics 2001–2022. 2024. https://openknowledge.fao.org/handle/20.500.14283/cd1484en (accessed July 4, 2024).

179 Curtis PG, Slay CM, Harris NL, Tyukavina A, Hansen MC. Classifying drivers of global forest loss. *Science* 2018; **361**: 1108–11.

180 Pendrill F, Gardner TA, Meyfroidt P, *et al.* Disentangling the numbers behind agriculture-driven tropical deforestation. *Science* 2022; **377**: eabm9267.

181 Springmann M. A multicriteria analysis of meat and milk alternatives from nutritional, health, environmental, and cost perspectives. *Proc Natl Acad Sci* 2024; **121**: e2319010121.

CONFIDENTIAL

182 Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. *Science* 2018; **360**: 987–92.

183 Richardson K, Steffen W, Lucht W, *et al.* Earth beyond six of nine planetary boundaries. *Sci Adv* 2023; **9**: eadh2458.

184 Mohamed A, DeClerck F, Verburg PH, *et al.* Securing Nature's Contributions to People requires at least 20%–25% (semi-)natural habitat in human-modified landscapes. *One Earth* 2024; **7**: 59–71.

185 Garibaldi LA, Oddi FJ, Miguez FE, *et al.* Working landscapes need at least 20% native habitat. *Conserv Lett* 2021; **14**: e12773.

186 Stenzel F, Braun J, Breier J, *et al.* biospheremetrics v1.0.2: an R package to calculate two complementary terrestrial biosphere integrity indicators – human colonization of the biosphere (BioCol) and risk of ecosystem destabilization (EcoRisk). *Geosci Model Dev* 2024; **17**: 3235–58.

187 Foley JA, Ramankutty N, Brauman KA, *et al.* Solutions for a cultivated planet. *Nature* 2011; **478**: 337–42.

188 UNEP. Food Waste Index Report 2024. Think Eat Save: Tracking Progress to Halve Global Food Waste. Nairobi, 2024 https://wedocs.unep.org/handle/20.500.11822/45230 (accessed May 20, 2025).

189 Ingemarsson ML, Weinberg J, Rudebeck T, Wang-Erlandsson L. The essential drop to Net-Zero: Unpacking freshwater's role in climate change mitigation. Stockholm International Water Institute, Stockholm Resilience Centre, Potsdam Institute of Climate Impact Research, United Nations Development Programme and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH., 2022 https://siwi.org/publications/essential-drop-to-net-zero/ (accessed Nov 13, 2024).

190 Gleeson T, Wang-Erlandsson L, Porkka M, *et al.* Illuminating water cycle modifications and Earth system resilience in the Anthropocene. *Water Resour Res* 2020; **56**: e2019WR024957.

191 Porkka M, Virkki V, Wang-Erlandsson L, *et al.* Notable shifts beyond pre-industrial streamflow and soil moisture conditions transgress the planetary boundary for freshwater change. *Nat Water* 2024; **2**: 262–73.

192 Gerten D, Hoff H, Rockström J, Jägermeyr J, Kummu M, Pastor AV. Towards a revised planetary boundary for consumptive freshwater use: role of environmental flow requirements. *Curr Opin Environ Sustain* 2013; **5**: 551–8.

193 McDermid S, Nocco M, Lawston-Parker P, *et al.* Irrigation in the Earth system. *Nat Rev Earth Environ* 2023; : 1–19.

194 Springmann M, Clark M, Mason-D'Croz D, *et al.* Options for keeping the food system within environmental limits. *Nature* 2018; **562**: 519–25.

195 Te Wierik SA, Rockström J, Norberg A, *et al.* Food system boundaries: identifying the safe operating space for food. *Prep*.

196 Gerten D, Heinke J, Hoff H, Biemans H, Fader M, Waha K. Global Water Availability and Requirements for Future Food Production. 2011; published online Oct 1. DOI:10.1175/2011JHM1328.1.

CONFIDENTIAL

197 Te Wierik S, Gerten D, Anderson L, *et al.* Attribution of global freshwater changes to climate and land use changes. *Manuscr Prep* n.d.

198 Jägermeyr J, Pastor A, Biemans H, Gerten D. Reconciling irrigated food production with environmental flows for Sustainable Development Goals implementation. *Nat Commun* 2017; **8**: 15900.

199 Scarborough P, Clark M, Cobiac L, *et al.* Vegans, vegetarians, fish-eaters and meat-eaters in the UK show discrepant environmental impacts. *Nat Food* 2023; **4**: 565–74.

200 Lal R. Soil organic matter and water retention. *Agron J* 2020; **112**: 3265–77.

201 Muchane MN, Sileshi GW, Gripenberg S, Jonsson M, Pumariño L, Barrios E. Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. *Agric Ecosyst Environ* 2020; **295**: 106899.

202 Gerten D, Heck V, Jägermeyr J, *et al.* Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nat Sustain* 2020; **3**: 200–8.

203 Tang FHM, Lenzen M, McBratney A, Maggi F. Risk of pesticide pollution at the global scale. *Nat Geosci* 2021; **14**: 206–10.

204 De Vries W. Impacts of nitrogen emissions on ecosystems and human health: A mini review. *Curr Opin Environ Sci Health* 2021; **21**: 100249.

205 Poikane S, Kelly MG, Salas Herrero F, *et al.* Nutrient criteria for surface waters under the European Water Framework Directive: Current state-of-the-art, challenges and future outlook. *Sci Total Environ* 2019; **695**: 133888.

206 Poikane S, Phillips G, Birk S, Free G, Kelly MG, Willby NJ. Deriving nutrient criteria to support 'good' ecological status in European lakes: An empirically based approach to linking ecology and management. *Sci Total Environ* 2019; **650**: 2074–84.

207 de Vries W, Schulte-Uebbing LF, Beusen AHW, Te Wierik SA. Revisiting planetary boundaries for nitrogen and phosphorus. *Prep*.

208 You L, Ros GH, Chen Y, *et al.* Global mean nitrogen recovery efficiency in croplands can be enhanced by optimal nutrient, crop and soil management practices. *Nat Commun* 2023; **14**: 5747.

209 Wee SY, Aris AZ. Revisiting the "forever chemicals", PFOA and PFOS exposure in drinking water. *Npj Clean Water* 2023; **6**: 1–16.

210 Persson L, Carney Almroth BM, Collins CD, *et al.* Outside the Safe Operating Space of the Planetary Boundary for Novel Entities. *Environ Sci Technol* 2022; **56**: 1510–21.

211 He L, Li Z, Jia Q, Xu Z. Soil microplastics pollution in agriculture. *Science* 2023; **379**: 547–547.

212 MacLeod M, Breitholtz M, Cousins IT, *et al.* Identifying Chemicals That Are Planetary Boundary Threats. *Environ Sci Technol* 2014; **48**: 11057–63.

213 FAO. Pesticides use and trade, 1990–2022. 2024. https://openknowledge.fao.org/handle/20.500.14283/cd1486en (accessed Nov 12, 2024).

CONFIDENTIAL

214 Jørgensen PS, Aktipis A, Brown Z, *et al.* Antibiotic and pesticide susceptibility and the Anthropocene operating space. *Nat Sustain* 2018; **1**: 632–41.

215 Cassou E. Pesticides. World Bank. 2018. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/689281521218090562/Pesticides (accessed Aug 19, 2024).

216 Geissen V, Silva V, Lwanga EH, *et al.* Cocktails of pesticide residues in conventional and organic farming systems in Europe – Legacy of the past and turning point for the future. *Environ Pollut* 2021; **278**: 116827.

217 Wyckhuys KAG, Gu B, Ben Fekih I, *et al.* Restoring functional integrity of the global production ecosystem through biological control. *J Environ Manage* 2024; **370**: 122446.

218 Schar D, Klein EY, Laxminarayan R, Gilbert M, Van Boeckel TP. Global trends in antimicrobial use in aquaculture. *Sci Rep* 2020; **10**: 21878.

219 Van Boeckel TP, Glennon EE, Chen D, *et al.* Reducing antimicrobial use in food animals. *Science* 2017; **357**: 1350–2.

220 Van Boeckel TP, Pires J, Silvester R, *et al.* Global trends in antimicrobial resistance in animals in low- and middle-income countries. *Science* 2019; **365**: eaaw1944.

221 Burke, Springmann M. Dietary and food system changes can drastically reduce anti-microbial use in animals. in prep.

222 Lobell DB, Burney JA. Cleaner air has contributed one-fifth of US maize and soybean yield gains since 1999. *Environ Res Lett* 2021; **16**: 074049.

223 Crippa M, Solazzo E, Guizzardi D, Van Dingenen R, Leip A. Air pollutant emissions from global food systems are responsible for environmental impacts, crop losses and mortality. *Nat Food* 2022; **3**: 942–56.

224 Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature* 2015; **525**: 367–71.

225 Liu Y, Chen J, Shi Y, Zheng W, Shan T, Wang G. Global Emissions Inventory from Open Biomass Burning (GEIOBB): utilizing Fengyun-3D global fire spot monitoring data. *Earth Syst Sci Data* 2024; **16**: 3495–515.

226 Springmann M, Van Dingenen R, Vandyck T, Latka C, Witzke P, Leip A. The global and regional air quality impacts of dietary change. *Nat Commun* 2023; **14**: 6227.

227 Burton C, Lampe S, Kelley DI, *et al.* Global burned area increasingly explained by climate change. *Nat Clim Change* 2024; : 1–7.

228 Gruber N. Warming up, turning sour, losing breath: ocean biogeochemistry under global change. *Philos Trans R Soc Math Phys Eng Sci* 2011; **369**: 1980–96.

229 Friedlingstein P, O'sullivan M, Jones MW, *et al.* Global carbon budget 2024. *Earth Syst Sci Data Discuss* 2024; **2024**: 1–133.

CONFIDENTIAL

230 Tian H, Pan N, Thompson RL, *et al.* Global nitrous oxide budget (1980–2020). *Earth Syst Sci Data* 2024; **16**: 2543–604.

231 Dynarski KA, Bossio DA, Scow KM. Dynamic Stability of Soil Carbon: Reassessing the "Permanence" of Soil Carbon Sequestration. *Front Environ Sci* 2020; **8**. DOI:10.3389/fenvs.2020.514701.

232 Chenu C, Angers DA, Barré P, Derrien D, Arrouays D, Balesdent J. Increasing organic stocks in agricultural soils: Knowledge gaps and potential innovations. *Soil Tillage Res* 2019; **188**: 41–52.

233 Rasmussen LV, Grass I, Mehrabi Z, *et al.* Joint environmental and social benefits from diversified agriculture. *Science* 2024; **384**: 87–93.

234 McClelland SC, Bossio D, Gordon DR, *et al.* Managing for climate and production goals on crop-lands. *Nat Clim Change* 2025; : 1–8.

235 Arndt C, Hristov AN, Price WJ, *et al.* Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 °C target by 2030 but not 2050. *Proc Natl Acad Sci* 2022; **119**: e2111294119.

236 Beillouin D, Ben-Ari T, Malézieux E, Seufert V, Makowski D. Positive but variable effects of crop diversification on biodiversity and ecosystem services. *Glob Change Biol* 2021; **27**: 4697–710.

237 Beillouin D, Corbeels M, Demenois J, *et al.* A global meta-analysis of soil organic carbon in the Anthropocene. *Nat Commun* 2023; **14**: 3700.

238 Bonfanti J, Langridge J, Avadí A, *et al.* Global review of meta-analyses reveals key data gaps in agricultural impact studies on biodiversity in croplands. 2024; : 2024.04.19.590051.

239 Grados D, Butterbach-Bahl K, Chen J, *et al.* Synthesizing the evidence of nitrous oxide mitigation practices in agroecosystems. *Environ Res Lett* 2022; **17**: 114024.

240 Young MD, Ros GH, de Vries W. Impacts of agronomic measures on crop, soil, and environmental indicators: A review and synthesis of meta-analysis. *Agric Ecosyst Environ* 2021; **319**: 107551.

241 He X, Batáry P, Zou Y, *et al.* Agricultural diversification promotes sustainable and resilient global rice production. *Nat Food* 2023; **4**: 788–96.

242 Van Zanten HHE, Herrero M, Van Hal O, *et al.* Defining a land boundary for sustainable livestock consumption. *Glob Change Biol* 2018; **24**: 4185–94.

243 Blanco-Canqui H, Wilke K, Holman J, Creech CF, Obour AK, Anderson L. Grazing cover crops: How does it influence soils and crops? *Agron J* 2023; **115**: 2801–28.

244 Cui J, Liu H, Wang H, *et al.* Rice-Animal Co-Culture Systems Benefit Global Sustainable Intensification. *Earths Future* 2023; **11**: e2022EF002984.

245 Byrnes RC, Eastburn DJ, Tate KW, Roche LM. A Global Meta-Analysis of Grazing Impacts on Soil Health Indicators. *J Environ Qual* 2018; **47**: 758–65.

246 Crona BI, Wassénius E, Jonell M, *et al.* Four ways blue foods can help achieve food system ambitions across nations. *Nature* 2023; **616**: 104–12.

CONFIDENTIAL

247 Costello C, Cao L, Gelcich S, *et al.* The future of food from the sea. *Nature* 2020; **588**: 95–100.

248 Melnychuk MC, Kurota H, Mace PM, *et al.* Identifying management actions that promote sustainable fisheries. *Nat Sustain* 2021; **4**: 440–9.

249 He, P.; Chopin, F.; Suuronen, P.; Ferro, R.S.T.; Lansley, J. Classification and illustrated definition of fishing gears. FAO, 2021 DOI:10.4060/cb4966en.

250 Smallhorn-West P, Cohen PJ, Phillips M, Jupiter SD, Govan H, Pressey RL. Linking small-scale fisheries co-management to U.N. Sustainable Development Goals. *Conserv Biol* 2022; **36**: e13977.

251 Gelcich S, Reyes-Mendy F, Arriagada R, Castillo B. Assessing the implementation of marine ecosystem based management into national policies: Insights from agenda setting and policy responses. *Mar Policy* 2018; **92**: 40–7.

252 Little DC, Young JA, Zhang W, Newton RW, Al Mamun A, Murray FJ. Sustainable intensification of aquaculture value chains between Asia and Europe: A framework for understanding impacts and challenges. *Aquaculture* 2018; **493**: 338–54.

253 Halpern BS, Frazier M, Verstaen J, *et al.* The environmental footprint of global food production. *Nat Sustain* 2022; **5**: 1027–39.

254 Henriksson PJG, Belton B, Jahan KM-, Rico A. Measuring the potential for sustainable intensification of aquaculture in Bangladesh using life cycle assessment. *Proc Natl Acad Sci* 2018; **115**: 2958–63.

255 Naylor RL, Kishore A, Sumaila UR, *et al.* Blue food demand across geographic and temporal scales. *Nat Commun* 2021; **12**: 5413.

256 Nederlof MAJ, Verdegem MCJ, Smaal AC, Jansen HM. Nutrient retention efficiencies in integrated multi-trophic aquaculture. *Rev Aquac* 2022; **14**: 1194–212.

257 Stevens JR, Newton RW, Tlusty M, Little DC. The rise of aquaculture by-products: Increasing food production, value, and sustainability through strategic utilisation. *Mar Policy* 2018; **90**: 115–24.

258 Bohnes FA, Hauschild MZ, Schlundt J, Laurent A. Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development. *Rev Aquac* 2019; **11**: 1061–79.

259 Coolsaet B, Néron P-Y. Recognition and environmental justice. In: Environmental Justice. Routledge, 2020.

260 Walker G, Day R. Fuel poverty as injustice: Integrating distribution, recognition and procedure in the struggle for affordable warmth. *Energy Policy* 2012; **49**: 69–75.

261 Fraser N. Abnormal Justice. *Crit Inq* 2008; **34**: 393–422.

262 Blackstone NT, Battaglia K, Rodríguez-Huerta E, *et al.* Diets cannot be sustainable without ensuring the well-being of communities, workers and animals in food value chains. *Nat Food* 2024; **5**: 818–24.

263 Okereke C. Global Justice and Neoliberal Environmental Governance: Ethics, Sustainable Development and International Co-Operation, 1st edn. Routledge, 2010

CONFIDENTIAL

https://www.routledge.com/Global-Justice-and-Neoliberal-Environmental-Governance-Ethics-Sustainable/Okereke/p/book/9780415599467 (accessed Nov 9, 2023).

264 Rawls J, editor. Justice as Fairness: A Restatement. Cambridge: Harvard University Press, 2001.

265 Petersmann E-U. Theories of Justice, Human Rights, and the Constitution of International Markets. *Loyola Los Angel Law Rev* 2003; **37**: 407.

266 Ensor J, Hoddy E. Securing the social foundation: A rights-based approach to planetary boundaries. *Earth Syst Gov* 2021; **7**: 100086.

267 Raworth K. Doughnut Economics. Chelsea Green Publishing, 2017 https://www.chelseagreen.com/product/doughnut-economics-paperback/ (accessed Nov 20, 2024).

268 O'Neill DW, Fanning AL, Lamb WF, Steinberger JK. A good life for all within planetary boundaries. *Nat Sustain* 2018; **1**: 88–95.

269 Sen A. Poverty and Famines: An Essay on Entitlement and Deprivation. Oxford: Clarendon Press, 1981.

270 Clapp J, Vriezen R, Laila A, *et al.* Concentrated Corporate Power Matters for Agency in Food Systems. 2025.

271 UN. General Comment No. 12 on the right to adequate food. 1999 https://www.ohchr.org/en/documents/general-comments-and-recommendations/ec1219995-general-comment-no-12-right-adequate-food (accessed Nov 29, 2024).

272 UN. International Covenant on Economic, Social and Cultural Rights. 1966 https://www.ohchr.org/en/instruments-mechanisms/instruments/international-covenant-economic-social-and-cultural-rights (accessed Nov 29, 2024).

273 FAO. Voluntary guidelines to support the progressive realization of the right to adequate food in the context of national food security. Rome: FAO, 2005 https://www.fao.org/4/y7937e/y7937e00.htm (accessed May 23, 2025).

274 Herforth A, Bai Y, Venkat A, Mahrt K, Ebel A, Masters WA. Cost and affordability of healthy diets across and within countries. FAO, 2020 DOI:10.4060/cb2431en.

275 Popkin BM, Ng SW. The nutrition transition to a stage of high obesity and noncommunicable disease prevalence dominated by ultra-processed foods is not inevitable. *Obes Rev* 2022; **23**: e13366.

276 Baker P, Machado P, Santos T, *et al.* Ultra-processed foods and the nutrition transition: Global, regional and national trends, food systems transformations and political economy drivers. *Obes Rev* 2020; **21**: e13126.

277 Carducci B, Chen Y, Luo H, Webb P, Fanzo J. Nutrition Transition Patterns in the Context of Global Food Systems Transformation. 2024; published online July 19. DOI:10.21203/rs.3.rs-4657489/v1.

278 He P, Feng K, Baiocchi G, Sun L, Hubacek K. Shifts towards healthy diets in the US can reduce environmental impacts but would be unaffordable for poorer minorities. *Nat Food* 2021; **2**: 664–72.

CONFIDENTIAL

279 Unar-Munguía M, Cervantes-Armenta MA, Rodríguez-Ramírez S, Bonvecchio Arenas A, Fernández Gaxiola AC, Rivera JA. Mexican national dietary guidelines promote less costly and environmentally sustainable diets. *Nat Food* 2024; **5**: 703–13.

280 Mayén A-L, Marques-Vidal P, Paccaud F, Bovet P, Stringhini S. Socioeconomic determinants of dietary patterns in low- and middle-income countries: a systematic review1234. *Am J Clin Nutr* 2014; **100**: 1520–31.

281 HLPE. Strengthening urban and peri-urban food systems to achieve food security and nutrition, in the context of urbanization and rural transformation. Rome: CFS HLPE-FSN, 2024 https://sfcs.fao.org/docs/devhlpelibraries/report-19/hlpe-19---main-report_en_cd1459en.pdf (accessed Aug 22, 2024).

282 HLPE. Nutrition and food systems. 2017. https://www.fao.org/3/i7846e/i7846e.pdf (accessed Jan 9, 2024).

283 Lara-Castor L, Micha R, Cudhea F, *et al.* Sugar-sweetened beverage intakes among adults between 1990 and 2018 in 185 countries. *Nat Commun* 2023; **14**: 5957.

284 Herforth A, Ahmed S. The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Secur* 2015; **7**: 505–20.

285 Monteiro CA, Cannon G, Levy RB, *et al.* Ultra-processed foods: what they are and how to identify them. *Public Health Nutr* 2019; **22**: 936–41.

286 Bevel MS, Tsai M-H, Parham A, Andrzejak SE, Jones S, Moore JX. Association of Food Deserts and Food Swamps With Obesity-Related Cancer Mortality in the US. *JAMA Oncol* 2023; **9**: 909–16.

287 FAO. The State of Food and Agriculture 2024 – Value-driven transformation of agrifood systems. Rome: FAO, 2024 DOI:10.4060/cd2616en.

288 Martin A, Eckert K, Haines J, Fraser E. Food literacy, pedagogies, and dietary guidelines: Converging approaches for health and sustainability. In: Routledge Handbook of Sustainable Diets. Routledge, 2022.

289 Rao N, Raju S. Gendered Time, Seasonality, and Nutrition: Insights from Two Indian Districts. *Fem Econ* 2019; **26**: 95–125.

290 Johnston D, Stevano S, Malapit HJ, Hull E, Kadiyala S. Review: Time Use as an Explanation for the Agri-Nutrition Disconnect: Evidence from Rural Areas in Low and Middle-Income Countries. *Food Policy* 2018; **76**: 8–18.

291 Pearson J, Jackson G, McNamara KE. Climate-driven losses to knowledge systems and cultural heritage: A literature review exploring the impacts on Indigenous and local cultures. *Anthr Rev* 2023; **10**: 343–66.

292 Key J, Burnett D, Babu JR, Geetha T. The Effects of Food Environment on Obesity in Children: A Systematic Review. *Children* 2023; **10**: 98.

293 Mingay E, Hart M, Yoong S, Hure A. Why We Eat the Way We Do: A Call to Consider Food Culture in Public Health Initiatives. *Int J Environ Res Public Health* 2021; **18**: 11967.

CONFIDENTIAL

294 UNDEP. What is the Right to a Healthy Environment. 2022 https://www.undp.org/sites/g/files/zskgke326/files/2023-01/UNDP-UNEP-UNHCHR-What-is-the-Right-to-a-Healthy-Environment.pdf (accessed Nov 29, 2024).

295 Domínguez L, Luoma C. Decolonising Conservation Policy: How Colonial Land and Conservation Ideologies Persist and Perpetuate Indigenous Injustices at the Expense of the Environment. *Land* 2020; **9**: 65.

296 Laila A, Hicks C, Rao N, *et al.* An overview of food systems injustices experienced by marginalised groups: A scoping review of reviews. .

297 Lenton TM, Xu C, Abrams JF, *et al.* Quantifying the human cost of global warming. *Nat Sustain* 2023; **6**: 1237–47.

298 Xu C, Kohler TA, Lenton TM, Svenning J-C, Scheffer M. Future of the human climate niche. *Proc Natl Acad Sci* 2020; **117**: 11350–5.

299 Daoudy M, Sowers J, Weinthal E. What is climate security? Framing risks around water, food, and migration in the Middle East and North Africa. *WIREs Water* 2022; **9**: e1582.

300 Woodhill J, Kishore A, Njuki J, Jones K, Hasnain S. Food systems and rural wellbeing: challenges and opportunities. *Food Secur* 2022; **14**: 1099–121.

301 Jain V, Tewathia N, Barik K. Gender-differentiated labor and adaptation effects of climate change in rural areas: A systematic literature review. *Gend Issues* 2023; **40**: 168–84.

302 Castillo F, Mora AM, Kayser GL, *et al.* Environmental health threats to Latino migrant farmworkers. *Annu Rev Public Health* 2021; **42**: 257–76.

303 Levy BS, Patz JA. Climate change, human rights, and social justice. *Ann Glob Health* 2015; **81**: 310–22.

304 WHO. Nitrate and Nitrite in Drinking-water. 2016 https://cdn.who.int/media/docs/default-source/wash-documents/wash-chemicals/nitrate-nitrite-background-jan17.pdf?sfvrsn=1c1e1502_4 (accessed Nov 20, 2024).

305 Glenn BE, Espira LM, Larson MC, Larson PS. Ambient air pollution and non-communicable respiratory illness in sub-Saharan Africa: a systematic review of the literature. *Environ Health* 2022; **21**: 40.

306 Katoto PDMC, Byamungu L, Brand AS, *et al.* Ambient air pollution and health in Sub-Saharan Africa: Current evidence, perspectives and a call to action. *Environ Res* 2019; **173**: 174–88.

307 ILO. ILO Constitution. 2021 https://www.ilo.org/sites/default/files/wcmsp5/groups/public/%40asia/%40ro-bangkok/%40ilo-hanoi/documents/publication/wcms_818973.pdf (accessed Nov 7, 2024).

308 ILO. General Survey of the reports on the Minimum Wage Fixing Convention, 1970 (No. 131), and the Minimum Wage Fixing Recommendation, 1970 (No. 135) | International Labour Organization. 2014; published online Feb 7. https://www.ilo.org/resource/conference-paper/ilc/103/general-survey-reports-minimum-wage-fixing-convention-1970-no-131-and (accessed Nov 7, 2024).

CONFIDENTIAL

309 UNICEF. What is child labour?| UNICEF. 2021. https://www.unicef.org/protection/female-genital-mutilation?copy_content (accessed Nov 20, 2024).

310 FAO. The state of Food Security and Nutrition in the World 2023. Rome, 2023 DOI:10.4060/cc3017en.

311 Kawarazuka N, Doss CR, Farnworth CR, Pyburn R. Myths about the feminization of agriculture: Implications for global food security. *Glob Food Secur* 2022; **33**: 100611.

312 Barrick K. Human trafficking, labor exploitation and exposure to environmental hazards: The abuse of farmworkers in the US. In: The Routledge International Handbook of Rural Criminology. Routledge, 2016.

313 Asadullah MN, Kambhampati U. Feminization of farming, food security and female empowerment. *Glob Food Secur* 2021; **29**: 100532.

314 Rao N, Lawson ET, Raditloaneng WN, Solomon D, Angula MN. Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Clim Dev* 2019; **11**: 14–26.

315 Reinecke J, Donaghey J. Towards Worker-Driven Supply Chain Governance: Developing Decent Work Through Democratic Worker Participation. *J Supply Chain Manag* 2021; **57**: 14–28.

316 ILO. Social Dialogue Report 2022: Collective bargaining for an inclusive, sustainable and resilient recovery. 2022; published online May 5. https://www.ilo.org/publications/flagship-reports/social-dialogue-report-2022-collective-bargaining-inclusive-sustainable-and (accessed Nov 7, 2024).

317 ILO. Convention C098 - Right to Organise and Collective Bargaining Convention, 1949 (No. 98). 1949. https://normlex.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_Ilo_Code:C098 (accessed Nov 7, 2024).

318 European Parliament, Council of the European Union. Directive (EU) 2022/2041 of the European Parliament and of the Council of 19 October 2022 on adequate minimum wages in the European Union. Strasbourg, 2022 https://eur-lex.europa.eu/eli/dir/2022/2041/oj/eng (accessed May 25, 2025).

319 ILO. Statistics on labour income and inequality. ILOSTAT. 2023. https://ilostat.ilo.org/topics/labour-income/ (accessed Nov 25, 2024).

320 Davis B, Mane E, Gurbuzer LY, *et al.* Estimating global and country-level employment in agrifood systems. FAO, 2023 DOI:10.4060/cc4337en.

321 Corrado A, Caruso FS. Essential but Exploitable: Migrant Agri-Food Workers in Italy and Spain. 2022; published online July 28. DOI:10.1163/15718166-12340126.

322 Liverpool-Tasie LSO, Wineman A, Young S, *et al.* A scoping review of market links between value chain actors and small-scale producers in developing regions. *Nat Sustain* 2020; **3**: 799–808.

323 Resnick D, Sivasubramanian B. Political trust and informal traders in African cities. *J Mod Afr Stud* 2023; **61**: 389–412.

CONFIDENTIAL

3705 324 Guidi CF, Berti F. Labor exploitation in the Italian agricultural sector: the case of vulnerable
3706 migrants in Tuscany. *Front Sociol* 2023; **8**. DOI:10.3389/fsoc.2023.1234873.

3707 325 Blackstone NT, Rodríguez-Huerta E, Battaglia K, *et al.* Forced labour risk is pervasive in the US
3708 land-based food supply. *Nat Food* 2023; **4**: 596–606.

3709 326 Michael Fakhri. Starvation and the right to food, with an emphasis on the Palestinian people's
3710 food sovereignty - Report of the Special Rapporteur on the right to food, Michael Fakhri
3711 (A/79/171). 2024 https://www.un.org/unispal/document/right-to-food-report-17jul24/
3712 (accessed Sept 12, 2024).

3713 327 HLPE. Conflict-induced acute food crises: potential policy responses in light of current
3714 emergencies. 2024 https://openknowledge.fao.org/server/api/core/bitstreams/836632c4-0108-
3715 4c66-bd68-08150fee2d81/content (accessed Nov 19, 2024).

3716 328 Kabeer N. The Conditions and Consequences of Choice: Reflections on the Measurement of
3717 Women's Empowerment. 1999.

3718 329 Rao N. Agency and the Capacity to Adapt: Addressing gendered vulnerabilities to climate change.
3719 In: Handbook on Climate Change Vulnerability, Environments and Communities. London: Edward
3720 Elgar Publishing, 2025.

3721 330 Clapp J, Moseley WG, Burlingame B, Termine P. Viewpoint: The case for a six-dimensional food
3722 security framework. *Food Policy* 2022; **106**: 102164.

3723 331 World Bank. Women, Business and the Law 2024. The World Bank, 2024 DOI:10.1596/978-1-
3724 4648-2063-2.

3725 332 Berry S, Gaynor M, Scott Morton F. Do Increasing Markups Matter? Lessons from Empirical
3726 Industrial Organization. *J Econ Perspect* 2019; **33**: 44–68.

3727 333 Béné C. Why the Great Food Transformation may not happen – A deep-dive into our food
3728 systems' political economy, controversies and politics of evidence. *World Dev* 2022; **154**: 105881.

3729 334 Law J, editor. A Dictionary of Business and Management. In: A Dictionary of Business and
3730 Management. Oxford University Press, 2016.
3731 https://www.oxfordreference.com/display/10.1093/acref/9780199684984.001.0001/acref-
3732 9780199684984 (accessed Nov 7, 2024).

3733 335 Clapp J, Scrinis G. Big Food, Nutritionism, and Corporate Power. *Globalizations* 2017; **14**: 578–95.

3734 336 Dempsey SE, Zoller HM, Hunt KP. The meatpacking industry's corporate exceptionalism:
3735 racialized logics of food chain worker disposability during the COVID-19 crisis. *Food Cult Soc*
3736 2023; **26**: 571–90.

3737 337 Grabs J, Carodenuto SL. Traders as sustainability governance actors in global food supply chains:
3738 A research agenda. *Bus Strategy Environ* 2021; **30**: 1314–32.

3739 338 Fabbri A, Holland TJ, Bero LA. Food industry sponsorship of academic research: investigating
3740 commercial bias in the research agenda. *Public Health Nutr* 2018; **21**: 3422–30.

CONFIDENTIAL

339 Pedroza-Tobias A, Crosbie E, Mialon M, Carriedo A, Schmidt LA. Food and beverage industry interference in science and policy: efforts to block soda tax implementation in Mexico and prevent international diffusion. *BMJ Glob Health* 2021; **6**: e005662.

340 Buthelezi T, Hammadi M, Roberts S, Smaller C. Empowering African Food Producers and Agricultural Enterprises Through Stronger Competition Law and Policy. 2023; published online Nov.

341 Rao N, Marzi E, Baudish I, Laila A, Conti C, Hicks C. Citizen voice and state response in the context of food system transformation. .

342 Bujdei-Tebeica V. Green Policies, Gray Areas: *Civ Szle* 2024; **21**: 31–47.

343 Altuna N, Dell'Era C, Landoni P, Verganti R. Developing radically new meanings through the collaboration with radical circles. *Eur J Innov Manag* 2017; **20**: 269–90.

344 Häyhä T, Lucas PL, van Vuuren DP, Cornell SE, Hoff H. From Planetary Boundaries to national fair shares of the global safe operating space — How can the scales be bridged? *Glob Environ Change* 2016; **40**: 60–72.

345 MA. Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press, 2005 http://www.maweb.org/en/Global.aspx.

346 IPCC. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,. International Panel on Climate Change, 2018 https://www.ipcc.ch/sr15/.

347 IPCC. Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Interngovernmental Panel on Climate Change, 2019.

348 IPBES. The IPBES assessment report on land degradation and restoration. Zenodo, 2018 DOI:10.5281/ZENODO.3237393.

349 Hasegawa T, Fujimori S, Havlík P, *et al.* Risk of increased food insecurity under stringent global climate change mitigation policy. *Nat Clim Change* 2018; **8**: 699–703.

350 Stehfest E, Zeist W-J van, Valin H, *et al.* Key determinants of global land-use projections. *Nat Commun* 2019; **10**: 2166.

351 Nelson GC, Valin H, Sands RD, *et al.* Climate change effects on agriculture: Economic responses to biophysical shocks. *Proc Natl Acad Sci* 2014; **111**: 3274–9.

352 Rosenzweig C, Ruane AC, Antle JM, *et al.* Coordinating AgMIP data and models across global and regional scales for 1.5°C and 2.0°C assessments. *Philos Trans R Soc Math Phys Eng Sci* 2018; **376**: 20160455.

353 van Vuuren DP, Riahi K, Calvin K, *et al.* The Shared Socio-economic Pathways: Trajectories for human development and global environmental change. *Glob Environ Change* 2017; **42**: 148–52.

354 Vuuren DP van, Kriegler E, O'Neill BC, *et al.* A new scenario framework for Climate Change Research: scenario matrix architecture. *Clim Change* 2014; **122**: 373–86.

CONFIDENTIAL

355 O'Neill BC, Kriegler E, Riahi K, *et al.* A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Clim Change* 2014; **122**: 387–400.

356 Riahi K, Vuuren DP van, Kriegler E, *et al.* The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Glob Environ Change* 2017; **42**: 153–68.

357 Dellink R, Chateau J, Lanzi E, Magné B. Long-term economic growth projections in the Shared Socioeconomic Pathways. *Glob Environ Change* 2017; **42**: 200–14.

358 KC S, Lutz W. The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Glob Environ Change* 2017; **42**: 181–92.

359 IIASA. SSP Scenario Explorer version 3.0.1. 2024. https://data.ece.iiasa.ac.at/ssp.

360 Jägermeyr J, Müller C, Ruane AC, *et al.* Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. *Nat Food* 2021; **2**: 873–85.

361 Thornton P, Nelson G, Mayberry D, Herrero M. Impacts of heat stress on global cattle production during the 21st century: a modelling study. *Lancet Planet Health* 2022; **6**: e192–201.

362 Nelson GC, Vanos J, Havenith G, Jay O, Ebi KL, Hijmans RJ. Global reductions in manual agricultural work capacity due to climate change. *Glob Change Biol* 2024; **30**: e17142.

363 Robinson S, Dunston S, Mishra A, *et al.* The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model documentation for version 3.6. 2024; published online July 8. https://hdl.handle.net/10568/148953 (accessed Nov 21, 2024).

364 Zeist W-J van, Stehfest E, Doelman JC, *et al.* Are scenario projections overly optimistic about future yield progress? *Glob Environ Change* 2020; **64**: 102120.

365 FAO. FAOSTAT Database. 2024. https://www.fao.org/faostat/en/#data.

366 Sundiang M, Oliveira TD, Mason D'Croz D, *et al.* Bundling of actions can unlock the potential for food systems transformation. *forthcoming* 2025.

367 Herrero M, Thornton PK, Mason-D'Croz D, *et al.* Innovation can accelerate the transition towards a sustainable food system. *Nat Food* 2020; **1**: 266–72.

368 Herrero M, Thornton PK, Mason-D'Croz D, *et al.* Articulating the effect of food systems innovation on the Sustainable Development Goals. *Lancet Planet Health* 2021; **5**: e50–62.

369 Leip A, Bodirsky BL, Kugelberg S. The role of nitrogen in achieving sustainable food systems for healthy diets. *Glob Food Secur* 2021; **28**: 100408.

370 van Zanten HHE, Simon W, van Selm B, *et al.* Circularity in Europe strengthens the sustainability of the global food system. *Nat Food* 2023; **4**: 320–30.

371 Van Zanten HHE, Bekkers V, Gerwien L, *et al.* Circularity contributes to achieve the EAT-Lancet 2.0 food systems transformation. 2025.

372 Zhao X, Sheng D, Edmonds J, *et al.* Agroeconomic and environmental implications of future labor market evolution. 2024; published online May 16. DOI:10.21203/rs.3.rs-4259856/v1.

CONFIDENTIAL

373 Jiang L, O'Neill BC. Global urbanization projections for the Shared Socioeconomic Pathways. *Glob Environ Change* 2017; **42**: 193–9.

374 Chen S, Huang Q, Muttarak R, *et al.* Updating global urbanization projections under the Shared Socioeconomic Pathways. *Sci Data* 2022; **9**: 137.

375 Vittis Y, Obersteiner M, Godfray, H. Charles J, Springmann M. Labour requirements for healthy and sustainable diets at global, regional, and national levels. 2023.

376 Gibson MF, Sundiang M, Mason D'Croz D, *et al.* Food systems transformation leads to radical revaluing of global agriculture. 2025.

377 World Bank. World Bank Development Indicators (WDI). 2024.

378 Thais Diniz Oliveira, Marina Sundiang, Daniel Mason-D'Croz, *et al.* Regional Food Systems Transformation in a 1.5C World: Challenges and Opportunities. .

379 Springmann M, Mason-D'Croz D, Robinson S, *et al.* Mitigation potential and global health impacts from emissions pricing of food commodities. *Nat Clim Change* 2017; **7**: 69–74.

380 Springmann M, Mason-D'Croz D, Robinson S, *et al.* Health-motivated taxes on red and processed meat: A modelling study on optimal tax levels and associated health impacts. *PLOS ONE* 2018; **13**: e0204139.

381 FAO. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. Rome, Italy: FAO, 2023 DOI:10.4060/cc7724en.

382 Meadows D. Leverage points: Places to intervene in a system. Hartland: The Sustainability Institute., 1999.

383 Dorninger C, Abson DJ, Apetrei CI, *et al.* Leverage points for sustainability transformation: a review on interventions in food and energy systems. *Ecol Econ* 2020; **171**: 106570.

384 Clark MA, Domingo NGG, Colgan K, *et al.* Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science* 2020; **370**: 705–8.

385 Schneider KR, Remans R, Bekele TH, *et al.* Governance and resilience as entry points for transforming food systems in the countdown to 2030. *Nat Food* 2025; **6**: 105–16.

386 Marteau TM, Conti C, Bunge AC, *et al.* Food environment interventions to shift consumption patterns towards planetary health diets for all: protocol for a scoping review of reviews. 2023; published online May 6. DOI:10.17605/OSF.IO/KBFEP.

387 Swinburn BA, Sacks G, Hall KD, *et al.* The global obesity pandemic: shaped by global drivers and local environments. 2011; **378**: 804–14.

388 Marteau TM, White M, Rutter H, *et al.* Increasing healthy life expectancy equitably in England by 5 years by 2035: could it be achieved? *The Lancet* 2019; **393**: 2571–3.

389 Peeters A. Obesity and the future of food policies that promote healthy diets. *Nat Rev Endocrinol 2018 147* 2018; **14**: 430–7.

CONFIDENTIAL

390 Philipsborn P von, Stratil JM, Burns J, *et al.* Environmental interventions to reduce the consumption of sugar-sweetened beverages and their effects on health. *Cochrane Database Syst Rev* 2019. DOI:10.1002/14651858.CD012292.pub2.

391 Andreyeva T, Marple K, Moore TE, Powell LM. Evaluation of Economic and Health Outcomes Associated With Food Taxes and Subsidies: A Systematic Review and Meta-analysis. *JAMA Netw Open* 2022; **5**: e2214371.

392 Pineda E, Gressier M, Li D, *et al.* Review: Effectiveness and policy implications of health taxes on foods high in fat, salt, and sugar. *Food Policy* 2024; **123**: 102599.

393 Andreyeva T, Marple K, Marinello S, Moore TE, Powell LM. Outcomes Following Taxation of Sugar-Sweetened Beverages: A Systematic Review and Meta-analysis. *JAMA Netw Open* 2022; **5**: e2215276.

394 Boyland E, McGale L, Maden M, *et al.* Association of Food and Nonalcoholic Beverage Marketing With Children and Adolescents' Eating Behaviors and Health: A Systematic Review and Meta-analysis. *JAMA Pediatr* 2022; **176**: e221037.

395 Yau A, Berger N, Law C, *et al.* Changes in household food and drink purchases following restrictions on the advertisement of high fat, salt, and sugar products across the Transport for London network: A controlled interrupted time series analysis. *PLOS Med* 2022; **19**: e1003915.

396 Taillie LS, Bercholz M, Popkin B, Rebolledo N, Reyes M, Corvalán C. Decreases in purchases of energy, sodium, sugar, and saturated fat 3 years after implementation of the Chilean food labeling and marketing law: An interrupted time series analysis. *PLOS Med* 2024; **21**: e1004463.

397 Clarke N, Ferrar J, Pechey E, *et al.* Impact of health warning labels and calorie labels on selection and purchasing of alcoholic and non-alcoholic drinks: A randomized controlled trial. *Addiction* 2023; **118**: 2327–41.

398 Evans R, O'Flaherty M, Putra IGNE, Kypridemos C, Robinson E, Colombet Z. The estimated impact of mandatory front-of-pack nutrition labelling policies on adult obesity prevalence and cardiovascular mortality in England: a modelling study. 2024; : 2024.10.14.24315283.

399 Mingay E, Hart M, Yoong S, *et al.* The Impact of Modifying Food Service Practices in Secondary Schools Providing a Routine Meal Service on Student's Food Behaviours, Health and Dining Experience: A Systematic Review and Meta-Analysis. *Nutrients* 2022; **14**: 3640.

400 Hollands GJ, Cartwright E, Pilling M, *et al.* Impact of reducing portion sizes in worksite cafeterias: a stepped wedge randomised controlled pilot trial. *Int J Behav Nutr Phys Act* 2018; **15**: 78.

401 Hollands GJ, Shemilt I, Marteau TM, *et al.* Portion, package or tableware size for changing selection and consumption of food, alcohol and tobacco. *Cochrane Database Syst Rev* 2015; **2015**: CD011045.

402 Robinson E, McFarland-Lesser I, Patel Z, Jones A. Downsizing food: a systematic review and meta-analysis examining the effect of reducing served food portion sizes on daily energy intake and body weight. *Br J Nutr* 2023; **129**: 888–903.

403 McCullough EB, Lu M, Nouve Y, Arsenault J, Zhen C. Nutrient adequacy for poor households in Africa would improve with higher income but not necessarily with lower food prices. *Nat Food* 2024; **5**: 171–81.

CONFIDENTIAL

404 Sumaila UR, Wabnitz CCC, Teh LSL, *et al.* Utilizing basic income to create a sustainable, poverty-free tomorrow. *Cell Rep Sustain* 2024; **1**: 100104.

405 Nomura M, Yamaguchi M, Inada Y, Nishi N. Current dietary intake of the Japanese population in reference to the planetary health diet-preliminary assessment. *Front Nutr* 2023; **10**. DOI:10.3389/fnut.2023.1116105.

406 Salis S, Virmani A, Priyambada L, Mohan M, Hansda K, Beaufort C de. 'Old Is Gold': How Traditional Indian Dietary Practices Can Support Pediatric Diabetes Management. *Nutrients* 2021; **13**: 4427.

407 Sidiq FF, Coles D, Hubbard C, Clark B, Frewer LJ. The Role of Traditional Diets in Promoting Food Security for Indigenous Peoples in Low- and Middle-Income Countries: A Systematic Review. *IOP Conf Ser Earth Environ Sci* 2022; **978**: 012001.

408 IFFO. Case study: Peruvian Anchovy - Why feed, not food? 2017. https://www.iffo.com/case-study-peruvian-anchovy-why-feed-not-food (accessed Oct 8, 2024).

409 UNICEF. Review of national Food-Based Dietary Guidelines and associated guidance for infants, children, adolescents, and pregnant and lactating women. New York: UNICEF, 2020.

410 FAO. Unleashing the potential of millets – International Year of Millets 2023. Rome: FAO, 2023 https://doi.org/10.4060/cc7484en.

411 Li X, Yadav R, Siddique KHM. Neglected and Underutilized Crop Species: The Key to Improving Dietary Diversity and Fighting Hunger and Malnutrition in Asia and the Pacific. *Front Nutr* 2020; **7**. DOI:10.3389/fnut.2020.593711.

412 IPES-Food. Food from somewhere: Building food security and resilience through territorial markets. 2024 https://ipes-food.org/wp-content/uploads/2024/06/FoodFromSomewhere.pdf.

413 GAIN. Strengthening Demand for Underutilised Crops: A Summary Report of a Workshop Focused on the 'Vision for Adapted Crops and Soils' Initiative. Global Alliance for Improved Nutrition, 2024 DOI:10.36072/cp.8.

414 FAO. Compendium of forgotten foods in Africa – A companion publication for Integrating Africa's forgotten foods for better nutrition. Accra: FAO, 2024 DOI:10.4060/cc5044en.

415 Pimbert M. Reclaiming Diverse Seed Commons Through Food Sovereignty, Agroecology and Economies of Care. In: Nishikawa Y, Pimbert M, eds. Seeds for Diversity and Inclusion: Agroecology and Endogenous Development. Cham: Springer International Publishing, 2022: 21–39.

416 Béné C, Devereux S. Resilience, Food Security and Food Systems: Setting the Scene. In: Béné C, Devereux S, eds. Resilience and Food Security in a Food Systems Context. Cham: Springer International Publishing, 2023: 1–29.

417 FAO. A multi-billion-dollar opportunity – Repurposing agricultural support to transform food systems. Rome, Italy: FAO, UNDP, and UNEP, 2021 DOI:10.4060/cb6562en.

418 Chapman M, Wiltshire S, Baur P, *et al.* Social-ecological feedbacks drive tipping points in farming system diversification. *One Earth* 2022; **5**: 283–92.

CONFIDENTIAL

419 FAO. The gender gap in land rights. Rome, 2018.

420 Davis KE, Makhija S, Spielman DJ. Agricultural extension and rural advisory services: What have we learned? What's next? Washington, DC: IFPRI, 2021 DOI:10.2499/p15738coll2.134719.

421 Blesh J, Mehrabi Z, Wittman H, *et al.* Against the odds: Network and institutional pathways enabling agricultural diversification. *One Earth* 2023; **6**: 479–91.

422 Hertel T, Elouafi I, Tanticharoen M, Ewert F. Diversification for enhanced food systems resilience. *Nat Food* 2021; **2**: 832–4.

423 IPES-Food. From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems, 2016 https://www.ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf (accessed July 11, 2024).

424 IPES-Food. Another perfect storm? 2022.

425 DeLonge MS, Miles A, Carlisle L. Investing in the transition to sustainable agriculture. *Environ Sci Policy* 2016; **55**: 266–73.

426 Jackson L, Rosenstock T, Thomas M, Wright J, Symstad A. Managed ecosystems: biodiversity and ecosystem functions in landscapes modified by human use. In: Naeem S, Bunker DE, Hector A, Loreau M, Perrings C, eds. Biodiversity, Ecosystem Functioning, and Human Wellbeing, 1st edn. Oxford University PressOxford, 2009: 178–94.

427 Springmann M, Freund F. Options for reforming agricultural subsidies from health, climate, and economic perspectives. *Nat Commun* 2022; **13**: 82.

428 Meyfroidt P, de Bremond A, Ryan CM, *et al.* Ten facts about land systems for sustainability. *Proc Natl Acad Sci* 2022; **119**: e2109217118.

429 Dawson NM, Coolsaet B, Sterling EJ, *et al.* The role of Indigenous peoples and local communities in effective and equitable conservation. *Ecol Soc* 2021; **26**: art19.

430 FAO. Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security. Rome: FAO, 2022.

431 IPBES. Summary for Policymakers of the Thematic Assessment Report on the Sustainable Use of Wild Species of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Bonn, Germany: IPBES secretariat, Bonn, Germany, 2022 https://doi.org/10.5281/zenodo.6425599.

432 Cesar de Oliveira SEM, Nakagawa L, Lopes GR, *et al.* The European Union and United Kingdom's deforestation-free supply chains regulations: Implications for Brazil. *Ecol Econ* 2024; **217**: 108053.

433 Carlson KM, Heilmayr R, Gibbs HK, *et al.* Effect of oil palm sustainability certification on deforestation and fire in Indonesia. *Proc Natl Acad Sci U S A* 2018; **115**: 121–6.

434 Garrett RD, Levy S, Carlson KM, *et al.* Criteria for effective zero-deforestation commitments. *Glob Environ Change* 2019; **54**: 135–47.

CONFIDENTIAL

435 Lambin EF, Furumo PR. Deforestation-Free Commodity Supply Chains: Myth or Reality? *Annu Rev Environ Resour* 2023; **48**: 237–61.

436 Papargyropoulou E, Lozano R, K. Steinberger J, Wright N, Ujang Z bin. The food waste hierarchy as a framework for the management of food surplus and food waste. *J Clean Prod* 2014; **76**: 106–15.

437 GLOPAN. Preventing nutrient loss and waste across the food system: Policy actions for high-quality diets. London: Global Panel on Agriculture and Food Systems for Nutrition, 2018.

438 Rolker H, Eisler M, Cardenas L, Deeney M, Takahashi T. Food waste interventions in low-and-middle-income countries: A systematic literature review. *Resour Conserv Recycl* 2022; **186**: 106534.

439 Fesenfeld LP, Sun Y. A systematic literature review on food waste/loss prevention and minimization methods. *J Environ Manage* 2021; **286**: 112268.

440 Messner R, Johnson H, Richards C. From surplus-to-waste: A study of systemic overproduction, surplus and food waste in horticultural supply chains. *J Clean Prod* 2021; **278**: 123952–123952.

441 FAO. The status of women in agrifood systems. FAO, 2023 DOI:10.4060/cc5343en.

442 HLPE. Promoting youth engagement and employment in agriculture and food systems. Rome, 2021.

443 ILO. Convention C182 - Worst Forms of Child Labour Convention, 1999 (No. 182). 1999. https://normlex.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C182 (accessed Nov 19, 2024).

444 ILO. Convention C184 - Safety and Health in Agriculture Convention, 2001 (No. 184). 2001. https://normlex.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C184 (accessed Nov 19, 2024).

445 ILO. Convention C190 - Violence and Harassment Convention, 2019 (No. 190). 2019. https://normlex.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C190 (accessed Nov 19, 2024).

446 Herens MC, Pittore KH, Oosterveer PJM. Transforming food systems: Multi-stakeholder platforms driven by consumer concerns and public demands. *Glob Food Secur* 2022; **32**: 100592.

447 FAO, Rikolto, Ruaf. Urban and peri-urban agriculture sourcebook – From production to food systems. Rome: FAO and Rikolto, 2022 DOI:10.4060/cb9722en.

448 Gupta C, Campbell D, Munden-Dixon K, *et al.* Food Policy Councils and Local Governments: Creating Effective Collaboration for Food Systems Change. *J Agric Food Syst Community Dev* 2018; **8**: 11–28.

449 Aktar S, McIntyre-Mills J. Reserved Seats for Women in Rural Local Government: Achieving a Level Playing Field. In: McIntyre-Mills J, Romm NRA, eds. Mixed Methods and Cross Disciplinary Research: Towards Cultivating Eco-systemic Living. Cham: Springer International Publishing, 2019: 371–97.

CONFIDENTIAL

450 Morison J. Citizen Participation: A Critical Look at the Democratic Adequacy of Government Consultations. *Oxf J Leg Stud* 2017; **37**: 636–59.

451 Shekar M, Kyoko SO, Mireya V-C, Dell'Aira C. Investment Framework for Nutrition 2024. Washington, D.C.: World Bank, 2024 https://hdl.handle.net/10986/42164 (accessed Nov 19, 2024).

452 HLPE. Social protection for food security. Rome, 2012.

453 Eseonu T. Co-creation as social innovation: including 'hard-to-reach' groups in public service delivery. *Public Money Manag* 2022; **42**: 306–13.

454 OECD. The OECD Reinforcing Democracy Initiative: Monitoring Report – Assessing Progress and Charting the Way Forward. OECD, 2024 DOI:10.1787/9543bcfb-en.

455 Klerkx L, Rose D. Dealing with the game-changing technologies of Agriculture 4.0: How do we manage diversity and responsibility in food system transition pathways? *Glob Food Secur* 2020; **24**: 100347–100347.

456 Klerkx L, Jakku E, Labarthe P. A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS - Wagening J Life Sci* 2019; **90–91**: 100315–100315.

457 Hall A, Dijkman J. Public Agricultural Research in an Era of Transformation : The Challenge of Agri-Food System Innovation. Rome and Canberra: CGIAR Independent Science and Partnership Council (ISPC) Secretariat and Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2019.

458 Bunge AC, Wood A, Halloran A, Gordon LJ. A systematic scoping review of the sustainability of vertical farming, plant-based alternatives, food delivery services and blockchain in food systems. *Nat Food* 2022; **3**: 933–41.

459 Barrett CB, Benton TG, Cooper KA, *et al.* Bundling innovations to transform agri-food. *Nat Sustain* 2020; **23**: 974–6.

460 Remans R, Zornetzer H, Mason-D'Croz D, *et al.* Backcasting supports cross-sectoral collaboration and social-technical innovation bundling: case studies in agri-food systems. *Front Sustain Food Syst* 2024; **8**. DOI:10.3389/fsufs.2024.1378883.

461 Barrett CB, Benton T, Fanzo J, *et al.* Socio-Technical Innovation Bundles Tailored to Distinct Agri-Food Systems. In: Barrett CB, Benton T, Fanzo J, *et al.*, eds. Socio-Technical Innovation Bundles for Agri-Food Systems Transformation. Cham: Springer International Publishing, 2022: 159–68.

462 Nesta. A blueprint to halve obesity in the UK. Blueprint. 2024. https://blueprint.nesta.org.uk/ (accessed Nov 20, 2024).

463 De Schutter O, Jacobs N, Clément C. A 'Common Food Policy' for Europe: How governance reforms can spark a shift to healthy diets and sustainable food systems. *Food Policy* 2020; **96**: 101849.

464 Fesenfeld LP, Wicki M, Sun Y, Bernauer T. Policy packaging can make food system transformation feasible. *Nat Food* 2020; **1**: 173–82.

CONFIDENTIAL

465 Fesenfeld LP, Sun Y. Enabling Positive Tipping Points in Public Support for Food System Transformation: The Case of Meat Consumption. In: Resnick D, Swinnen J, eds. The Political Economy of Food System Transformation: Pathways to Progress in a Polarized World. Oxford University Press, 2023: 0.

466 Carattini S, Dur R, List J. Policy evaluation and the causal analysis of public support. *Science* 2024; **386**: 490–2.

467 Malkanth SHP. Outlook of Present Organic Agriculture Policies and Future Needs in Sri Lanka. 2021; **21**: 55–72.

468 Collet AM. Dissecting misalignment in agri-environmental policy design : The Case of the PAS and the Dutch Nitrogen Crisis. University of Twente, 2023 https://essay.utwente.nl/96165/ (accessed Nov 20, 2024).

469 Tatham M, Peters Y. Fueling opposition? Yellow vests, urban elites, and fuel taxation. *J Eur Public Policy* 2023; **30**: 574–98.

470 FAO. The Fome Zero (Zero Hunger) Program: The Brazilian experience. 2011 https://www.fao.org/fsnforum/resources/reports-and-briefs/fome-zero-zero-hunger-program-brazilian-experience (accessed Nov 15, 2024).

471 Sachs J, Silva GJ. Brazil's Fome Zero Strategy: Can It Be Replicated. 2010.

472 Lucas E, Guo M, Guillén-Gosálbez G. Low-carbon diets can reduce global ecological and health costs. *Nat Food* 2023; **4**: 394–406.

473 Sutton WR, Lotsch A, Prasann A. Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System. Washington, DC: World Bank, 2024 http://hdl.handle.net/10986/41468 (accessed Nov 24, 2024).

474 Dengerink J, Dirks F, Likoko E, Guijt J. One size doesn't fit all: regional differences in priorities for food system transformation. *Food Secur* 2021; **13**: 1455–66.

475 Eckert N, Rusch G, Lyytimäki J, *et al.* Sustainable Development Goals and risks: The Yin and the Yang of the paths towards sustainability. *Ambio* 2023; **52**: 683–701.

476 Andersen I, Ishii N, Brooks T, *et al.* Defining 'science-based targets'. *Natl Sci Rev* 2021; **8**: nwaa186.

477 Kalibata A, Nabarro D. Food systems transformation through dialogues. *Nat Food* 2024; published online Oct 22. DOI:10.1038/s43016-024-01060-4.

478 Committee on World Food Security. CFS: Voluntary Guidelines on Food Systems and Nutrition. 2022. https://www.fao.org/cfs/vgfsn/en) (accessed March 8, 2025).

479 Bjørn A, Tilsted JP, Addas A, Lloyd SM. Can Science-Based Targets Make the Private Sector Paris-Aligned? A Review of the Emerging Evidence. *Curr Clim Change Rep* 2022; **8**: 53–69.

480 Fink LO. What drives firms to successfully cooperate on climate change? - an institutional analysis of the Science Based Targets initiative. 2018. https://www.iri-thesys.org/media/Masterarbeit_Fink.pdf.

CONFIDENTIAL

481 Thomas H, Chung YF, Maron M, *et al.* Achieving "nature positive" requires net gain legislation. *Science* 2024; **386**: 383–5.

482 Nordhagen S, Fanzo J. Tracking Progress and Generating Accountability for Global Food System Commitments. In: Resnick D, Swinnen J, eds. The Political Economy of Food System Transformation, 1st edn. Oxford University PressOxford, 2023: 338–59.

483 Caron P, Ferrero de Loma-Osorio G, Ferroni M, Lehmann B, Mettenleiter TC, Sokona Y. Global food security: pool collective intelligence. *Nature* 2022; **612**: 631–631.

484 Fanzo J, Haddad L, Schneider KR, *et al.* Viewpoint: Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals. *Food Policy* 2021; **104**: 102163–102163.

485 Govaerts B, Negra C, Villa TCC, *et al.* One CGIAR and the Integrated Agri-food Systems Initiative: From short-termism to transformation of the world's food systems. *PLOS ONE* 2021; **16**: e0252832.

486 Conti C, Hall A, Orr A, Hambloch C, Mausch K. Complexity-aware principles for agri-food system interventions: Lessons from project encounters with complexity. *Agric Syst* 2024; **220**: 104080.

487 Duncan J, DeClerck F, Báldi A, *et al.* Democratic directionality for transformative food systems research. *Nat Food* 2022; **3**: 183–6.

488 Turnhout E, Metze T, Wyborn C, Klenk N, Louder E. The politics of co-production: participation, power, and transformation. *Curr Opin Environ Sustain* 2020; **42**: 15–21.

489 Den Boer AC, Broerse JE, Regeer BJ. The need for capacity building to accelerate food system transformation. *Curr Opin Food Sci* 2021; **42**: 119–26.

490 den Boer ACL, Kok KPW, Gill M, *et al.* Research and innovation as a catalyst for food system transformation. 2021; **107**: 150–6.

491 Swinnen J, Resnick D. Policy coalitions in food systems transformation. International Food Policy Research Institute, 2023 https://hdl.handle.net/10568/140100 (accessed Nov 15, 2024).

492 Conti C, Hall A, Moallemi EA, *et al.* Top-down vs bottom-up processes: A systematic review clarifying roles and patterns of interactions in food system transformation. *Glob Food Secur* 2025; **44**: 100833.

493 Conti C, Hall A, Percy H, Stone-Jovicich S, Turner J, McMillan L. What does the agri-food systems transformation agenda mean for agricultural research organisations? Exploring organisational prototypes for uncertain futures. *Glob Food Secur* 2024; **40**: 100733.

494 Slater S, Lawrence M, Wood B, Serodio P, Akker AVD, Baker P. The rise of multi-stakeholderism, the power of ultra-processed food corporations, and the implications for global food governance: a network analysis. *Agric Hum Values* 2024. DOI:10.1007/s10460-024-10593-0.

495 Resnick D, Swinnen J, editors. Conclusions. In: The Political Economy of Food System Transformation: Pathways to Progress in a Polarized World. Oxford University Press, 2023: 0.

496 Deconinck K, Giner C, Jackson LA, Toyama L. Making better policies for food systems will require reducing evidence gaps. *Glob Food Secur* 2022; **33**: 100621.

CONFIDENTIAL

497 Béné C, Lundy M. Political economy of protein transition: Battles of power, framings and narratives around a false wicked problem. *Front Sustain* 2023; **4**. DOI:10.3389/frsus.2023.1098011.

498 Conti C, Zanello G, Hall A. Why are agri-food systems resistant to new directions of change ? A systematic review. *Glob Food Secur* 2021; **31**: 100576–100576.

499 IPES-Food. Too Big to Feed: Exploring the impacts of mega-mergers, consolidation and concentration of power in the agri-food sector. 2017 https://ipes-food.org/report/too-big-to-feed/ (accessed Nov 24, 2024).

500 Gaucher-Holm A, Wood B, Sacks G, Vanderlee L. The structure of the Canadian packaged food and non-alcoholic beverage manufacturing and grocery retailing sectors through a public health lens. *Glob Health* 2023; **19**: 18.

501 Swinburn B. Power dynamics in 21st-century food systems. *Nutrients* 2019; **11**. DOI:10.3390/nu11102544.

502 Morris V, Jacquet J. The animal agriculture industry, US universities, and the obstruction of climate understanding and policy. *Clim Change* 2024; **177**: 41.

503 Krattenmacher J, Espinosa R, Sanders E, Twine R, Ripple WJ. The Dublin Declaration: Gain for the Meat Industry, Loss for Science. *Environ Sci Policy* 2024; : 103922.

504 Clapp J, Noyes I, Grant Z. The Food Systems Summit's Failure to Address Corporate Power. *Development* 2021; **64**: 192–8.

505 Clapp J, Fuchs DA. Corporate Power in Global Agrifood Governance. MIT Press, 2009.

506 Gahman L, Smith S-J, Penados F, Mohamed N, Reyes J-R, Mohamed A. Health, food sovereignty, solidarity economies. In: A Beginner's Guide to Building Better Worlds - Ideas and Inspiration from the Zapatistas. Bristol, UK: UK Policy Press, 2022: 128–49.

507 Conti C, Hall A, Williams TG, Kumar V, Zanello G. Detecting 'green shoots' of agri-food systems transformation: a framework and insights from the spread of non-pesticide approaches in South India. *Innov Dev* 2024; : 1–19.

508 Baker P, Hawkes C, Wingrove K, *et al.* What drives political commitment for nutrition? A review and framework synthesis to inform the United Nations Decade of Action on Nutrition. *BMJ Glob Health* 2018; **3**: e000485.

509 Astill J, Dara RA, Campbell M, *et al.* Transparency in food supply chains: A review of enabling technology solutions. *Trends Food Sci Technol* 2019; **91**: 240–7.

510 Kortleve AJ, Mogollón JM, Harwatt H, Behrens P. Over 80% of the European Union's Common Agricultural Policy supports emissions-intensive animal products. *Nat Food* 2024; **5**: 288–92.

511 Damania R, Balseca E, de Fontaubert C, *et al.* Detox Development: Repurposing Environmentally Harmful Subsidies. Washington, DC : World Bank, 2023 DOI:10.1596/978-1-4648-1916-2.

512 Segerson K, Polasky S, Scheffer M, *et al.* A cautious approach to subsidies for environmental sustainability. *Science* 2024; **386**: 28–30.

CONFIDENTIAL

513 WHO. Action framework for developing and implementing public food procurement and service policies for a healthy diet. Geneva: WHO, 2021.

514 Vansant E, den Braber B, Hall C, *et al.* Food-sourcing from on-farm trees mediates positive relationships between tree cover and dietary quality in Malawi. *Nat Food* 2024; **5**: 661–6.

515 Ickowitz A, McMullin S, Rosenstock T, *et al.* Transforming food systems with trees and forests. *Lancet Planet Health* 2022; **6**: e632–9.

516 Singh BK, Arnold T, Biermayr-Jenzano P, *et al.* Enhancing science–policy interfaces for food systems transformation. *Nat Food* 2021; **2**: 838–42.

517 Black S, Parry I, Vernon-Lin N. Fossil Fuel Subsidies Surged to Record $7 Trillion. IMF. 2023; published online Aug 24. https://www.imf.org/en/Blogs/Articles/2023/08/24/fossil-fuel-subsidies-surged-to-record-7-trillion (accessed Nov 24, 2024).

518 IRENA. Offshore renewables: An action agenda for deployment. Abu Dhabi: International Renewable Energy Agency, 2021 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jul/IRENA_G20_Offshore_renewables_2021.pdf.

519 World Bank. Climate change action plan 2021-2025. 2021 https://documents1.worldbank.org/curated/en/705731624380363785/pdf/World-Bank-Group-Climate-Change-Action-Plan-2021-2025-Supporting-Green-Resilient-and-Inclusive-Development.pdf.

Panel References

P1 Hill AB. The Environment and Disease: Association or Causation? Proc R Soc Med 1965; 58: 295–300.

P2 Mozaffarian D, Forouhi NG. Dietary guidelines and health-is nutrition science up to the task? BMJ 2018; 360: k822.

P3 Guasch-Ferre M, Satija A, Blondin SA, et al. Meta-Analysis of Randomized Controlled Trials of Red Meat Consumption in Comparison With Various Comparison Diets on Cardiovascular Risk Factors. Circulation 2019; 139: 1828–45.

P4 Song M, Fung TT, Hu FB, et al. Association of Animal and Plant Protein Intake With All-Cause and Cause-Specific Mortality. JAMA Intern Med 2016; 176: 1453–63.

P5 Wang Y, Liu B, Han H, et al. Associations between plant-based dietary patterns and risks of type 2 diabetes, cardiovascular disease, cancer, and mortality - a systematic review and meta-analysis. Nutr J 2023; 22: 46.

P6 Filippou CD, Tsioufis CP, Thomopoulos CG, et al. Dietary Approaches to Stop Hypertension (DASH) Diet and Blood Pressure Reduction in Adults with and without Hypertension: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Adv Nutr 2020; 11: 1150–60.

CONFIDENTIAL

P7 Hollaender PL, Ross AB, Kristensen M. Whole-grain and blood lipid changes in apparently healthy adults: a systematic review and meta-analysis of randomized controlled studies. Am J Clin Nutr 2015; 102: 556–72.

P8 Mensink RP, Katan MB. Effect of dietary fatty acids on serum lipids and lipoproteins. A meta-analysis of 27 trials. Arter Thromb 1992; 12: 911–9.

P9 Hu FB, Drescher G, Trichopoulou A, Willett WC, Martínez-González MA. Three Decades of the Mediterranean Diet Pyramid: A Narrative Review of Its History, Evolution, and Advances. Am J Clin Nutr 2025; : S0002-9165(25)00259-X.

P10 Guasch-Ferre M, Willett WC. The Mediterranean diet and health: a comprehensive overview. J Intern Med 2021; 290: 549–66.

P11 Estruch R, Ros E, Salas-Salvado J, et al. Primary Prevention of Cardiovascular Disease with a Mediterranean Diet Supplemented with Extra-Virgin Olive Oil or Nuts. N Engl J Med 2018; 378: e34.

P12 Salas-Salvado J, Bullo M, Estruch R, et al. Prevention of diabetes with Mediterranean diets: a subgroup analysis of a randomized trial. Ann Intern Med 2014; 160: 1–10.

P13 Martinez-Lapiscina EH, Clavero P, Toledo E, et al. Mediterranean diet improves cognition: the PREDIMED-NAVARRA randomised trial. J Neurol Neurosurg Psychiatry 2013; 84: 1318–25.

P14 Valls-Pedret C, Sala-Vila A, Serra-Mir M, et al. Mediterranean Diet and Age-Related Cognitive Decline: A Randomized Clinical Trial. JAMA Intern Med 2015; 175: 1094–103.

P15 Guasch-Ferre M, Salas-Salvado J, Ros E, et al. The PREDIMED trial, Mediterranean diet and health outcomes: How strong is the evidence? Nutr Metab Cardiovasc Dis 2017; 27: 624–32.

P16 Salas-Salvado J, Diaz-Lopez A, Ruiz-Canela M, et al. Effect of a Lifestyle Intervention Program With Energy-Restricted Mediterranean Diet and Exercise on Weight Loss and Cardiovascular Risk Factors: One-Year Results of the PREDIMED-Plus Trial. Diabetes Care 2019; 42: 777–88.

P17 Shai I, Schwarzfuchs D, Henkin Y, et al. Weight loss with a low-carbohydrate, Mediterranean, or low-fat diet. N Engl J Med 2008; 359: 229–41.

P18 Schwarzfuchs D, Golan R, Shai I. Four-year follow-up after two-year dietary interventions. N Engl J Med 2012; 367: 1373–4.

P19 Springmann M, Auclair O, Bajaj S, *et al.* Many diets for many people: planetary health diets and their health and environmental impacts at global, regional, national, and demographic levels. *Nature*; **Submitted**.

P20 Willett W, Rockström J, Loken B, et al. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet 2019; 393: 447–92.

P21 Bui LP, Pham TT, Wang F, et al. Planetary Health Diet Index and risk of total and cause-specific mortality in three prospective cohorts. Am J Clin Nutr 2024; 120: 80–91.

P22 Gu X, Bui LP, Wang F, Wang DD, Springmann M, Willett WC. Global adherence to a healthy and sustainable diet and potential reduction in premature death. Proc Natl Acad Sci 2024; 121: e2319008121.

CONFIDENTIAL

P23 Romanello M, Napoli C di, Green C, et al. The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. Lancet Lond Engl 2023; 402: 2346–94.

P24 Rezaei EE, Webber H, Asseng S, et al. Climate change impacts on crop yields. Nat Rev Earth Environ 2023; 4: 831–46.

P25 Smith MR, Myers SS. Impact of anthropogenic CO2 emissions on global human nutrition. Nat Clim Change 2018; 8: 834–9.

P26 Fuller R, Landrigan PJ, Balakrishnan K, et al. Pollution and health: a progress update. Lancet Planet Health 2022; 6: e535–47.

P27 Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 2015; 525: 367–71.

P28 Achakulwisut P, Brauer M, Hystad P, Anenberg SC. Global, national, and urban burdens of paediatric asthma incidence attributable to ambient NO2 pollution: estimates from global datasets. Lancet Planet Health 2019; 3: e166–78.

P29 Springmann M, Van Dingenen R, Vandyck T, Latka C, Witzke P, Leip A. The global and regional air quality impacts of dietary change. Nat Commun 2023; 14: 6227.

P30 Ward MH, Jones RR, Brender JD, et al. Drinking water nitrate and human health: an updated review. Int J Environ Res Public Health 2018; 15: 1557.

P31 De Vries W. Impacts of nitrogen emissions on ecosystems and human health: A mini review. Curr Opin Environ Sci Health 2021; 21: 100249.

P32 Schulte-Uebbing LF, Beusen AHW, Bouwman AF, de Vries W. From planetary to regional boundaries for agricultural nitrogen pollution. Nature 2022; 610: 507–12.

P33 Tang FHM, Lenzen M, McBratney A, Maggi F. Risk of pesticide pollution at the global scale. Nat Geosci 2021; 14: 206–10.

P34 Nicolopoulou-Stamati P, Maipas S, Kotampasi C, Stamatis P, Hens L. Chemical Pesticides and Human Health: The Urgent Need for a New Concept in Agriculture. Front Public Health 2016; 4: 148.

P35 Pathak VM, Verma VK, Rawat BS, et al. Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. Front Microbiol 2022; 13: 962619.

P36 Shepon A, Wu T, Kremen C, et al. Exploring scenarios for the food system-zoonotic risk interface. Lancet Planet Health 2023; 7: e329–35.

P37 WHO. Red and processed meat in the context of health and the environment: many shades of red and green. Information brief. World Health Organization, 2023.

P38 Moreno-Madriñan MJ, Kontowicz E. Stocking Density and Homogeneity, Considerations on Pandemic Potential. Zoonotic Dis 2023; 3: 85–92.

P39 Greenspoon L, Krieger E, Sender R, et al. The global biomass of wild mammals. Proc Natl Acad Sci 2023; 120: e2204892120.

CONFIDENTIAL

P40 Bar-On YM, Phillips R, Milo R. The biomass distribution on Earth. Proc Natl Acad Sci U S A 2018; 115: 6506–11.

P41 Marani M, Katul GG, Pan WK, Parolari AJ. Intensity and frequency of extreme novel epidemics. Proc Natl Acad Sci 2021; 118: e2105482118.

P42 Mulchandani R, Wang Y, Gilbert M, Van Boeckel TP. Global trends in antimicrobial use in food-producing animals: 2020 to 2030. PLOS Glob Public Health 2023; 3: e0001305.

P43 Tang KL, Caffrey NP, Nobrega DB, et al. Restricting the use of antibiotics in food-producing animals and its associations with antibiotic resistance in food-producing animals and human beings: a systematic review and meta-analysis. Lancet Planet Health 2017; 1: e316–27.

P44 Antimicrobial Resistance C. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet 2022; 399: 629–55.

P45 Van Boeckel TP, Pires J, Silvester R, et al. Global trends in antimicrobial resistance in animals in low- and middle-income countries. Science 2019; 365: eaaw1944.

P46 Burke, Springmann M. Dietary and food system changes can drastically reduce anti-microbial use in animals. in prep.

P47 van Zanten HHE, Simon W, van Selm B, et al. Circularity in Europe strengthens the sustainability of the global food system. Nat Food 2023; 4: 320–30.

P48 Van Zanten HHE, Bekkers V, Gerwien L, et al. Circularity contributes to achieve the EAT-Lancet 2.0 food systems transformation. 2025.

P49 Springmann M, Clark M, Mason-D'Croz D, et al. Options for keeping the food system within environmental limits. Nature 2018; 562: 519–25.

P50 Kassam A, editor. Advances in Conservation Agriculture: Volume 1: Systems and science. London: Burleigh Dodds Science Publishing, 2020 DOI:10.1201/9780429268724.

P51 Kassam A, editor. Advances in Conservation Agriculture: Volume 2: Practice and Benefits. London: Burleigh Dodds Science Publishing, 2020 DOI:10.1201/9780429268731.

P52 Kassam A. Advances in Conservation Agriculture: Volume 3: Adoption and Spread. London: Burleigh Dodds Science Publishing, 2022.

P53 Jat ML, Chakraborty D, Ladha JK, et al. Conservation agriculture for sustainable intensification in South Asia. Nat Sustain 2020; 3: 336–43.

P54 Pittelkow CM, Liang X, Linquist BA, et al. Productivity limits and potentials of the principles of conservation agriculture. Nature 2015; 517: 365–8.

P55 Mosnier A, Javalera-Rincon V, Jones SK, et al. A decentralized approach to model national and global food and land use systems. Environ Res Lett 2023; 18: 045001.

P56 Stewart CE, Paustian K, Conant RT, Plante AF, Six J. Soil carbon saturation: concept, evidence and evaluation. Biogeochemistry 2007; 86: 19–31.

P57 Skinner K, Pratley E, Burnett K. Eating in the City: A Review of the Literature on Food Insecurity and Indigenous People Living in Urban Spaces. Societies 2016; 6: 7.

CONFIDENTIAL

4304 P58 Bryan E, Ringler C, Meinzen-Dick R. Gender, Resilience, and Food Systems. In: Béné C,
4305 Devereux S, eds. Resilience and Food Security in a Food Systems Context. Cham: Springer
4306 International Publishing, 2023: 239–80.

4307 P59 FAO. The status of women in agrifood systems. FAO, 2023 DOI:10.4060/cc5343en.

4308 P60 Arndt C, Diao X, Dorosh P, Pauw K, Thurlow J. The Ukraine war and rising commodity prices:
4309 Implications for developing countries. Glob Food Secur 2023; 36: 100680.

4310 P61 Michael Fakhri. Starvation and the right to food, with an emphasis on the Palestinian
4311 people's food sovereignty - Report of the Special Rapporteur on the right to food, Michael
4312 Fakhri (A/79/171). 2024 https://www.un.org/unispal/document/right-to-food-report-
4313 17jul24/ (accessed Sept 12, 2024).

4314 P62 HLPE. Strengthening urban and peri-urban food systems to achieve food security and
4315 nutrition, in the context of urbanization and rural transformation. Rome: CFS HLPE-FSN, 2024
4316 https://sfcs.fao.org/docs/devhlpelibraries/report-19/hlpe-19---main-
4317 report_en_cd1459en.pdf (accessed Aug 22, 2024).

4318 P63 Kuran CHA, Morsut C, Kruke BI, et al. Vulnerability and vulnerable groups from an
4319 intersectionality perspective. Int J Disaster Risk Reduct 2020; 50: 101826.

4320 P64 Brock S, Baker L, Jekums A, et al. Knowledge democratization approaches for food systems
4321 transformation. Nat Food 2024; 5: 342–5.

4322 P65 Schneider KR, Fanzo J, Haddad L, et al. The state of food systems worldwide in the
4323 countdown to 2030. Nat Food 2023; 4: 1090–110.

4324 P66 Gibson M, Sundiang M, Mason-D'Croz D, et al. Food systems transformation leads to radical
4325 revaluing of global agriculture. 2025.

4326 P67 FAO. FAOSTAT Database. 2024. https://www.fao.org/faostat/en/#data.

4327 P68 Arndt C, Hristov AN, Price WJ, et al. Full adoption of the most effective strategies to mitigate
4328 methane emissions by ruminants can help meet the 1.5 °C target by 2030 but not 2050. Proc
4329 Natl Acad Sci 2022; 119: e2111294119.

4330 P69 Tricarico JM, Kebreab E, Wattiaux MA. MILK Symposium review: Sustainability of dairy
4331 production and consumption in low-income countries with emphasis on productivity and
4332 environmental impact. J Dairy Sci 2020; 103: 9791–802.

4333 P70 Scholtz R, Twidwell D. The last continuous grasslands on Earth: Identification and
4334 conservation importance. Conserv Sci Pract 2022; 4: e626.

4335 P71 Mi W, Ren W, Chi Y, et al. Heavy grazing reduces the potential for grassland restoration: a
4336 global meta-analysis. Environ Res Lett 2024; 19: 103001.

4337 P72 Ren S, Terrer C, Li J, Cao Y, Yang S, Liu D. Historical impacts of grazing on carbon stocks and
4338 climate mitigation opportunities. Nat Clim Change 2024; 14: 380–6.

4339 P73 Wang C, Tang Y. A global meta-analyses of the response of multi-taxa diversity to grazing
4340 intensity in grasslands. Environ Res Lett 2019; 14: 114003.

4341 P74 Bai Y, Cotrufo MF. Grassland soil carbon sequestration: Current understanding, challenges,
4342 and solutions. Science 2022; 377: 603–8.

CONFIDENTIAL

P75 Pendrill F, Persson UM, Godar J, Kastner T. Deforestation displaced: trade in forest-risk commodities and the prospects for a global forest transition. Environ Res Lett 2019; 14: 055003.

P76 Pent GJ. Over-yielding in temperate silvopastures: a meta-analysis. Agrofor Syst 2020; 94: 1741–58.

P77 van Huis A, Gasco L. Insects as feed for livestock production. Science 2023; 379: 138–9.

P78 Bonaudo T, Bendahan AB, Sabatier R, et al. Agroecological principles for the redesign of integrated crop–livestock systems. Eur J Agron 2014; 57: 43–51.

P79 Notenbaert AMO, Douxchamps S, Villegas DM, et al. Tapping Into the Environmental Co-benefits of Improved Tropical Forages for an Agroecological Transformation of Livestock Production Systems. Front Sustain Food Syst 2021; 5. DOI:10.3389/fsufs.2021.742842.

P80 Van Zanten HHE, Herrero M, Van Hal O, et al. Defining a land boundary for sustainable livestock consumption. Glob Change Biol 2018; 24: 4185–94.

P81 Bryant C, Aiking H, Alessandrini R, et al. The Dublin Declaration fails to recognize the need to reduce industrial animal agriculture. Nat Food 2024; : 1–3.

P82 Schodl K, Wiesauer L, Winckler C, Leeb C. Reduced Stocking Density and Provision of Straw in a Rack Improve Pig Welfare on Commercial Fattening Farms. Front Vet Sci 2021; 8. DOI:10.3389/fvets.2021.656211.

P83 EFSA Panel on Animal Health and Welfare (AHAW), Nielsen SS, Alvarez J, et al. Welfare of cattle during transport. EFSA J 2022; 20: e07442.

P84 Mikuš T, Marzel R, Mikuš O. Early weaning: new insights on an ever-persistent problem in the dairy industry. J Dairy Res 2020; 87: 88–92.

P85 Temple D, Manteca X. Animal Welfare in Extensive Production Systems Is Still an Area of Concern. Front Sustain Food Syst 2020; 4. DOI:10.3389/fsufs.2020.545902.

P86 Ammann J, Mack G, Irek J, Finger R, El Benni N. Consumers' meat commitment and the importance of animal welfare as agricultural policy goal. Food Qual Prefer 2023; 112: 105010.

P87 Blaxter T, Åsbjer E, Fraanje W. Animal welfare and ethics in food and agriculture. TABLE, 2024 DOI:10.56661/f2d8f4c7.

P88 Mason-D'Croz D, Sulser TB, Wiebe KD, et al. Agricultural investments and hunger in Africa modeling potential contributions to SDG2 – Zero Hunger. World Dev 2019; 116: 38–53.

P89 Laborde D, Bizikova L, Lallemant T, Smaller C. Ending Hunger: What would it cost? .

P90 Chichaibelu BB, Bekchanov M, Braun J von, Torero M. The global cost of reaching a world without hunger: Investment costs and policy action opportunities. Food Policy 2021; 104: 102151.

P91 Wiebe K, Sulser TB, Dunston S, et al. Modeling impacts of faster productivity growth to inform the CGIAR initiative on Crops to End Hunger. PLOS ONE 2021; 16: e0249994.

P92 Fehér A, Gazdecki M, Véha M, Szakály M, Szakály Z. A Comprehensive Review of the Benefits of and the Barriers to the Switch to a Plant-Based Diet. Sustainability 2020; 12: 4136.

CONFIDENTIAL

P93 UNEP. Frontiers 2023. What's Cooking? An assessment of the potential impacts of selected novel alternatives to conventional animal products. United Nations Environment Programme, 2023 DOI:10.59117/20.500.11822/44236.

P94 Bunge AC, Wood A, Halloran A, Gordon LJ. A systematic scoping review of the sustainability of vertical farming, plant-based alternatives, food delivery services and blockchain in food systems. Nat Food 2022; 3: 933–41.

P95 Nájera Espinosa S, Hadida G, Jelmar Sietsma A, et al. Mapping the evidence of novel plant-based foods: a systematic review of nutritional, health, and environmental impacts in high-income countries. Nutr Rev 2024; : nuae031.

P96 Mazac R, Meinilä J, Korkalo L, Järviö N, Jalava M, Tuomisto HL. Incorporation of novel foods in European diets can reduce global warming potential, water use and land use by over 80%. Nat Food 2022; 3: 286–93.

P97 Springmann M. A multi-criteria analysis of meat and milk alternatives from nutritional, health, environmental, and cost perspectives. Submitt Manuscr submitted manuscript.

P98 Tuomisto HL. Challenges of assessing the environmental sustainability of cellular agriculture. Nat Food 2022; 3: 801–3.

P99 Garrison GL, Biermacher JT, Brorsen BW. How much will large-scale production of cell-cultured meat cost? J Agric Food Res 2022; 10: 100358.

P100 Humbird D. Scale-up economics for cultured meat. Biotechnol Bioeng 2021; 118: 3239–50.

P101 Risner D, Li F, Fell JS, et al. Preliminary Techno-Economic Assessment of Animal Cell-Based Meat. Foods 2021; 10: 3.

P102 IPES-Food. Another perfect storm? 2022.

P103 Guthman J, Butler M, Martin SJ, Mather C, Biltekoff C. In the name of protein. Nat Food 2022; 3: 391–3.

P104 Rubio NR, Xiang N, Kaplan DL. Plant-based and cell-based approaches to meat production. Nat Commun 2020; 11: 6276.

P105 Bundy DA, Gentilini U, Schultz L, et al. School Meals, Social Protection, and Human Development: Revisiting Trends, Evidence, and Practices in South Asia and Beyond. Washington, DC: World Bank, 2024 DOI:10.1596/41431.

P106 GLOPAN. Healthy Meals in Schools: Policy Innovations Linking Agriculture, Food Systems and Nutrition. London, UK: Global Panel on Agriculture and Food Systems for Nutrition, 2015 https://glopan.org/sites/default/files/HealthyMealsBrief.pdf (accessed Nov 26, 2024).

P107 Pastorino S, Hughes D, Schultz L, et al. School meals and food systems: Rethinking the consequences for climate, environment, biodiversity, and food sovereignty. London School of Hygiene & Tropical Medicine, 2023 https://hdl.handle.net/10568/137479 (accessed Nov 20, 2024).

P108 European Parliament. European Parliament resolution of 9 May 2023 on the implementation of the school scheme for fruit, vegetables, milk and dairy products under the Common Market Organisation Regulation (2021/2205(INI)). 2023.

CONFIDENTIAL

https://www.europarl.europa.eu/doceo/document/TA-9-2023-0135_EN.html (accessed Nov 26, 2024).

P109 GCNF. School Meals Programs around the World: Results from the 2021 Global Survey of School Meal Programs. Seattle: GCNF (Global Child Nutrition Foundation), 2022 https://gcnf.org/global-reports/ (accessed Nov 20, 2024).

P110 Alves Da Silva E, Pedrozo EA, Nunes Da Silva T. The PNAE (National School Feeding Program) activity system and its mediations. Front Environ Sci 2023; 10. DOI:10.3389/fenvs.2022.981932.

P111 Springmann M. The health, environmental, and cost implications of providing healthy and sustainable school meals for every child by 2030: a global modelling study with country-level detail. Prep.

CONFIDENTIAL