The importance of food systems and the environment for nutrition.

Citation for published version:
Fanzo, J, Bellows, AL, Spiker, ML, Thorne-Lyman, AL & Bloem, MW 2023, 'The importance of food systems and the environment for nutrition.', *The American Journal of Clinical Nutrition (AJCN)*, vol. 113, no. 1, pp. 7-16. https://doi.org/10.1093/ajcn/nqaa313

Digital Object Identifier (DOI):
10.1093/ajcn/nqaa313

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
The American Journal of Clinical Nutrition (AJCN)

Special Article

The importance of food systems and the environment for nutrition

Jessica Fanzo,[1] *Alexandra L Bellows,*[2] *Marie L Spiker,*[3,4] *Andrew L Thorne-Lyman,*[2,5] *and Martin W Bloem*[5]

[1]Berman Institute of Bioethics, Nitze School of Advanced International Studies, Bloomberg School of Public Health, Johns Hopkins University, Washington, DC, USA; [2]Department of International Health, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA; [3]Nutritional Sciences Program, University of Washington School of Public Health, Seattle, WA, USA; [4]Department of Epidemiology, University of Washington School of Public Health, Seattle, WA, USA; and [5]Center for a Livable Future, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, MD, USA

ABSTRACT
Global and local food system transformation is necessary in order to ensure the delivery of healthy, safe, and nutritious foods in both sustainable and equitable ways. Food systems are complex entities that affect diets, human health, and a range of other outcomes including economic growth, natural resource and environmental resiliency, and sociocultural factors. However, food systems contribute to and are vulnerable to ongoing climate and environmental changes that threaten their sustainability. Although there has been increased focus on this topic in recent years, many gaps in our knowledge persist on the relation between environmental factors, food systems, and nutritional outcomes. In this article, we summarize this emerging field and describe what innovative nutrition research is needed in order to bring about food policy changes in the era of climate disruption and environmental degradation. *Am J Clin Nutr* 2021;113:7–16.

Keywords: environmental sustainability, sustainable diets, food systems, Anthropocene, climate disruption, COVID-19, planetary health

Introduction

For clinical nutrition to be impactful, it is essential to consider how the broader food system affects diets, nutrition, and health outcomes of populations. There is considerable debate on how food systems can be better positioned to provide safe and healthy diets and support human health in a way that is environmentally sustainable and resilient to climate change, as well as other disruptions and shocks (1). As *The American Journal of Clinical Nutrition* (AJCN) embarks on new territories (2), it is only fitting that the Journal delves into the relation between food systems and dietary, nutritional, and environmental outcomes. Food systems involve the production, processing, packaging, distribution, marketing, purchasing, consumption, and waste of food (3). There remain many research questions and gaps in evidence on how to transform food systems so that they benefit both human nutrition and health while protecting ecological resources, supporting livelihoods and affordable foods, and upholding social, cultural, and ethical values. This article will summarize this emerging field, and describe what new science, research, and evidence are needed to bring about food policy changes in the era of climate disruption and environmental degradation.

The Climate Crisis and Environmental Degradation across the Planet

The era of the Anthropocene

The Anthropocene Epoch was first described by Paul Crutzen and Eugene Stoermer (4) as an unofficial time period that signifies when human activity began having substantial effects on planetary health—the health of human civilization and the state of the natural systems on which it depends (5). There is a growing body of evidence documenting how human activity has altered, in some instances irreversibly, Earth's systemic processes (6). The sheer growth and migration of the world's human population, along with the need for food, water, shelter, and livelihoods, have been major driving forces that have changed the equilibrium of the planet. These changes include deforestation, ocean acidification, pollution, loss of biodiversity, desertification, and destruction of habitats and natural resources such as water, soil, and ecosystems (1, 7, 8). Some of these processes have triggered climate change, climate-related natural disasters, poor air quality, water and food shortages, depletion of aquatic food sources, and conflicts over resources (9–11). Many of these changes are driven by the need to feed an ever-growing,

---

The authors reported no funding received for this study.
JF is an Associate Editor of the Journal.

Address correspondence to JF (e-mail: jfanzo1@jhu.edu).

Abbreviations used: GHG, greenhouse gas; HIC, high-income country; LMIC, low- and middle-income country; NCD, noncommunicable disease.

Received June 30, 2020. Accepted for publication October 7, 2020.
First published online November 24, 2020; doi: https://doi.org/10.1093/ajcn/nqaa313.

Am J Clin Nutr 2021;113:7–16. Printed in USA.

increasingly urban population that demands different and more diverse diets (7, 12).

Climate disruption and environmental degradation

Climate models continue to show that a change of >0.5°C in global surface temperature will have devastating, irreparable effects on the planet's habitability for humans and many other species (8). If we continue on a business-as-usual path without serious action on climate change mitigation, the global surface temperature will increase by >2°C above the preindustrial period (13). The projected warming of the planet will result in more hot days and hotter hot days across the globe, with regions around the equator becoming unsafe for human health (13). There will be significant changes to precipitation patterns and more intense and stronger hurricanes and tropical cyclones, as well as extreme droughts (14). Despite numerous calls for action to mitigate these anthropogenic effects (8, 13, 15), global temperature and greenhouse gases (GHGs) are increasing, and sea levels continue to rise, which will have detrimental impacts on many environmental processes, including declining terrestrial and marine biodiversity, soil salination, and diminishing water quality (15–17).

Impacts of climate and environmental change on health and nutrition

Climate and environmental change are and will continue to affect human health on a grand scale. As climate change progresses, the environmental conditions needed for optimal human health will come under threat, including clean air, drinkable water, low pathogen exposure, and the ability to produce, raise, harvest, and gather crops, animals, seafood, and wild foods in sufficient and safe quantities and/or qualities. Climate change introduces instability into the food supply, raises prices of food, and ultimately reduces access to nutrient-dense and healthy foods for certain populations (1). For example, rising sea temperatures are affecting marine life and threatening fish populations, a major source of protein, essential fatty acids, and micronutrients for many around the world. The impacts of lost biomass from the oceans are expected to disproportionally affect countries in the global South (18, 19). Some models suggest that changes in food availability due to climate change, specifically reduced availability of fruit and vegetables, are estimated to result in an additional 529,000 deaths by 2050 (20).

Climate change will likely affect the nutritional status of all populations, but it will continue to have a disproportionate impact on poor and marginalized populations, widening existing equity gaps in nutrition and health outcomes. Climate change has the potential to increase the prevalence of undernutrition by affecting the immediate, underlying, and basic causes outlined in UNICEF's conceptual framework for maternal and child nutrition (21). Examples at each level include facilitating optimal conditions for infectious diseases; reducing household food security; and altering livelihoods, particularly of those in the agricultural sector. Nutritionally vulnerable populations, including pregnant and lactating women, infants, and small children, are likely to be the most affected by these trends; the International Food Policy Research Institute's IMPACT model predicts that under conditions with limited intervention to mitigate climate change, there will be an additional 4.8 million undernourished children by 2050 (22).

Role of Food Systems, Agriculture, and Diet on the Climate and Environment

The relation between food systems and the environment is complex because environmental changes are both a driver and an outcome of food systems. As **Figure 1** shows, environmental inputs such as soil and water quality, weather patterns, and temperature influence food systems through their impact on the production, storage, and transportation of food. This, in turn, affects localized food environments—the place or places where consumers interact with the food system to buy and consume food (including markets, restaurants, and cafeterias, for example)—by influencing food availability, quality, safety, and affordability (23–25). Proximal outcomes of food systems include increased or minimized exposure to contaminants, diet quality, and food loss and waste. Each of these proximal outcomes affects both human and environmental health outcomes.

Food systems exemplify the characteristics of complex systems, including the existence of feedback loops. One important feedback loop in the food system is that environmental outcomes affect environmental inputs; for example, GHG emissions from food production and waste affect temperatures, and eutrophication from agricultural runoff affects water quality. In the context of food systems, resilience has been characterized as the ability to provide safe and sufficient food to all, not only in times of normalcy but also in times of disturbance and shocks to the system (26). Although shocks to the food system can include natural disasters, pandemics, economic instability, and political or social unrest, shocks can also include environmental stressors that push beyond the boundaries of the system. The COVID-19 pandemic is demonstrating the fragility of certain parts of current food systems and underscoring the interconnectedness of each component of the food system (27).

Numerous reports have measured the impact of food systems on the environment (28–32). Globally, agriculture and livestock production utilize ∼40% of arable land (33), account for ∼70% of fresh water withdrawn for human purposes (29, 34), and are responsible for ∼11% of GHG emissions (although some estimates range from 11% to 24% depending on what is counted) (35). Of all GHG emissions from the food system, 80%–86% come from agriculture (with the remaining food systems–related emissions coming from food processing, packaging, transportation, or retail) (32). Expanding agricultural land use is a major contributor to rising carbon dioxide concentrations in the atmosphere, biodiversity loss due to deforestation, and draining of wetlands (31, 32). Furthermore, the use of synthetic fertilizers—which contain high concentrations of nitrogen and phosphorus—is a significant source of eutrophication globally (36, 37).

Climate change puts the quantity, quality, stability, and safety of the global food supply at risk (29). Changes such as rising temperatures, increasing atmospheric carbon dioxide, rising sea levels, and changing weather patterns all affect the functionality and efficiency of food supply chains (38). Because optimal food production requires specific conditions (for

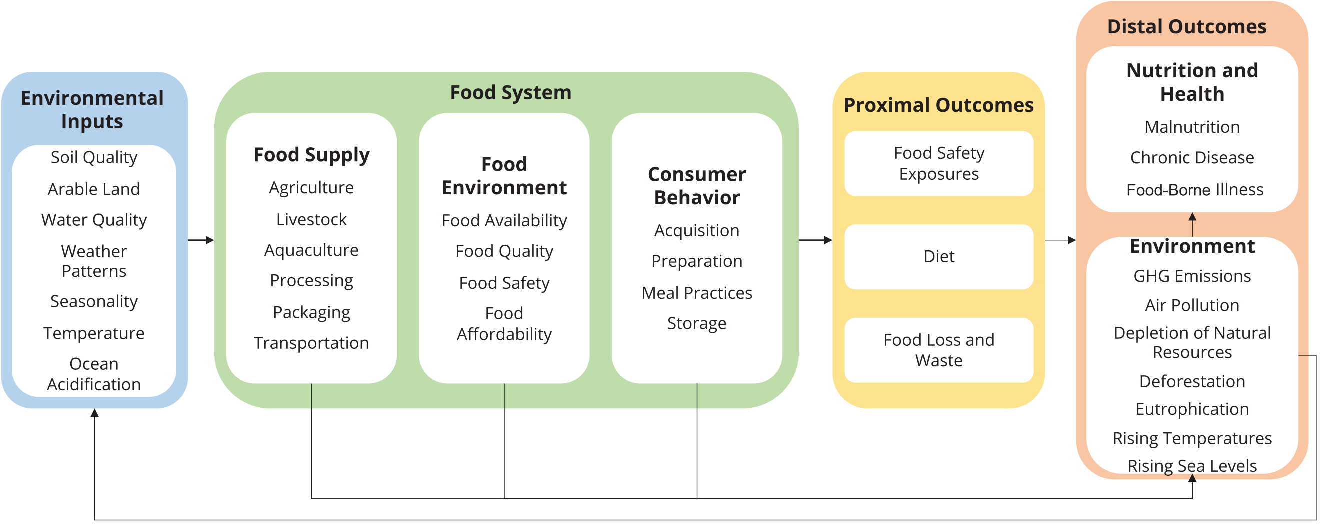

FIGURE 1 Conceptual framework for food systems and the environment. Environmental inputs such as soil and water quality, weather patterns, and temperature influence food systems through their impact on the production, storage, and transportation of food. This affects localized food environments—the place or places where consumers interact with the food system to buy and consume food—by influencing food availability, quality, safety, and affordability (23–25). Proximal outcomes of food systems include increased or minimized exposure to contaminants, diet quality, and food loss and waste. Each of these proximal outcomes affects both human and environmental health outcomes. Finally, a feedback loop exists in that environmental outcomes affect environmental inputs. GHG, greenhouse gas.

example, certain crops or pests may thrive in a narrow band of temperatures), disruptions to environmental conditions can negatively affect crop yields, the nutrient content of crops, and the broader ecosystems that support food production and livelihoods (20). Climate forecasting models estimate that average land temperatures will increase in the next 100 y (29). As land temperatures increase, certain areas of the globe, particularly tropical low-latitude areas, will experience decreased crop yields, whereas higher-latitude areas may experience increased yields in the short term (39). Lower yields and instability of production, in turn, threaten food security and nutrition by increasing food prices, which can affect the dietary diversity of poor households (40–42). In addition, geospatial differences in crop yields may result in greater reliance on a global rather than on a local food supply (43), which in turn may affect the equity of food distribution, food sovereignty, and the sustainability of food systems.

Although rising atmospheric carbon dioxide may stimulate photosynthesis and improve water efficiency of crops (44), simulation models suggest that potential gains in crop yields from rising carbon dioxide will not fully offset diminished crop yields due to rising temperatures and other environmental consequences of climate change (45). Myers et al. (38) argue that with increased climate disruption, the protected purchasing power of wealthier populations could leave those who are poor more food insecure because of their inability to access and afford food. The impact of floods and heat stress will affect the health and welfare of animals as well (46).

In addition to affecting the quantity of food, rising atmospheric carbon dioxide concentrations may also diminish the quality of food. Certain staple crops such as rice and wheat have decreased protein, iron, and zinc content when grown under high carbon dioxide conditions (38, 47–49). Even if the decrements in micronutrient content are minor, they may disproportionately affect populations of lower socioeconomic status whose diets rely predominantly on nutrient-poor staple grains. When combined with rising food prices, particularly for more nutrient-dense foods that are already out of reach (50, 51), this may worsen the risk of micronutrient deficiencies among more vulnerable populations.

The effects of climate change on human health are not limited to impacts on crop yields and the nutrient content of those crops. Temperature increases will also result in the proliferation of pests and pathogens in ways that may harm both crop production and human health. For example, aflatoxins—carcinogenic and immunosuppressive pathogens produced by certain molds—afflict crops such as maize and peanuts in tropical regions of the world and their consumption may be associated with increased risk of morbidity and mortality, poor pregnancy outcomes, and child growth (52). Researchers predict that aflatoxins may become a more prevalent food safety issue even in temperate regions where aflatoxin exposure has typically not been a concern: for example, for maize grown in Europe (53). In addition, increased proliferation of pests may result in increased use of pesticides, and we will discuss potential effects on human health in a subsequent section. Finally, warmer weather and increased atmospheric carbon dioxide facilitate harmful algal blooms that produce toxins, which can have negative impacts on the ability to access blue (aquatic) foods for diets, on human and marine health, and significant economic consequences (17).

Increased Attention to the Issue

National governments have been negotiating a response to climate change for nearly 3 decades, since the adoption of the UN Framework Convention on Climate Change in 1992. Yet states have still not reached a binding international agreement with provisions to avert environmental disaster (54). At the Paris climate conference in 2015, 196 states agreed on a goal to keep average global warming <2°C, but national pledges added up to only one-third of the emissions reductions required to meet the Paris deal's goal. In addition, some countries have yet to ratify the agreement, and the United States, the largest emitter of GHGs per capita, formally withdrew from the agreement on 4 November, 2020.

However, over the last 5 y we have seen increased attention from both nutrition and environmental scientists on the relation between food systems and the environment. Landmark reports on the causes and consequences of climate change have highlighted the importance of food systems and human diets for planetary health (1, 7, 30, 55). The cyclical nature of the relation between the environment and nutrition demands that nutrition scientists engage in food systems transformation to improve diets of the current population while conserving natural resources for diets of future generations. Nutrition scientists are in a unique position to contribute to collaborative efforts that support both human and planetary health. Nutrition is inherently a multidisciplinary science with a wide umbrella that includes expertise ranging from molecular biology to community-level behavior change communication. In addition to encouraging dietary shifts that support both human and planetary health, nutrition scientists can collaborate with other disciplines to connect the dots between human health and efforts to promote sustainable agricultural practices, reduce food loss and waste, improve food processing or packaging, and conserve resources in foodservice settings and food environments (56, 57).

Nutrition scientists have been traditionally siloed into those who study undernutrition and food insecurity and those who study overweight, obesity, and diet-related noncommunicable diseases (NCDs) (58, 59). There is also a disconnect between those who work on nutrition within a humanitarian context and those who focus on prevention or long-term development issues related to undernutrition (60). Given that many of the challenges we face are global in nature, and with rapid convergence in the type of diets being consumed and growing commonality in the type of disease burdens faced in both low- and middle-income countries (LMICs) and high-income countries (HICs), these traditional boundaries may adversely affect our ability to identify and implement public health interventions relevant to the field (61, 62).

Because of the nature of food systems—complex and interconnected with multiple drivers, outcomes, and stakeholders—we cannot gain a better understanding of interventions and policies that will reduce all forms of malnutrition and mitigate environmental consequences without a systems approach that facilitates collaboration between experts in undernutrition, overweight and NCDs, environment, climate, and agriculture. Many gaps in our knowledge still persist on the relation between environmental factors, food systems, and nutritional outcomes. Evidence is just beginning to gather as nutrition research embraces a more inter- and transdisciplinary approach to improve diet quality and reduce all forms of malnutrition (63).

Gaps in Our Knowledge

We need to better understand how food systems will affect diets, nutrition, and health outcomes in different contexts, under different drivers, with different political and societal transitions, and the potential implications for environments and overall planetary health. Currently, there is a growing body of scientific effort in this space, but we need to ensure the generation of evidence includes a "nutrition lens" and disentangles the bidirectional relation between the environment and human diets, nutrition, and health. We also need to go beyond just understanding associations and impacts to also understanding levers of change within food systems and how to operate them.

The field of nutrition has further built upon its original focus on specific nutrients to now include examination of whole dietary patterns, with the rationale that behavior change may be more easily attained by addressing the whole of diet—a unit of analysis that more closely aligns with how people make food choices (64). A growing body of literature takes an even broader view on dietary patterns, assessing their associations with not only human health but also environmental impacts including GHG emissions, land and water use, and biodiversity (65–67), and the EAT–*Lancet* Commission Report represented an attempt to find synergies between healthy diets and sustainable food production at a global level (1). Research on the sustainability of various dietary patterns increasingly highlights the existence of both co-benefits and trade-offs between nutrition and environmental impacts (68, 69). Although some research has shown that diets which rely mostly on plant-based sources have lower GHG emissions, reduced deforestation, and decreased water footprints (especially in HICs) (1, 65), in many LMIC contexts improving nutritional status may benefit from a focus on adequate nutrients with more inclusion of animal source foods in the diet, which may be accompanied by an increased environmental footprint (70). Even in specific contexts where a reduction in animal source food consumption may be warranted (e.g., among populations where animal source foods are consumed beyond what is necessary to meet nutrient needs), the path to achieving this is not straightforward. To recommend such solutions, we need more information on local and country contexts, including the agricultural and livestock systems which livelihoods are dependent upon, micro-food environments, dietary needs and health considerations, the affordability of foods and overall diets, sociocultural norms, and lifestyles of specific subpopulations.

Environmental inputs and food system processes

Thus far, most research on the connection between food systems and nutrition has focused on the 2 "ends" of food systems: agricultural production and consumer dietary intake. However, a host of other activities exist between the farm and the fork that affect nutrition and health, which some have referred to as the "missing middle" of the food supply chain (71). Issues such as food processing and packaging, postharvest loss along the supply chain, and food distribution mechanisms all have an important bearing on nutrition and health outcomes.

Most research on the impact of climate change on the nutrient content of crops has focused on staple crops; to date, very few studies have examined how climate change may influence changes in the production and consumption of nonstaple food groups (20, 72). More research is needed on how different kinds of crops—particularly those that are nutrient-dense such as fruits, vegetables, and legumes—will fare in a +2°C world. Understanding how nutrient content may differ in food grown under various climate change conditions will be vitally important for policies and interventions designed to promote diet quality and reduce the prevalence of micronutrient deficiencies. Similarly, there is a need to better understand the relation between climate and food production more broadly. For example, how is climate resilience in agriculture affected by the scale of food production, the extent of trade, or the amount of biodiversity?

In addition, further research is needed to identify and measure sustainability within food environments. An individual's food environment influences the food they choose to purchase and consume (23, 73). Sustainability has not been incorporated within traditional food environment frameworks (74), but as more research and policies consider the sustainability of dietary patterns, there is a need to understand how food environments should be designed to address both health and sustainability. These measures include the ecological footprint of foods available within an environment (with metrics including water, land, and GHG emission footprints), the amount and type of packaging companies and retailers use, the availability of combined eco- and health labeling on food packages, the availability of consumer-facing information on food sourcing and origins, food safety labels and checks, and minimization of food waste in food environments (75). Governments may also prioritize the importance of sustainability relative to the food security of their populations very differently depending on the dominant problem they are trying to solve, leading to different policy choices (76).

A growing area of research is how climate change may affect food purchasing behaviors and whether environmental sustainability is a motivation for behavior change among food systems stakeholders, including consumers. For stakeholders involved in food production and supply chains, how might economic incentives or other measures increase the adoption of practices that benefit human health while stewarding ecological resources? For consumers, how might environmentally motivated behaviors differ between various age groups, socioeconomic classes, and in different country contexts? Are the synergies with health sufficient for environmental sustainability to be a motivator for consumers when making dietary choices? Whose ability to purchase nutritious foods is more resilient to the impacts of climate change, and for those who are disadvantaged, how can we ensure they are not left behind? We need to better understand the extent to which people in different contexts are aware of the environmental impact of the food they buy, and how this awareness may affect food choices—does it bolster or hinder the healthiness of food choices? Finally, we need more research on policies and interventions that incentivize healthy and sustainable diets—both from the standpoint of consumer choice and from the standpoint of agricultural and food supply chain practices.

Proximal outcomes of the food system

Diet.

Shifting dietary intake at the population level is a formidable challenge, regardless of whether it is motivated by health, environmental, or other reasons. In the United States, for example, diets do not align with the Dietary Guidelines for Americans, as illustrated by the nationwide average Healthy Eating Index-2015 score of 56.6 out of 100 (77). Human dietary behavior is complex, and the extent to which it is driven by social norms related to environmental impact compared with health or other motivations is uncertain and an important topic for further research. One environmental motivation for dietary change is related to a question of resource use: even if the food system can produce adequate calories for a growing global population, can food production systems keep up with the demand for more resource-intensive foods? Rising incomes worldwide may increase the demand for animal source foods by 70% (7), which tend to have the highest environmental impact depending on where and how food is grown and raised.

In order to effectively change dietary intake, we need a comprehensive understanding of what people consume. Global dietary intake data that are nationally and subnationally representative remain sparse (78). Most countries do not consistently and systematically collect individual dietary intake data, and the data that do exist are often based on models relying on household expenditure and consumption survey data, food balance sheet data, and/or data from subpopulation nutrition surveys (79, 80). Although these modeled estimates may give us a sense of dietary intake and patterns of consumption, they are an uncertain substitute for robust, representative individual dietary intake data reflecting recent consumption patterns at a national level. Collection of robust longitudinal dietary data will also allow researchers and policymakers to better understand how diets are changing over time and why. Since the early 1990s, researchers have been aware that diets are rapidly changing globally (81), but surprisingly little evidence has been collected to document this change and identify the primary drivers of change. Given that dietary factors are a leading cause of the global burden of disease (79), the time for a systematic global effort to understand how diets are changing is overdue.

There is a long, tangled history of discussions, definitions, and metrics around sustainable diets (82). Rachel Carson's influential *Silent Spring*, published in the 1960s, highlighted the human footprint on the environment, and Francis Moore Lappe's *Diet for a Small Planet* politicized the impact of large-scale animal production on natural resources. Joan Dye Gussow's work on "ecological nutrition" in the 1970s stressed the unsustainable nature of the United States' food systems (83). Since that time, a growing body of literature has bridged the disciplines of public health, environmental sciences, and ecology. The terms may have changed—econutrition, sustainable diets, public health ecology—but the topic continues to be in the spotlight owing to the growing severity of climate change in the last 20 y and increased public awareness of the contribution of food systems to environmental degradation. Notably, the UN has not reached a consensus on an agreed definition of sustainable diets, although draft definitions have been developed. The definition drafted by the FAO in 2010 (84) did not provide substantive guidance on what specifically constitutes a sustainable diet from an environmental, biological, cultural, and health standpoint. A second attempt was made in 2019, where the FAO and WHO established guiding principles for sustainable and healthy diets (85). These guiding principles are a set of broad qualitative recommendations but may not be useful for quantitively assessing if a diet is sustainable. At the same time, *Food in the Anthropocene: The EAT*–Lancet *Commission on Healthy Diets from Sustainable Food Systems* published in 2019 (1) proposed a healthy reference diet that could meet both human and planetary health needs. Although the Commission report had serious limitations (86), it called for grand food system transformation and laid out a roadmap for this transformation, starting with significant changes to what is currently consumed around the world.

One of the shortcomings of the EAT–*Lancet* Commission report was that it provided a single healthy reference diet for the world, and did not take into account that healthy and sustainable diets may differ in their availability, accessibility, and cost at the global, regional, and individual levels (87). Even more so, what is considered healthy is not always sustainable, and what is considered a sustainable diet is not always a healthy one (88). Moving forward, nutrition scientists need a better understanding of how diets are changing, more scientific consensus on definitions and metrics to assess the sustainability of dietary patterns (87), and methods to test the effectiveness of interventions to promote diets that are both healthy and sustainable.

Food safety in the food system.

Human exposure to harmful chemical and biological agents occurs throughout multiple stages of food supply chains. In food production, agricultural workers may be exposed to high amounts of pesticides or other agrochemicals, which are associated with increased risk of poisoning, decreased fertility, and potential increased risk of cancer and diabetes (89–91). More research is needed on the nutrition and health effects of pesticide usage (92), particularly in LMICs, where a significant proportion of the population depend on agriculture for their livelihoods. Currently, few studies have explored the relation between pesticide exposure and adverse maternal and nutritional outcomes in LMIC settings (91, 93–95). Because pesticide and chemical regulation varies from country to country, it is important to have representative data regarding the health and nutritional risks associated with pesticide and chemical use and exposure within the food system. It is also critical to assess the extent to which consumer perceptions of pesticide, chemical, and antimicrobial exposure may influence food purchasing decisions (96). Information regarding food safety and its impacts on producer behavior, consumer awareness, and consumer behavior is limited, particularly in Sub-Saharan Africa and Asia (97).

The world's reliance on plastics for production, manufacturing, and packaging has made plastics ubiquitous in the environment and, in turn, in food systems. Plastics enter food systems directly through food packaging or indirectly through the environment. As countries develop longer supply chains, packaging becomes necessary to preserve shelf life. Plastic packaging can lead to exposure to chemicals such as Bisphenol A and phthalates, which have been linked to increased risk of obesity, cancer, and diabetes (98–100). Although some governments in HICs have mandated more regulation over these chemicals, in many instances they are replaced by structurally similar chemicals that may have similar or worse health effects (101). On the other hand, little is known about the use of these chemicals in food packaging in LMICs, and more research is needed to assess the prevalence of exposure, potential health outcomes, and to find solutions to reduce these exposures (102). More distal sources of plastic enter the food supply when discarded plastic breaks down into particles known as microplastics and these are released into the surrounding environment. The prevalence of microplastics has been documented in oceans and marine life, but currently, little evidence is available on how microplastic consumption affects human health (103).

Food loss and waste.

Food loss typically refers to losses that occur earlier in the supply chain between the farm and the retail market. Food waste typically refers to food discarded at the retail or consumption phase of the food supply chain. Food loss and waste increase the environmental footprint of food systems owing to methane emissions from the breakdown of organic materials in landfills and owing to the natural resources embedded in the production of wasted food. Food loss and waste also expose inequities in access to safe and healthy foods and represent a missed opportunity for nutrition. Food waste is nutrient waste. In the United States, nutrient-rich foods such as animal source foods, fruits, and vegetables account for $>70\%$ of food loss and waste (104). Food wasted at the retail and consumer levels alone averages 1217 calories, 33 g protein, 6 g fiber, and 286 g Ca per person per day (105). What does nutrient waste look like in other countries, especially those with a higher prevalence of micronutrient deficiencies? There is a need for more accurate data on the scale of food loss and waste globally and subnationally, and a need for research to identify cost-effective policies and interventions to reduce food loss and waste (106). The FAO has established 2 new indexes to measure food loss and waste. The *food loss index* estimates that 14% of the world's food produced is lost up to the retail level, with South and Central Asia experiencing the most significant losses of $\leq 20\%$. The *food waste index* will be published later this year (107).

Distal outcomes of food systems

Nutrition and health outcomes.

The Global Syndemic Commission recently published a report in *The Lancet* in which they defined the "syndemic"—the consequences of undernutrition, overweight/obesity, and climate change—as being related, interactive, and bound. The authors make a strong case with the support of other studies that climate change will diminish projected reductions in undernutrition (59). Policymakers and researchers have noted that many policies and interventions to address obesity may also have simultaneous positive effects on climate change progression (59, 108), but more evidence is needed on how climate change may affect obesity prevalence and how the rising prevalence of obesity affects climate change. Furthermore, there are uncertainties on the impacts of environmental degradation and climate change on micronutrient deficiencies. Plenty of research is emerging on the micronutrient content of foods with increased temperature changes and the carbon dioxide fertilization effect earlier described, but much less so on the impacts that climate change may have on the micronutrient status of populations.

Environmental outcomes.

The effects of food systems on environmental outcomes may vary by region and by method of food production. Many data gaps and methodological gaps remain in our understanding of how different foods, food groups, and dietary patterns affect a suite of environmental outcomes, including GHG emissions,

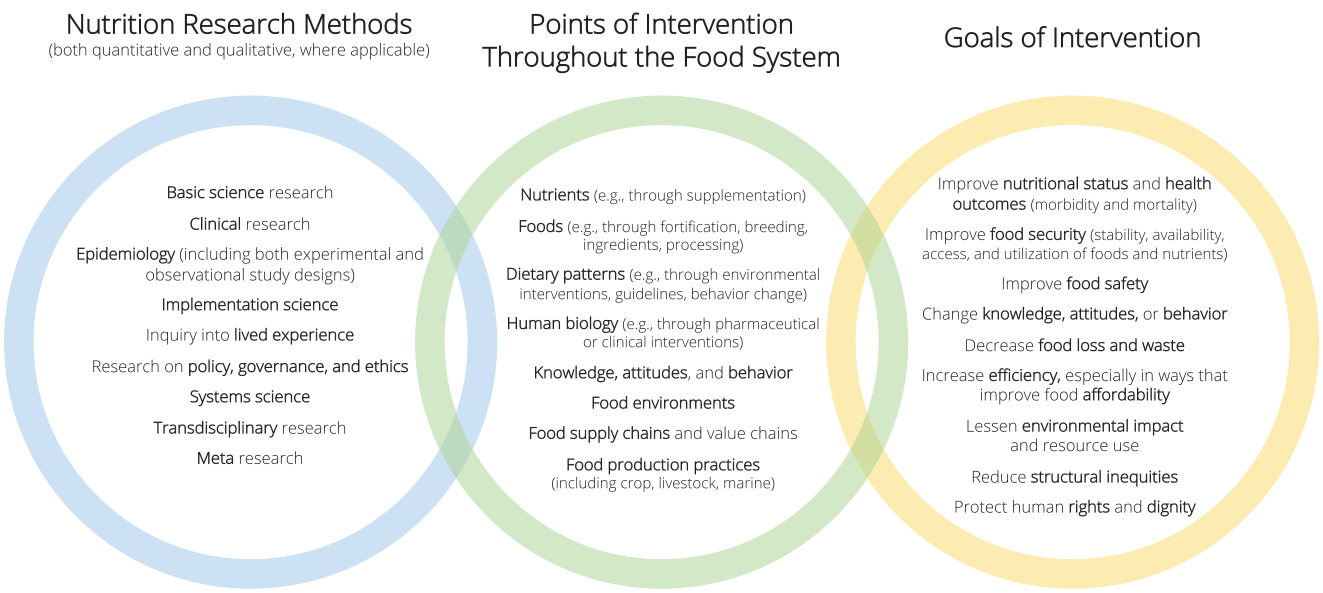

FIGURE 2 Roadmap for evidence at the intersection of food systems, the environment, and nutrition. An innovative program of food systems research draws from a range of methods, intervenes on multiple points throughout the food system, and embraces a diversity of goals that support and complement the traditional goal of improving nutritional status and health outcomes. Within each domain, the items are not intended to be hierarchical; the goal is to show that there are a range of complementary methods, points of intervention, and goals.

blue and green water use, land-use change and deforestation, eutrophication, and acidification. These effects, of course, depend on how food is grown, where, and by whom. For example, the livestock animal systems of Brazil have very different water and land use footprints than a pastoralist system in Northern Kenya (109–111). Tomatoes grown in hothouses have a different GHG profile than tomatoes grown in Southern California (112). Cashews have a much higher blue and green water footprint than peanuts (113). Live lobsters flown from Maine to Paris have a different GHG emissions footprint than mussels harvested locally (114). Our current knowledge of the environmental footprint of food is limited by the fact that most data to date focus on a few specific foods (livestock and staple grains), on a few specific environmental stressors (namely GHG emissions), and mostly on HIC settings (115).

There is a need for the nutrition community to work with climate and environmental scientists to go beyond global and regional averages and understand how healthy and unhealthy dietary patterns and the foods that comprise those diets affect the environment in more localized contexts. For example, a given dietary pattern may have a low average environmental impact at the global level; but what is the environmental impact of that dietary pattern in a specific region, and how might that dietary pattern align with the nutritional needs of specific subpopulations such as hospital patients or university students? A higher resolution of data is required before dietitians and other nutrition professionals are equipped to make menu planning or nutrition education decisions that appropriately reflect both health and environmental considerations.

The Call for Research and Innovation

AJCN's call for innovative food systems research is looking for work that draws from a broader range of research methods, points of intervention within food systems, and goals of intervention—as outlined in **Figure 2**—as well as work that attempts to make connections within each domain. For example, in looking at points of intervention throughout the food system, how do food supply chains affect dietary patterns? In looking at how intervention goals may complement each other, how might reducing structural inequities improve nutrition and health outcomes? Areas of research include:

- Research that illuminates the connections between agriculture, food value chains, climate, environment, diet, nutrition, and human health.
- Research that seeks to improve public health through efforts related to environmentally sustainable food production and value chains.
- Studies of food systems stakeholders, food environments, consumer behavior, and dietary consumption that are representative of low- and middle-income contexts and how health and environment are measured in these contexts.
- High-quality analytical methods and tools to collate, curate, and analyze data across food systems; integration of data sets across disciplines; and new empirical research to solve the grand challenge of sustainable development. The recently launched Food Systems Dashboard is one such tool that brings together a vast array of food system indicators across countries (116).

Transforming food systems to ensure that the food we produce is accessible, affordable, safe, nutritious, sustainable, and equitable for all is our moral imperative. At a time when science, evidence, and facts are increasingly scrutinized, and, at times, disregarded in political decision-making processes, research and scientific endeavor has never been more important. Research plays an important role in charting the course for nutrition, health, and sustainability. This will require a creative approach that bridges knowledge across disciplines in publications that inform action at different levels from subnational and national to regional and global. As researchers and generators of data and evidence, we need to ensure that our scientific pursuits answer the critical, real-time questions that are dividing our world. One of those questions is how both human and planetary health can thrive while meeting the demands of a growing human population, and if we can't have it all, what trade-offs are we willing to live with? It is time for the nutrition community to answer this question, laying out the paths forward along with the trade-offs. To fully address this question, it will require that nutrition scientists collaborate with other sectors, disciplines, and experts to develop a more nuanced understanding of how specific shifts in food systems can have broad impacts on sustainability.

We thank Parul Christian for providing comments to the manuscript in its earlier drafts and Andrew Jones and Anna Herforth for providing expertise on existing gaps in the literature.

The authors' responsibilities were as follows—JF and ALB: drafted the initial manuscript; MLS: contributed to the conceptualization of Figure 2; MLS, ALT-L, and MWB: provided extensive edits and feedback throughout the review process; and all authors: read and approved the final manuscript. MLS has received fellowship funding from the Academy of Nutrition and Dietetics Foundation through an educational grant from the National Dairy Council (2018–2020). The other authors report no conflicts of interest.

References

1. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, et al. Food in the Anthropocene: the EAT–*Lancet* Commission on healthy diets from sustainable food systems. Lancet 2019;393:447–92.
2. Duggan CP, Brennan L, Christian P, Fanzo J, Ludwig DS, Editors of the American Journal of Clinical Nutrition. Knowledge and debate in the *American Journal of Clinical Nutrition*: new sections, new science, and looking forward and outward. Am J Clin Nutr 2020;111:1–3.
3. HLPE. Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition. Rome, Italy: Committee on World Food Security High Level Panel of Experts (HLPE); 2017.
4. Crutzen PJ, Stoermer EF. The Anthropocene. Glob Change Newsl 2000;41:17–18.
5. Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, Ezeh A, Frumkin H, Gong P, Head P, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–*Lancet* Commission on planetary health. Lancet 2015;386:1973–2028.
6. Steffen W, Crutzen PJ, McNeill JR. The Anthropocene: are humans now overwhelming the great forces of nature? AMBIO 2007;36:614–21.
7. Searchinger T, Waite R, Hanson C, Ranganathan J, Dumas P, Matthews E. Creating a sustainable food future: a menu of solutions to feed nearly 10 billion people by 2050. Washington (DC): World Resources Institute; 2019.
8. Hoegh-Guldberg O, Jacob D, Taylor M, Bindi M, Brown S, Camilloni I, Diedhiou A, Djalante R, Ebi KL, Engelbrecht F, et al. Impacts of 1.5°C of global warming on natural and human systems. In: Masson-Delmotte V, Zhai P, Pörtner HO, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, et al., editors. 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, sustainable development, and efforts to eradicate poverty. Geneva, Switzerland: IPCC; 2018. p. 175–311.
9. Venter O, Sanderson EW, Magrach A, Allan JR, Beher J, Jones KR, Possingham HP, Laurance WF, Wood P, Fekete BM, et al. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nat Commun 2016;7:12558.
10. Crist E, Mora C, Engelman R. The interaction of human population, food production, and biodiversity protection. Science 2017;356:260–4.
11. Jones KR, Venter O, Fuller RA, Allan JR, Maxwell SL, Negret PJ, Watson JEM. One-third of global protected land is under intense human pressure. Science 2018;360:788–91.
12. Mbow C, Rosenzweig C, Barioni LG, Benton TG, Herrero M, Krishnapillai M, Liwenga E, Pradhan P, Rivera-Ferre MG, Sapkota T, et al. Food security. [Internet]. In: Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner HO, Roberts DC, Zhai P, Slade R, Connors S, van Diemen R, et al., editors. 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. Geneva, Switzerland: IPCC; 2019 [cited 26 June, 2020]. p. 437–550. Available from: https://www.ipcc.ch/site/assets/uploads/2019/11/08_Chapter-5.pdf.
13. Hoegh-Guldberg O, Jacob D, Taylor M, Guillén Bolaños T, Bindi M, Brown S, Camilloni IA, Diedhiou A, Djalante R, Ebi K, et al. The human imperative of stabilizing global climate change at 1.5°C. Science 2019;365:eaaw6974.
14. IPCC. Summary for policymakers, In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM. editors. Climate change 2013: the physical science basis contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press; 2013. p. 3-33
15. Ripple WJ, Wolf C, Newsome TM, Galetti M, Alamgir M, Crist E, Mahmoud MI, Laurance WF, 15,364 scientist signatories from 184 countries. World scientists' warning to humanity: a second notice. Bioscience 2017;67:1026–8.
16. Okur B, Örçen N. Soil salinization and climate change. In: Prasad MNV, Pietrzykowski M, editors. Climate change and soil interactions. Amsterdam: Elsevier; 2020. p. 331–50.
17. Michalak AM. Study role of climate change in extreme threats to water quality. Nature 2016;535:349–50.
18. Golden CD, Allison EH, Cheung W, Dey MM, Halpern BS, McCauley DJ, Smith M, Vaitla B, Zeller D, Myers SS. Fall in fish catch threatens human health. Nature 2016;534:317–20.
19. Boyce DG, Lotze HK, Tittensor DP, Carozza DA, Worm B. Future ocean biomass losses may widen socioeconomic equity gaps. Nat Commun 2020;11:2235.
20. Springmann M, Mason-D'Croz D, Robinson S, Garnett T, Godfray HCJ, Gollin D, Rayner M, Ballon P, Scarborough P. Global and regional health effects of future food production under climate change: a modelling study. Lancet 2016;387:1937–46.
21. UNICEF. A UNICEF policy review: strategy for improved nutrition of children and women in developing countries. New York, NY: UNICEF; 1990.
22. Fanzo J, Davis C, McLaren R, Choufani J. The effect of climate change across food systems: implications for nutrition outcomes. Glob Food Sec 2018;18:12–19.
23. 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.
24. Turner C, Aggarwal A, Walls H, Herforth A, Drewnowski A, Coates J, Kalamatianou S, Kadiyala S. Concepts and critical perspectives for food environment research: a global framework with implications for action in low- and middle-income countries. Glob Food Sec 2018;18:93–101.
25. Swinburn B, Kraak V, Rutter H, Vandevijvere S, Lobstein T, Sacks G, Gomes F, Marsh T, Magnusson R. Strengthening of accountability systems to create healthy food environments and reduce global obesity. Lancet 2015;385:2534–45.
26. Tendall DM, Joerin J, Kopainsky B, Edwards P, Shreck A, Le QB, Kruetli P, Grant M, Six J. Food system resilience: defining the concept. Glob Food Sec 2015;6:17–23.
27. Barrett CB. Actions now can curb food systems fallout from COVID-19. Nat Food 2020;1:319–20.
28. Davis KF, Gephart JA, Emery KA, Leach AM, Galloway JN, D'Odorico P. Meeting future food demand with current agricultural resources. Global Environ Change 2016;39:125–32.
29. Intergovernmental Panel on Climate Change. 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 [Internet]. Geneva,

Switzerland: IPCC; 2019 [cited 26 June 2020]. Available from: https://www.ipcc.ch/report/srccl/.

30. Springmann M, Clark M, Mason-D'Croz D, Wiebe K, Bodirsky BL, Lassaletta L, de Vries W, Vermeulen SJ, Herrero M, Carlson KM, et al. Options for keeping the food system within environmental limits. Nature 2018;562:519–25.
31. Tilman D, Clark M, Williams DR, Kimmel K, Polasky S, Packer C. Future threats to biodiversity and pathways to their prevention. Nature 2017;546:73–81.
32. Vermeulen SJ, Campbell BM, Ingram JSI. Climate change and food systems. Annu Rev Environ Resour 2012;37:195–222.
33. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, et al. Solutions for a cultivated planet. Nature 2011;478:337–42.
34. Brauman KA, Richter BD, Postel S, Malsy M, Flörke M. Water depletion: an improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments. Elem Sci Anth 2016;4:000083.
35. Climate Watch. Historical GHG emissions [Internet]. Washington (DC): World Resources Institute; 2020 [cited 26 June, 2020]. Available from: https://www.climatewatchdata.org/ghg-emissions.
36. Glibert PM, Harrison J, Heil C, Seitzinger S. Escalating worldwide use of urea – a global change contributing to coastal eutrophication. Biogeochemistry 2006;77:441–63.
37. Carpenter SR. Eutrophication of aquatic ecosystems: bistability and soil phosphorus. Proc Natl Acad Sci U S A 2005;102: 10002–5.
38. Myers SS, Smith MR, Guth S, Golden CD, Vaitla B, Mueller ND, Dangour AD, Huybers P. Climate change and global food systems: potential impacts on food security and undernutrition. Annu Rev Public Health 2017;38:259–77.
39. Sánchez B, Rasmussen A, Porter JR. Temperatures and the growth and development of maize and rice: a review. Glob Change Biol 2014;20:408–17.
40. Anríquez G, Daidone S, Mane E. Rising food prices and undernourishment: a cross-country inquiry. Food Policy 2013;38:190–202.
41. Sari M, de Pee S, Bloem MW, Sun K, Thorne-Lyman AL, Moench-Pfanner R, Akhter N, Kraemer K, Semba RD. Higher household expenditure on animal-source and nongrain foods lowers the risk of stunting among children 0–59 months old in Indonesia: implications of rising food prices. J Nutr 2010;140:195S–200S.
42. Brinkman H-J, de Pee S, Sanogo I, Subran L, Bloem MW. High food prices and the global financial crisis have reduced access to nutritious food and worsened nutritional status and health. J Nutr 2010;140:153S–61S.
43. Kinnunen P, Guillaume JHA, Taka M, D'Odorico P, Siebert S, Puma MJ, Jalava M, Kummu M. Local food crop production can fulfil demand for less than one-third of the population. Nat Food 2020;1:229–37.
44. Deryng D, Elliott J, Folberth C, Müller C, Pugh TAM, Boote KJ, Conway D, Ruane AC, Gerten D, Jones JW, et al. Regional disparities in the beneficial effects of rising CO_2 concentrations on crop water productivity. Nat Clim Change 2016;6:786–90.
45. Long SP, Ainsworth E, Leakey ADB, Nösberger J, Ort DR. Food for thought: lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 2006;312:1918–21.
46. Lacetera N. Impact of climate change on animal health and welfare. Anim Front 2019;9:26–31.
47. Medek DE, Schwartz J, Myers SS. Estimated effects of future atmospheric CO_2 concentrations on protein intake and the risk of protein deficiency by country and region. Environ Health Perspect 2017;125:087002.
48. Myers SS, Zanobetti A, Kloog I, Huybers P, Leakey ADB, Bloom AJ, Carlisle E, Dietterich LH, Fitzgerald G, Hasegawa T, et al. Increasing CO_2 threatens human nutrition. Nature 2014;510:139–42.
49. Smith MR, Myers SS. Impact of anthropogenic CO_2 emissions on global human nutrition. Nat Clim Change 2018;8:834–9.
50. Hirvonen K, Bai Y, Headey D, Masters WA. Affordability of the EAT–*Lancet* reference diet: a global analysis. Lancet Glob Health 2020;8:e59–66.
51. Headey DD, Alderman HH. The relative caloric prices of healthy and unhealthy foods differ systematically across income levels and continents. J Nutr 2019;149:2020–33.
52. Smith LE, Prendergast AJ, Turner PC, Humphrey JH, Stoltzfus RJ. Aflatoxin exposure during pregnancy, maternal anemia, and adverse birth outcomes. Am J Trop Med Hyg 2017;96:770–6.
53. Battilani P, Toscano P, Van der Fels-Klerx HJ, Moretti A, Camardo Leggieri M, Brera C, Rortais A, Goumperis T, Robinson T. Aflatoxin B_1 contamination in maize in Europe increases due to climate change. Sci Rep 2016;6:24328.
54. Nordhaus W. The climate club: how to fix a failing global effort. Foreign Affairs 2020;99(3). Available from: https://www.foreignaffairs.com/articles/united-states/2020-04-10/climate-club.
55. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Belesova K, Boykoff M, Byass P, Cai W, Campbell-Lendrum D, Capstick S, et al. The 2019 report of The *Lancet* Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. Lancet 2019;394:1836–78.
56. Lartey A, Meerman J, Wijesinha-Bettoni R. Why food system transformation is essential and how nutrition scientists can contribute. Ann Nutr Metab 2018;72:193–201.
57. Spiker ML, Knoblock-Hahn A, Brown K, Giddens J, Hege AS, Sauer K, Enos DM, Steiber A. Cultivating sustainable, resilient, and healthy food and water systems: a nutrition-focused framework for action. J Acad Nutr Diet 2020;120:1057–67.
58. Menon P, Stoltzfus RJ. Building convergence in science, programs, and policy actions on child undernutrition: symposium rationale and overview. Adv Nutr 2012;3:224–6.
59. Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, Brinsden H, Calvillo A, De Schutter O, Devarajan R, et al. The global syndemic of obesity, undernutrition, and climate change: the *Lancet* Commission report. Lancet 2019;393:791–846.
60. Wells JCK, Briend A, Boyd EM, Berkely JA, Hall A, Isanaka S, Webb P, Khara T, Dolan C. Beyond wasted and stunted—a major shift to fight child undernutrition. Lancet Child Adolesc Health 2019;3:831–4.
61. Popkin BM, Corvalan C, Grummer-Strawn LM. Dynamics of the double burden of malnutrition and the changing nutrition reality. Lancet 2020;395:65–74.
62. Popkin BM. Nutrition, agriculture and the global food system in low and middle income countries. Food Policy 2014;47:91–6.
63. Stock P, Burton RJF. Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. Sustainability 2011;3:1090–113.
64. Mozaffarian D, Ludwig DS. Dietary guidelines in the 21st century—a time for food. JAMA 2010;304:681–2.
65. Kim BF, Santo RE, Scatterday AP, Fry JP, Synk CM, Cebron SR, Mekonnen MM, Hoekstra AY, de Pee S, Bloem MW, et al. Country-specific dietary shifts to mitigate climate and water crises. Glob Environ Change 2020;62:101926.
66. Rose D, Heller MC, Willits-Smith AM, Meyer RJ. Carbon footprint of self-selected US diets: nutritional, demographic, and behavioral correlates. Am J Clin Nutr 2019;109:526–34.
67. Green RF, Joy EJM, Harris F, Agrawal S, Aleksandrowicz L, Hillier J, Macdiarmid JI, Milner J, Vetter SH, Smith P, et al. Greenhouse gas emissions and water footprints of typical dietary patterns in India. Sci Total Environ 2018;643:1411–18.
68. Reinhardt SL, Boehm R, Blackstone NT, El-Abbadi NH, McNally Brandow JS, Taylor SF, DeLonge MS. Systematic review of dietary patterns and sustainability in the United States. Adv Nutr 2020;11:1016–31.
69. Semba RD, de Pee S, Kim B, McKenzie S, Nachman K, Bloem MW. Adoption of the 'planetary health diet' has different impacts on countries' greenhouse gas emissions. Nat Food 2020;1:481–4.
70. Headey D, Hirvonen K, Hoddinott J. Animal sourced foods and child stunting. Am J Agric Econ 2018;100:1302–19.
71. Veldhuizen LJL, Giller KE, Oosterveer P, Brouwer ID, Janssen S, van Zanten HHE, Slingerland MA. The Missing Middle: connected action on agriculture and nutrition across global, national and local levels to achieve Sustainable Development Goal 2. Glob Food Sec 2020;24:100336.
72. International Food Policy Research Institute (IFPRI). 2017 Global food policy report [Internet]. Washington (DC): IFPRI; 2017 [cited 26 June, 2020]. Available from: http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131085.
73. Caspi CE, Sorensen G, Subramanian SV, Kawachi I. The local food environment and diet: a systematic review. Health Place 2012;18:1172–87.

74. Lytle LA, Sokol RL. Measures of the food environment: a systematic review of the field, 2007–2015. Health Place 2017;44:18–34.
75. Downs SM, Ahmed S, Fanzo J, Herforth A. Food environment typology: advancing an expanded definition, framework, and methodological approach for improved characterization of wild, cultivated, and built food environments toward sustainable diets. Foods 2020;9:532.
76. Belton B, Reardon T, Zilberman D. Sustainable commoditization of seafood. Nat Sustain 2020;3:677–84.
77. Reedy J, Lerman JL, Krebs-Smith SM, Kirkpatrick SI, Pannucci TE, Wilson MM, Subar AF, Kahle LL, Tooze JA. Evaluation of the Healthy Eating Index-2015. J Acad Nutr Diet 2018;118:1622–33.
78. Micha R, Coates J, Leclercq C, Charrondiere UR, Mozaffarian D. Global dietary surveillance: data gaps and challenges. Food Nutr Bull 2018;39:175–205.
79. Afshin A, Sur PJ, Fay KA, Cornaby L, Ferrara G, Salama JS, Mullany EC, Abate KH, Abbafati C, Abebe Z, et al. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2019;393: 1958–72.
80. Del Gobbo L, Khatibzadeh S, Imamura F, Micha R, Shi P, Smith M, Myers SS, Mozaffarian D. Assessing global dietary habits: a comparison of national estimates from the FAO and the Global Dietary Database. Am J Clin Nutr 2015;101:1038–46.
81. Popkin BM. Nutritional patterns and transitions. Popul Dev Rev 1993;19:138–57.
82. Food Forum, Food and Nutrition Board, Health and Medicine Division, National Academies of Sciences, Engineering, and Medicine. Sustainable Diets, Food, and Nutrition: proceedings of a workshop—in brief [Internet]. Pray L, editor. Washington (DC): National Academies Press; 2018 [cited 1 September, 2020]. Available from: https://www.nap.edu/catalog/25289.
83. Gussow JD. Chicken Little, tomato sauce, and agriculture: who will produce tomorrow's food? New York: Bootstrap Press; 1994.
84. FAO. Sustainable diets and biodiversity: directions and solutions for policy, research and action. Rome: FAO; 2012.
85. FAO, WHO. Sustainable and healthy diets: guiding principles. Rome: FAO; 2019.
86. Béné C, Fanzo J, Haddad L, Hawkes C, Caron P, Vermeulen S, Herrero M, Oosterveer P. Five priorities to operationalize the EAT–*Lancet* Commission report. Nat Food 2020;1:457–9.
87. Jones AD, Hoey L, Blesh J, Miller L, Green A, Shapiro LF. A systematic review of the measurement of sustainable diets. Adv Nutr 2016;7:641–64.
88. Béné C, Oosterveer P, Lamotte L, Brouwer ID, de Haan S, Prager SD, Talsma EF, Khoury CK. When food systems meet sustainability – current narratives and implications for actions. World Dev 2019;113:116–30.
89. Mnif W, Hassine AIH, Bouaziz A, Bartegi A, Thomas O, Roig B. Effect of endocrine disruptor pesticides: a review. Int J Environ Res Public Health 2011;8:2265–303.
90. Aktar W, Sengupta D, Chowdhury A. Impact of pesticides use in agriculture: their benefits and hazards. Interdiscip Toxicol 2009;2:1–12.
91. Jørs E, Neupane D, London L. Pesticide poisonings in low- and middle-income countries. Environ Health Insights 2018;12:117863021775087.
92. Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N, Baldé AB, Bertollini R, Bose-O'Reilly S, Boufford JI, et al. The *Lancet* Commission on pollution and health. Lancet 2018;391: 462–512.
93. Jaacks LM, Yadav S, Panuwet P, Kumar S, Rajacharya GH, Johnson C, Rawal I, Mohan D, Mohan V, Tandon N, et al. Metabolite of the pesticide DDT and incident type 2 diabetes in urban India. Environ Int 2019;133:105089.
94. Jaacks LM, Diao N, Calafat AM, Ospina M, Mazumdar M, Ibne Hasan MOS, Wright R, Quamruzzaman Q, Christiani DC. Association of prenatal pesticide exposures with adverse pregnancy outcomes and stunting in rural Bangladesh. Environ Int 2019;133:105243.
95. Kartin A, Subagio HW, Hadisaputro S, Kartasurya MI, Suhartono S, Budiyono B. Pesticide exposure and stunting among children in agricultural areas. Int J Occup Environ Med 2019;10:17–29.
96. Yiridoe EK, Bonti-Ankomah S, Martin RC. Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: a review and update of the literature. Renew Agric Food Syst 2005;20:193–205.
97. Ortega DL, Tschirley DL. Demand for food safety in emerging and developing countries: a research agenda for Asia and Sub-Saharan Africa. J Agribus Dev Emerg Econ 2017;7:21–34.
98. Trasande L, Attina TM, Blustein J. Association between urinary bisphenol A concentration and obesity prevalence in children and adolescents. JAMA 2012;308:1113–21.
99. Hwang S, Lim J-e, Choi Y, Jee SH. Bisphenol A exposure and type 2 diabetes mellitus risk: a meta-analysis. BMC Endocr Disord 2018;18:81.
100. Stahlhut RW, Myers JP, Taylor JA, Nadal A, Dyer JA, vom Saal FS. Experimental BPA exposure and glucose-stimulated insulin response in adult men and women. J Endocr Soc 2018;2:1173–87.
101. Liu B, Lehmler H-J, Sun Y, Xu G, Liu Y, Zong G, Sun Q, Hu FB, Wallace RB, Bao W. Bisphenol A substitutes and obesity in US adults: analysis of a population-based, cross-sectional study. Lancet Planet Health 2017;1:e114–22.
102. Baluka SA, Rumbeiha WK. Bisphenol A and food safety: lessons from developed to developing countries. Food Chem Toxicol 2016;92:58–63.
103. Smith M, Love DC, Rochman CM, Neff RA. Microplastics in seafood and the implications for human health. Curr Environ Health Rep 2018;5:375–86.
104. Buzby JC, Hyman J. Total and per capita value of food loss in the United States. Food Policy 2012;37:561–70.
105. Spiker ML, Hiza HAB, Siddiqi SM, Neff RA. Wasted food, wasted nutrients: nutrient loss from wasted food in the United States and comparison to gaps in dietary intake. J Acad Nutr Diet 2017;117:1031–40.e22.
106. Global Panel on Agriculture and Food Systems for Nutrition. Preventing nutrient loss and waste across the food system: policy actions for high-quality diets. Policy Brief No. 12. London, UK: Global Panel on Agriculture and Food Systems for Nutrition; 2018.
107. FAO. The state of food and agriculture. 2019: moving forward on food loss and waste reduction. Rome: FAO; 2019.
108. Bloomberg MR, Aggarwala RT. Think locally, act globally. Am J Prev Med 2008;35:414–23.
109. Herrero M, Grace D, Njuki J, Johnson N, Enahoro D, Silvestri S, Rufino MC. The roles of livestock in developing countries. Animal 2013;7:3–18.
110. Reid RS, Galvin KA, Kruska RS. Global significance of extensive grazing lands and pastoral societies: an introduction [Internet]. In: Galvin KA, Reid RS, Behnke RH Jr, Hobbs NT, editors. Fragmentation in semi-arid and arid landscapes. Dordrecht: Springer Netherlands; 2008 [cited 9 June, 2020]. p. 1–24. Available from: http://link.springer.com/10.1007/978-1-4020-4906-4_1.
111. de Vries M, van Middelaar CE, de Boer IJM. Comparing environmental impacts of beef production systems: a review of life cycle assessments. Livest Sci 2015;178:279–88.
112. Lam WY, van Zelm R, Benítez-López A, Kulak M, Sim S, King JMH, Huijbregts MAJ. Variability of greenhouse gas footprints of field tomatoes grown for processing: interyear and intercountry assessment. Environ Sci Technol 2018;52:135–44.
113. Vanham D, Mekonnen MM, Hoekstra AY. Treenuts and groundnuts in the EAT-Lancet reference diet: concerns regarding sustainable water use. Glob Food Sec 2020;24:100357.
114. Nijdam D, Rood T, Westhoek H. The price of protein: review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 2012;37: 760–70.
115. Halpern BS, Cottrell RS, Blanchard JL, Bouwman L, Froehlich HE, Gephart JA, Sand Jacobsen N, Kuempel CD, McIntyre PB, Metian M, et al. Opinion: putting all foods on the same table: achieving sustainable food systems requires full accounting. Proc Natl Acad Sci U S A 2019;116:18152–6.
116. Fanzo J, Haddad L, McLaren R, Marshall Q, Davis C, Herforth A, Jones A, Beal T, Tschirley D, Bellows A, et al. The Food Systems Dashboard is a new tool to inform better food policy. Nat Food 2020;1:243–6.