nature food

PERSPECTIVE

https://doi.org/10.1038/s43016-021-00421-7

Check for updates

Food system development pathways for healthy, nature-positive and inclusive food systems

F. Gaupp [1,2] ✉, C. Ruggeri Laderchi [3,4], H. Lotze-Campen [2,5], F. DeClerck [1,6], B. L. Bodirsky [2], S. Lowder [3,4], A. Popp [2], R. Kanbur [7], O. Edenhofer [2], R. Nugent [8], J. Fanzo [9], S. Dietz [10], S. Nordhagen [11] and S. Fan [12]

Sustainable food systems require the integration of and alignment between recommendations for food and land use practices, as well as an understanding of the political economy context and identification of entry points for change. We propose a food systems transformation framework that takes these elements into account and links long-term goals with short-term measures and policies, ultimately guiding the decomposition of transformation pathways into concrete steps. Taking the transition to healthier and more sustainable diets as an example, we underscore the centrality of social inclusion to the food systems transformation debate.

Global food and land system models have shown that, biophysically and technically, the production of a healthy and environmentally sustainable diet to feed 10 billion people by 2050 is possible[1,2]. Nevertheless, proposals to shift to healthy and environmentally sustainable food systems are met with concerns about job and income losses and about the future affordability of nutritious foods. The latter concern is highlighted by recent evidence that current diets present a substantial risk for disease and death globally[3], while healthy diets are currently unaffordable for approximately 3 billion people[4,5].

Addressing the hidden costs (here referred to as monetarized losses to well-being that are not accounted for by standard estimates of the value of food systems, such as agricultural gross domestic product) that have characterized the current food system's trajectory (here referred to as business as usual (BAU)) is key to the transition towards nature-positive[6], healthy and inclusive food systems. While there is growing awareness of the inefficiencies and externalities of a BAU trajectory in current policy debates, a discussion of how to concretely internalize or reduce hidden costs in an outcome-oriented manner is largely absent. Integrated assessment models (IAMs) that are able to assess food systems' hidden costs and related measures (defined as required biophysical changes to achieve food systems outcomes) and internalize them on a global scale are still limited in their capacity to cover the interdependencies related to environment, health and inclusion. Often, IAM assessments are limited to measures (for example, a change in dietary patterns) without specifying the policies that could persuade, incentivize, nudge or force actors to adopt them. If policies are simulated, they are represented in a very stylized and idealized manner (for example, first-best greenhouse gas (GHG) emission taxes or lump-sum compensation payments)[7–9]. Linking IAMs with supporting policy and political analysis in a coherent, unified framework is thus an important next step towards successful food systems transformation.

If the goals of the Paris Climate Agreement and the Sustainable Development Goals (SDGs) are to be met, the impacts of food systems transformation on inclusion need to be explicitly analysed, as concerns for those effects often skew political feasibility considerations. We define inclusion as a focus on the weakest and most vulnerable, as it relates to access to and affordability of food, and employment and wages in the food system. At present, these groups tend to face systemic and institutional constraints, and are often left behind by governments and other stakeholders (such as the private sector) and disempowered within the food system. For food systems transformation to improve the livelihoods of the poorest and most marginalized groups and increase their opportunities, these constraints need to be addressed. Recent publications on sustainable development pathways[10–12] and the quantification of Shared Socioeconomic Pathways[7] stress how large and fundamental the required changes to food systems are, and give examples of how trade-offs and synergies have been identified in IAMs. To inform the current policy debate on how to achieve a food systems transformation, sustainable development pathways that specifically focus on food systems are required. Such food system development pathways (FSDPs), introduced here, elicit the biophysical and technical feasibility of food systems transformation and potential trade-offs among multiple food systems objectives, notably between health, environmental and inclusion goals. These pathways are meant to provide decision-makers with possible combinations of policy options to achieve an inclusive food systems transformation.

In this Perspective, we propose a food systems transformation framework that integrates detailed policy analysis and the consideration of policy implementation barriers across pathway modelling exercises. We decompose the desired ambition for transformational change (defined as the gap between BAU and the FSDP; Fig. 1) into discrete measures, such as income growth of the poor, shifts to healthy diets and technological changes to improve productivity. In that way, transformational change is broken down into clear steps (decomposition into discrete measures is shown as grey rectangles in Fig. 1). To implement this defined selection of measures, possible policy bundles are identified that lead to the desired level of change.

[1]EAT, Oslo, Norway. [2]Potsdam Institute for Climate Impact Research, Potsdam, Germany. [3]Food and Land Use Coalition, London, UK. [4]SYSTEMIQ, London, UK. [5]Humboldt-Universität zu Berlin, Berlin, Germany. [6]Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden. [7]Cornell University, Ithaca, NY, USA. [8]RTI International, Seattle, WA, USA. [9]Johns Hopkins University, Baltimore, MD, USA. [10]London School of Economics, London, UK. [11]GAIN, Geneva, Switzerland. [12]China Agricultural University, Beijing, China. ✉e-mail: franziska@eatforum.org

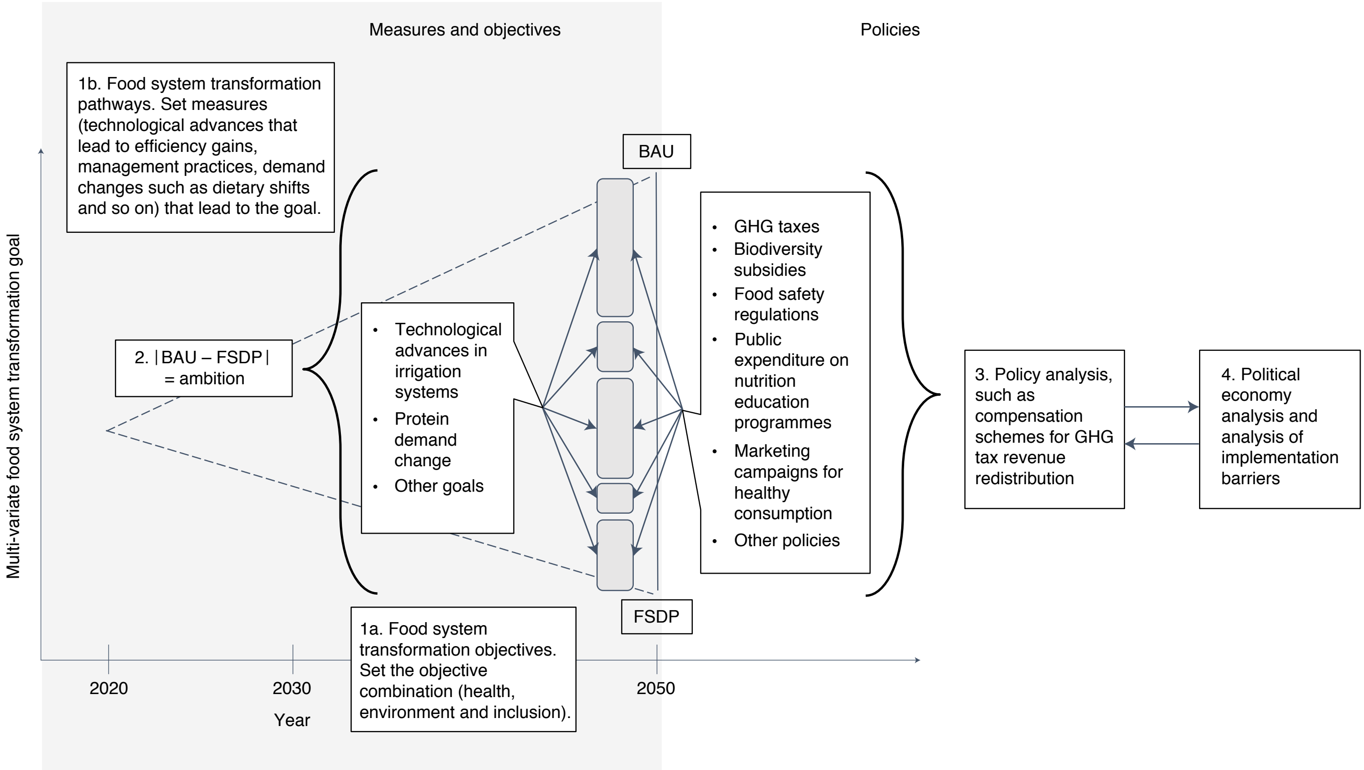

Fig. 1 | Food systems transformation framework. The framework identifies a successful path to reduce hidden food system costs and compares it with the BAU trajectory. The grey rectangles represent the different measures that collectively close the gap between the FSDP and BAU. Long-term goals (left, grey background) are linked to short-term policies (right) that are oriented towards the long-term goals. Policy design accounts for practical implementation constraints and political economy considerations.

We show how IAMs with a focus on food and land use can be used to design pathways to nature-positive, healthy and inclusive food systems and help policy analysts steer policies towards the required change in an outcome-oriented rather than incremental way. We use the example of dietary change to illustrate how policies are able to change demand. Below we provide examples of the most important policy levers to lead to a convergence towards a planetary health diet; identify key trade-offs between inclusion, health and environmental outcomes; and explore the political economy context. Finally, the need to bundle demand-side policies with those that change supply becomes evident, to enhance the likelihood that policies can be successfully implemented.

From pathways to policy to implementation

In 2015, the United Nations General Assembly agreed on reaching the SDGs, but current developments are not consistent with their achievement by 2030[13]. Similarly, the Farm-to-Fork strategy[14] of the European Commission clearly lays out targets for the European food system but has not been incorporated in the current Common Agricultural Policy reform. To make such targets more operational, IAMs can define necessary intermediate steps in line with the completion of a long-term sustainable pathway. This integrated view of systemic effects and consistency across the entire system is a strength of IAMs. They have been used to assess a large variety of trade-offs among the SDGs[15].

FSDPs represent coherent pathways that incorporate all three critical food systems transformation objectives (environment, health and inclusion), but can be diverse in their composition of goal indicators for a medium- to long-term future. Ranging from sustainable intensification to agro-ecological production and the diversity of practices that each encompasses, different FSDPs can be tested and compared in a way that explicitly considers implications for livelihoods and income distribution. Table 1 shows a range of possible indicators that can be used to measure and evaluate the desired food systems transformation.

FSDPs are a combination of biophysical projections and qualitative storylines that can include elements of Shared Socioeconomic Pathways[16] and Nationally Determined Contributions. Rather than being policy prescriptive, FSDPs are proposals that help concretize visions and that point out potential inconsistencies. They can be developed in a theoretical way, through expert consultations or with stakeholder involvement. In the first step, shown in Fig. 1, box 1a, a specific FSDP is developed that leads to a predefined multi-criteria food systems transformation, consisting of a combination of indicators (for example, Table 1). For inclusion, these indicators could be wealth distribution across and within countries, land inequality or poverty rates that are set according to the selected 2050 transformation goal. In the second step, a set of measures (Fig. 1, box 1b) is identified that will lead to the transformation goals covering environment, health and inclusion. These measures could include, for instance, dietary changes, technological advances or redistributive measures.

The FSDP is compared with a BAU scenario in the future (for example, 2050), and the difference (Fig. 1, box 2) marks the level of change (or ambition) that needs to be achieved through a range of coherent food systems policies (Fig. 1, box 3). The measures that break down a food system transformation into concrete steps (grey rectangles) on the left side of the figure are mapped to plausible combinations of policies that reduce food system hidden costs (carbon or nitrogen taxes, subsidies, regulations and so on) on the right side. This is a key component of the framework. Bundles of policies can then be evaluated to explore synergies and trade-offs. In particular, the direct compensation of 'losers' from the policy can

Table 1 | FSDP indicators (and base values)

Health	Environment
Deaths and disability-adjusted life years (DALYs) attributable to dietary risk factors (11 million per year and 255 million[46])	GHG emissions (18 $GtCO_2e$, 34% of global GHGs[47])
Number of overweight and obese people (absolute or relative) (2 billion (29%) in 2010[48,49]).	Nitrogen surplus in the food system (189 Mt N[50])
Number of undernourished people (absolute or relative) (688 million (8.9%) in 2019[5])	Phosphorus surpluses reaching oceans (4 Tg P yr^{-1}; ref. [51])
Population exposed to DALYs related to food system pollution (for example, household air pollution) (60.9 million DALYs in 2017[52])	Cropland area: agricultural land (4,801 Mha, of which 1,587 Mha were cropland in 2018[53])
Distribution of exposure to pollution (91% of the world population exposed to air pollution[54])	Biodiversity and habitat loss (20% reduction in the average abundance of native plant and animal species since 1900[55])
Inclusion	
Poverty headcounts (269 million in extreme poverty in 2018, 70% employed in the agricultural sector; estimates for 2020: 703–729 million[56])	
Affordability of a healthy diet (unaffordable for more than 3 billion people[5])	
Income distribution across countries (the average income of people located in the European Union is 11 times higher than in sub-Saharan Africa; the average income of people in the United States is 16 times higher than in sub-Saharan Africa; the gap between mean per capita incomes of high- and low-income countries increased from $27,600 in 1990 to $42,800 in 2018[57])	
Income distribution within countries (income inequality has grown in most developed countries; 71% of the world population lives in countries where income inequality has increased since 1990; the share of income earned by the richest 1% in the country increased in 59 of 100 countries between 1990 and 2015[57])	
Wealth distribution (in 2018, the bottom 50% of the world's population owned less than 1% of the global wealth; the top 10% owned 85%[57])	
Gender inequality (up to 43% of agricultural workers are women, but they are paid less, have limited access to inputs and are more exposed to violence[58,59])	
Land inequality (the largest 1% of farms operate more than 70% of global farmland; 84% of farms (smaller than 2 ha) operate 12% of the farmland[60])	

Indicators are grouped according to the food systems objectives health, environment and inclusion.

be modelled—for example, under the constraint of being revenue neutral. Other indirect measures could also be considered, such as redirecting resources to facilitate the transition to more sustainable production for smallholders, or research and innovation to make healthy diets more affordable. See Table 2 for a structured but non-exhaustive list of available food systems transformation measures and related policy options. Although for simplicity the table classifies policies into three categories, it is important to note that policies can target multiple, interlinked goals.

To enhance inclusion, measures include food waste reduction or national redistribution mechanisms for carbon pricing revenues[17]. Using FSDPs, the share of each of those measures that will lead to the desired transformation can be determined, and policymakers can be enabled to design policy bundles under specific biophysical and socioeconomic constraints.

Compensation schemes can be designed to help address the gap between 'winners' and 'losers' of such shifts. In that way, risks of adverse policy side effects (such as unaffordability of food after the introduction of carbon taxation) can be avoided. Such implementation barriers need to be carefully analysed from a political economy perspective (Fig. 1, box 4).

FSDPs can set a baseline for concrete debates and discussions about the real trade-offs that policymakers need to negotiate. They allow for the exploration of major drivers and their interactions in a food systems transformation, which would enable reducing hidden costs as part of food systems transformation in line with global goals. While other studies have focused on the development of global food system pathways and model-based scenario analysis[18,19] or on policy and governance recommendations for a food systems transformation[20,21], our framework is able to combine both approaches and thus enable outcome-oriented policy recommendations that will align with global climate and food systems targets.

Convergence towards a planetary health diet

Transformation to healthy diets by 2050 will require substantial dietary changes. It has been estimated that global consumption of unhealthy foods, such as red meat and sugar, needs to be reduced by more than 50%[1]. High levels of red and, in particular, processed meat intakes are related to increased health risks such as diabetes, cardiovascular disease and colorectal cancer[22]. The overconsumption of red and processed meat in certain populations, matched with underconsumption of whole grains, fruits, nuts and vegetables[3], was estimated to cost the world US$285 billion in health care alone in the year 2020[11]. The livestock sector, most importantly ruminant animals, is one example of a key contributor to agricultural emissions, accounting for 14.5% of GHG emissions annually[23]. The consumption of certain plant-based foods (such as nuts, fruits, vegetables and legumes), in contrast, has to increase by more than 100% to achieve a planetary health diet. Adopting a healthy diet has been estimated to avoid over 11 million deaths per year in 2030[24]. While this evidence suggests that unhealthy diets (such as red meat overconsumption) need to fall globally to stay within planetary boundaries and to improve human health, livestock rearing and processing are crucial to livelihoods for many around the world. Small-scale livestock production is a key source of income and much-needed nutrition in many parts of the world where hunger and malnutrition persist[23]. Vulnerable populations in low- and middle-income countries could also benefit from increased consumption of animal-source foods to improve their nutrition and health[25], as animal-source foods, including red meat, are dense sources of key micronutrients that are often lacking in the diets of the most vulnerable in these countries.

Using FSDPs and the food systems transformation framework, livelihood, environmental and health considerations can be included in pathway development as well as in a goal-oriented policy design process. First, the degree of dietary change required to achieve relevant food systems transformation ambitions (Fig. 1,

Table 2 | Food systems transformation measures and related policies

Inclusion		Health		Environment	
Measures	**Policies**	**Measures**	**Policies**	**Measures**	**Policies**
Support food affordability and access	Targeted transfers in cash or kind (food assistance)[61,62] Agricultural public R&D programme[63]	Internalize health externalities	Taxes on sugar, fat and ultra-processed food[11] Taxes on meat[40]	Rectify current distortions	Repurposing agricultural support towards more nature-positive production[55,64]
Support livelihoods along the value chain	Investments in smallholder agriculture[65] Certification standards (fair-trade, organic)[66] Enforced labour standards[67]	Influence the composition of supply	Targeted subsidies for healthy food production[5] Food industry regulation[5] Investments in R&D on orphan crops[68]	Internalize environmental externalities	Carbon tax[64] and possible border adjustment mechanism[69,70]
Achieve just transitions in food systems	Active labour market policies including finance for new self-employment activities or skills training[71] Targeted investment in rural infrastructure, market development and skills[64]	Shift consumption towards healthier and more sustainable diets	Food assistance measures for healthier food (food vouchers for fruits and vegetables)[61,72] Public procurement measures (for example, for school meals)[64] Education campaigns for healthier diets; behavioural interventions; nutrition labelling[26,73]	Protect nature	Protection of natural habitats[55]
				Change the composition of demand towards more nature-positive diets	Labelling and certification (organic[74], sustainable fishing[75])

For each measure, a number of concrete policy examples in the areas of health, environment and inclusion are provided.

box 2) can be quantitatively assessed on a global scale using the FSDPs, while inclusion aspects such as who makes those changes in diets and how livelihoods are impacted are simultaneously taken into account. Taking the example of dietary change, measures relate to a concrete biophysical change in the food system—for example, increasing vegetable consumption worldwide and decreasing meat consumption in high-income countries. IAMs of different designs have proved effective in simulating the consequences of such dietary shifts, including trade-offs and synergies with other societal objectives such as affordability of diets, health effects and environmental benefits. A recent study[2], for example, has shown with sustainable development pathways that a transition to healthy and sustainable diets, together with a decrease in food waste, can reduce land-use-related emissions at the same time. In addition to health and environmental considerations, dietary change might entail inclusion benefits. Reduced pressure on land, such as agricultural water-use savings, could eliminate food price increases. Depending on the level of detail of the analysis, dietary change in itself could be a measure, depicted as a grey rectangle in Fig. 1, or could be split into several measures, such as a decrease in red meat consumption or an increase in fruit and vegetable consumption.

On the basis of the required changes identified, in the second step, policymakers are able to design a range of interventions, including compensation schemes, that will lead to the required changes. Another recent study[26] grouped them as follows: administrative regulations affecting producers, retailers or local/national governments; market-based instruments such as taxes and subsidies; information-based policies such as communication of food-based dietary guidelines; and behavioural policies such as changes to the choice architecture of the food retail environment. Of these, increasingly common behavioural policies (such as those that alter the food environment in retail stores or cafeterias) may have the greatest impact on dietary patterns[26]. Methodologically, there is a plethora of policy assessment tools available to explore alternative policy pathways including trade-offs and synergies. Computable general equilibrium models, for instance, are able to assess the effects of policies and policy bundles on different outcomes, including their interlinkages at different scales. Related to healthy diets, this could include the effects of an agricultural subsidy reform on nutrition and food security[27,28]. Microsimulation models, based on household survey and microcensus data, are used to assess specific policies on a national or regional scale such as GHG taxes and a range of compensation schemes, as well as their effects on different income levels[29]. Pragmatic-enlightened models are a type of so-called pragmatic policy model that assess policy objectives and their means in light of practical consequences of the means, their secondary effects, trade-offs and synergies[30]. Further approaches include inventories of existing public sector policies and actions[31], econometric approaches[32], agent-based models[33] and literature reviews. An overview of policy analysis methods can be found in ref. [34]. Key in our framework is that policies and policy bundles aim to close the gap between BAU and the FSDP as quantified by global IAMs, and that they are able to account for interdependencies between food policy objectives.

Concrete policies addressing dietary change include taxes on unhealthy foods[35], some of which have been shown to work: a tax on sugar-sweetened beverages of 10% in Mexico led to a 12% reduction in sales after one year[36]. In other examples, however, very high tax rates would be needed to lead to substantial decreases in consumption because of substitution effects. A previous study[11] considered a more than 100% tax on meat in high-income countries to reduce consumption by 25%. This estimate may even be conservative, as the expenditure elasticities do not allow quantity substitution to be separated from quality substitution. Such taxes may be regressive[37,38], as lower-income households tend to purchase less expensive foods, but they can also be designed to reduce negative health and economic impacts on the poor[39]. Furthermore, the evidence on whether policies that successfully change meat consumption result in improved health is mixed, as reduced meat consumption can be replaced with increased consumption of either healthy or unhealthy substitutes. A systematic review[40], for example, did not find a reduction in calories consumed, emphasizing the importance of holistic dietary approaches and necessary complementary lifestyle measures (such as physical activity).

This suggests that changing consumption patterns at the scale required by the FSDPs and the food systems transformation framework might call for a combination of policies, including compensatory measures for lower-income groups (Fig. 1, box 3). Furthermore, long-term measures aimed at diversifying the supply of protein and key micronutrients for animal and human consumption would be needed to help address the livelihood impacts of these policies. For example, a shift in the relative prices of meat products vis-à-vis less emission-intensive foods in Latin America and the Caribbean has been estimated to have the potential to create 19 million more full-time-equivalent jobs in plant-based agriculture, against 4 million full-time-equivalent job losses in the livestock sector[41]. Governments could pursue increased research and development (R&D) spending in fruit, vegetable, nut, legume and blue foods production to facilitate the emergence of these new economic opportunities.

Viable policy packages

While the FSDPs provide an anchor to policymaking by highlighting the key measures needed to transform food systems and by identifying potential policy tools to support those, concrete policies need to be designed while keeping local realities in mind (Fig. 1, box 4). In the example of a global shift towards healthy diets, a combination of demand-side and supply-side measures could lead to localized job losses in economies highly dependent on livestock—some of which may have limited alternatives and be particularly vulnerable to poverty and malnutrition (such as pastoralists in semi-arid areas). Jobs would be created, however, in sectors producing alternative crops for human consumption, such as legumes, grains, fruits and vegetables. Evidence on the mechanisms at play is relatively limited and very context specific. Global insights on transformational change thus require additional, national policy analysis and awareness of where practical constraints might hamper change (for example, the work done by the Academy of Global Food Economics and Policy[42]).

The literature points to the importance of at least three sets of interrelated constraints that, in the end, shape the way reforms are implemented and are crucial for their success. The first set concerns the political economy of a radical transformation such as the one charted by the FSDPs. The redistributive impacts of measures such as those described in the previous section are central to policy design both directly (as the distribution of pay-offs from the reforms can help identify compensation needs, at least for the most vulnerable and least able to adapt) and indirectly (as different interest groups representing prospective winners and losers will be aligning themselves to lobby for or against the new policies). The repeal of the Danish fat tax, after only 15 months of operation, offers interesting insights into the dynamics at play, with strong lobbying campaigns by the food industry, retailers and farmers' organizations, including a political coalition of academia and corporate actors, playing an important role in this outcome[43].

The second set of constraints involves the governance of food systems (defined as the set of actors and their competencies in regulating food systems) and the capacities of the public sector to administer different policies and programmes. While there is a growing emphasis on the need for coherent sets of interventions to transform food systems[38], available evidence from existing institutional mapping exercises reveals how regulation is parcelled out to between 15 and 25 different departments in different ministries[44]. Such dispersion of decision-making might make it difficult to implement combinations of policies such as those involving taxes and compensation if different measures depend on different decision-makers.

The third set are the behavioural effects that can reinforce or undermine reform efforts. The policy literature is increasingly recognizing the importance of the way policy reforms interact with individuals' cognition, such as through income labelling effects[45], by which (contrary to standard economic theory) different streams of incomes are not fully fungible. Such effects, together with confidence in the capacity of the public and private sector to deliver, can play an important role in driving resistance to reforms even when a purely economic calculus would suggest that individuals would not be negatively affected.

Outlook

We call for new research and analysis that, in addition to environment and health, puts inclusion squarely in focus when analysing long-term pathways for food systems transformation. Our FSDP approach and the food systems transformation framework proposed here support a multi-criteria evaluation that considers all three objectives and aid the design of outcome-oriented policy bundles.

Renewed focus on and commitments to food systems transformation—resulting from the United Nations Food Systems Summit—offer the opportunity for new multi-stakeholder coalitions and constructive dialogue. Data, evidence and political economy were identified by the United Nations Food Systems Summit Scientific Group as key components for countries to take action. Scientific analysis based on an FSDP approach can aid the design of complex food systems transformation interventions.

Received: 19 May 2021; Accepted: 2 November 2021;
Published online: 13 December 2021

References

1. Willett, W. et al. Food in the Anthropocene: the EAT–*Lancet* Commission on healthy diets from sustainable food systems. *Lancet* **393**, 447–492 (2019).
2. Soergel, B. Climate action within the UN 2030 Agenda: a sustainable development pathway. *Nat. Clim. Change* **11**, 656–664 (2021).
3. Afshin, A. et al. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* **393**, 1958–1972 (2019).
4. Hirvonen, K., Bai, Y., Headey, D. & Masters, W. A. Affordability of the EAT–*Lancet* reference diet: a global analysis. *Lancet Glob. Health* **8**, e59–e66 (2020).
5. *The State of Food Security and Nutrition in the World 2020: Transforming Food Systems for Affordable Healthy Diets* Vol. 2020 (Food and Agriculture Organization, 2020).
6. Locke, H. et al. *A Nature-Positive World: The Global Goal for Nature* (Wildlife Conservation Society, 2020).
7. Popp, A. et al. Land-use futures in the Shared Socio-economic Pathways. *Glob. Environ. Change* **42**, 331–345 (2017).
8. Hasegawa, T. et al. Risk of increased food insecurity under stringent global climate change mitigation policy. *Nat. Clim. Change* **8**, 699–703 (2018).
9. Frank, S. et al. Reducing greenhouse gas emissions in agriculture without compromising food security? *Environ. Res. Lett.* **12**, 105004 (2017).
10. van Vuuren, D. P. et al. Pathways to achieve a set of ambitious global sustainability objectives by 2050: explorations using the IMAGE integrated assessment model. *Technol. Forecast. Soc. Change* **98**, 303–323 (2015).
11. Springmann, M. et al. Health-motivated taxes on red and processed meat: a modelling study on optimal tax levels and associated health impacts. *PLoS ONE* **13**, e0204139 (2018).
12. Gerten, D. et al. Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nat. Sustain.* **3**, 200–208 (2020).
13. Moyer, J. D. & Hedden, S. Are we on the right path to achieve the Sustainable Development Goals? *World Dev.* **127**, 104749 (2020).
14. *Farm to Fork Strategy: For a Fair, Healthy and Environmentally-Friendly Food System* (European Union, 2020).
15. Valin, H., Hertel, T., Bodirsky, B. L., Hasegawa, T. & Stehfest, E. *Achieving Zero Hunger by 2030: A Review of Quantitative Assessments of Synergies and Tradeoffs amongst the UN Sustainable Development Goals* (Scientific Group for the UN Food System Summit, 2021).
16. Riahi, K. et al. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview. *Glob. Environ. Change* **42**, 153–168 (2017).

17. Soergel, B. et al. Combining ambitious climate policies with efforts to eradicate poverty. *Nat. Commun.* **12**, 2342 (2021).
18. Mora, O. et al. Exploring the future of land use and food security: a new set of global scenarios. *PLoS ONE* **15**, e0235597 (2020).
19. van Meijl, H. et al. Modelling alternative futures of global food security: insights from FOODSECURE. *Glob. Food Secur.* **25**, 100358 (2020).
20. *Collaborative Framework for Food Systems Transformation: A Multi-Stakeholder Pathway for Sustainable Food Systems* (UN Environment, 2019).
21. Arslan, A. et al. *IFAD RDR 2021—Framework for the Analysis and Assessment of Food Systems Transformations* (IFAD and Wageningen Univ., 2021).
22. Ekmekcioglu, C. et al. Red meat, diseases, and healthy alternatives: a critical review. *Crit. Rev. Food Sci. Nutr.* **58**, 247–261 (2018).
23. *The State of Food and Agriculture: Livestock in the Balance* (FAO, 2009); http://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1235525/
24. Springmann, M. et al. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet. Health* **2**, e451–e461 (2018).
25. Zaharia, S. et al. Sustained intake of animal-sourced foods is associated with less stunting in young children. *Nat. Food* **2**, 246–254 (2021).
26. Temme, E. H. et al. Demand-side food policies for public and planetary health. *Sustainability* **12**, 5924 (2020).
27. Laborde, D., Mamun, A., Martin, W., Piñeiro, V., & Vos, R. *Modeling the Impacts of Agricultural Support Policies on Emissions from Agriculture (No. w27202)* (National Bureau of Economic Research, 2020).
28. *A Multi-Billion-Dollar Opportunity—Repurposing Agricultural Support to Transform Food Systems* (FAO, UNDP and UNEP, 2021); https://doi.org/10.4060/cb6562en
29. Kalkuhl, M., Knopf, B. & Edenhofer, O. *CO_2-Bepreisung: Mehr Klimaschutz mit mehr Gerechtigkeit* (MCC Working Paper, 2021).
30. Edenhofer, O. & Kowarsch, M. Cartography of pathways: a new model for environmental policy assessments. *Environ. Sci. Policy* **51**, 56–64 (2015).
31. Swinburn, B. et al. Monitoring and benchmarking government policies and actions to improve the healthiness of food environments: a proposed Government Healthy Food Environment Policy Index. *Obes. Rev.* **14**, 24–37 (2013).
32. Smed, S., Scarborough, P., Rayner, M. & Jensen, J. D. The effects of the Danish saturated fat tax on food and nutrient intake and modelled health outcomes: an econometric and comparative risk assessment evaluation. *Eur. J. Clin. Nutr.* **70**, 681–686 (2016).
33. Huber, R. et al. Representation of decision-making in European agricultural agent-based models. *Agric. Syst.* **167**, 143–160 (2018).
34. Dunn, W. N. *Public Policy Analysis* (Routledge, 2015).
35. *Implementing Fiscal and Pricing Policies to Promote Healthy Diets: A Review of Contextual Factors* (World Health Organisation, 2021).
36. Colchero, M. A., Popkin, B. M., Rivera, J. A. & Ng, S. W. Beverage purchases from stores in Mexico under the excise tax on sugar sweetened beverages: observational study. *Brit. Med. J.* **352**, h6704 (2016).
37. Kehlbacher, A., Tiffin, R., Briggs, A., Berners-Lee, M. & Scarborough, P. The distributional and nutritional impacts and mitigation potential of emission-based food taxes in the UK. *Climatic Change* **137**, 121–141 (2016).
38. *Making Better Policies for Food Systems* (OECD, 2021); https://doi.org/10.1787/ddfba4de-en
39. Saxena, A. et al. The distributional impact of taxing sugar-sweetened beverages: findings from an extended cost-effectiveness analysis in South Africa. *BMJ Glob. Health* **4**, e001317 (2019).
40. Maniadakis, N., Kapaki, V., Damianidi, L. & Kourlaba, G. A systematic review of the effectiveness of taxes on nonalcoholic beverages and high-in-fat foods as a means to prevent obesity trends. *Clin. Outcomes Res.* https://doi.org/10.2147/CEOR.S49659 (2013).
41. Saget, C., Vogt-Schilb, A. & Luu, T. *Jobs in a Net-Zero Emissions Future in Latin America and the Caribbean* (Inter-American Development Bank and International Labour Organization, 2020).
42. *China and Global Food Policy Report: Rethinking Agrifood Systems for the Post-COVID World* (AGFEP, 2021).
43. Vallgårda, S., Holm, L. & Jensen, J. D. The Danish tax on saturated fat: why it did not survive. *Eur. J. Clin. Nutr.* **69**, 223–226 (2015).
44. Parsons, K., Sharpe, R. & Hawkes, C. *Who Makes Food Policy in England? A Map of Government Actors and Activities* (Food Research Collaboration, 2020).
45. Beatty, T. K., Blow, L., Crossley, T. F. & O'Dea, C. Cash by any other name? Evidence on labeling from the UK Winter Fuel Payment. *J. Public Econ.* **118**, 86–96 (2014).
46. GBD Diet Collaborators Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* **393**, 1958–1972 (2019).
47. Crippa, M. et al. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat. Food* **2**, 198–209 (2021).
48. Abdeen, Z. & NCD Risk Factor Collaboration Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet* **390**, 2627–2642 (2017).
49. Bodirsky, B. L. et al. The ongoing nutrition transition thwarts long-term targets for food security, public health and environmental protection. *Sci. Rep.* **10**, 19778 (2020).
50. Sutton, M. A. et al. *Our Nutrient World: The Challenge to Produce More Food and Energy with Less Pollution* (Centre for Ecology & Hydrology, 2013).
51. Beusen, A. H., Bouwman, A. F., Van Beek, L. P., Mogollón, J. M. & Middelburg, J. J. Global riverine N and P transport to ocean increased during the 20th century despite increased retention along the aquatic continuum. *Biogeosciences* **13**, 2441–2451 (2016).
52. Lee, K. K. et al. Adverse health effects associated with household air pollution: a systematic review, meta-analysis, and burden estimation study. *Lancet Glob. Health* **8**, e1427–e1434 (2020).
53. *Statistical Database* (FAOSTAT, 2021); http://faostat3.fao.org/
54. *State of Global Air 2019: A Special Report on Global Exposure to Air Pollution and its Disease Burden* (Health Effects Institute, 2019).
55. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES, 2019).
56. *Poverty and Shared Prosperity 2020: Reversals of Fortune* (World Bank, 2020).
57. *World Social Report 2020: Inequality in a Rapidly Changing World* (United Nations, 2020).
58. Willoughby, R. & Gore, T. *Ripe for Change: Ending Human Suffering in Supermarket Supply Chains* (Oxfam, 2018).
59. *2020 Global Food Policy Report: Building Inclusive Food Systems* (IFPRI, 2020).
60. *Uneven Ground: Land Inequality at the Heart of Unequal Societies* (Land Inequality Initiative, 2020).
61. Andrews, C. et al. *The State of Economic Inclusion Report 2021: The Potential to Scale* (World Bank Publications, 2021).
62. *The State of Food and Agriculture—Social Protection and Agriculture: Breaking the Cycle of Rural Poverty* (Food and Agriculture Organization of the United Nations, 2015).
63. Barrett, C. B. et al. Bundling innovations to transform agri-food systems. *Nat. Sustain.* **3**, 974–976 (2020).
64. *Growing Better: Ten Critical Transitions to Transform Food and Land Use* (Food and Land Use Coalition, 2019).
65. *Nutrition and Food Systems: A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security* (HLPE, 2017).
66. Dragusanu, R., Giovanucci, D. & Nunn, N. The economics of fair trade. *J. Econ. Perspect.* **28**, 217–236 (2014).
67. Wilshaw, R. *UK Supermarket Supply Chains: Ending the Human Suffering Behind our Food* (Oxfam, 2018).
68. Thiele, G. & Friedmann, M. *The Vital Importance of RTB Crops in the One CGIAR Portfolio* Research Brief 02 (CGIAR, 2020).
69. Kuik, O. & Hofkes, M. Border adjustment for European emissions trading: competitiveness and carbon leakage. *Energy Policy* **38**, 1741–1748 (2010).
70. Mehling, M. A. & Ritz, R. A. *Going Beyond Default Intensities in an EU Carbon Border Adjustment Mechanism* Cambridge Working Papers in Economics 2087 (Faculty of Economics, University of Cambridge, 2020).
71. Brown, A. J. & Koettl, J. *Active Labor Market Programs: How, Why, When, and to What Extent are they Effective?* Europe and Central Asia Knowledge Brief Issue No. 58 (World Bank, 2012).
72. Olsho, L. E., Klerman, J. A., Wilde, P. E. & Bartlett, S. Financial incentives increase fruit and vegetable intake among Supplemental Nutrition Assistance Program participants: a randomized controlled trial of the USDA Healthy Incentives Pilot. *Am. J. Clin. Nutr.* **104**, 423–435 (2016).
73. Hartmann-Boyce, J. et al. Grocery store interventions to change food purchasing behaviors: a systematic review of randomized controlled trials. *Am. J. Clin. Nutr.* **107**, 1004–1016 (2018).
74. Janssen, M. & Hamm, U. Product labelling in the market for organic food: consumer preferences and willingness-to-pay for different organic certification logos. *Food Qual. Prefer.* **25**, 9–22 (2012).
75. *Global Impacts Report 2017* (Marine Stewardship Council, 2017).

Acknowledgements

We thank B. Harriss-White (University of Oxford) for helpful comments on the manuscript. This work has been supported by the Food System Economics Commission, funded by the Wellcome Trust, grant agreement no. 221362/Z/20/Z. The present work reflects only the authors' views, and the funding agency cannot be held responsible for any use that may be made of the information it contains. The work also does not necessarily reflect the views of the authors' organizations.

Author contributions

All authors contributed to the material, and all authors reviewed the manuscript. F.G., C.R.L., H.L.-C., F.D., B.L.B. and S.L. initially developed and drafted the concept. All other authors contributed equally to the further conceptualization, writing and editing of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence should be addressed to F. Gaupp.

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

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.