Ann. N.Y. Acad. Sci. ISSN 0077-8923

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES
Issue: *A Global Research Agenda for Nutrition Science*

# Toward an integrated approach to nutritional quality, environmental sustainability, and economic viability: research and measurement gaps

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**Nutrition is affected by numerous environmental and societal causes. This paper starts with a simple framework based on three domains: nutritional quality, economic viability, and environmental sustainability, and calls for an integrated approach in research to simultaneously account for all three. It highlights limitations in the current understanding of each domain, and how they influence one another. Five research topics are identified: measuring the three domains (nutritional quality, economic viability, environmental sustainability); modeling across disciplines; furthering the analysis of food systems in relation to the three domains; connecting climate change and variability to nutritional quality; and increasing attention to inequities among population groups in relation to the three domains. For an integrated approach to be developed, there is a need to identify and disseminate available metrics, modeling techniques, and tools to researchers, practitioners, and policy makers. This is a first step so that a systems approach that takes into account potential environmental and economic trade-offs becomes the norm in analyzing nutrition and food-security patterns. Such an approach will help fill critical knowledge gaps and will guide researchers seeking to define and address specific research questions in nutrition in their wider socioeconomic and environmental contexts.**

**Keywords:** climate change; health; nutrition; research gaps; sustainability

## Introduction

The Sackler Institute for Nutrition Science collaborated with the World Health Organization (WHO) and scientists from several academic and nonprofit institutions across the world to develop a Global Research Agenda for Nutrition Science.[1] A working group for the first focus area, entitled "Environmental and Societal Trends Affecting Food and Nutrition among Vulnerable Populations," was convened at the New York Academy of Sciences to consider research gaps. Fourteen research gaps grouped into five core categories were identified and submitted for an open online consultation that was disseminated through multiple channels between June and August 2012. Seventy-two scientists from the Americas, Europe, Africa, and South Asia participated. The expert review and e-consultation highlighted points of convergence on priorities, and led to the identification of five main research priorities (Box 1). This paper delves into the knowledge gaps that underlie the five areas where there is a need for research. It examines the current measures, approaches, tools, and strategies available to address them, and formulates recommendations for future research.

The review and consultation highlighted the need to consider nutrition holistically, requiring research

doi: 10.1111/nyas.12552

**Box 1.**

**Research Topic 1: Measuring economic and sustainability trade-offs for nutrition and health outcomes**

In a real world of very complex and ever-changing interactions, there is a need for better measurement of economic and sustainability trade-offs in relation to nutrition and health outcomes. This requires clarifying a subset of specific result issues related to measurement and metrics:

1. enhancing measurement of nutritional quality, status, and outcomes;
2. defining an adequate time scale to measure outcomes;
3. identifying (and finding reinforcement strategies) where there are opportunities for double- and triple-wins between nutrition, economic profitability, and environmental sustainability.

**Research Topic 2: Modeling an enabling environment for health and nutrition**

Developing our analytical toolbox to describe and model an enabling environment for health and nutrition that connects nutritional quality, environmental sustainability, and economic profitability, adding the dimension of household vulnerability and livelihood levels, including in subsistence economies and policies (using multidisciplinary approaches, including, for instance, climate change researchers, scientists working on health system strengthening, economists evaluating the cost of the double burden, and environmental and urban engineers).

**Research Topic 3: Describing the interactions between the food system and nutrition**

Specific aspects of the interactions between the food system and nutrition need to be better described and understood, such as:

1. evaluating the effects of government policies for production and trade on supply and demand for certain types of food, and impacts on nutrition;
2. assessing how agricultural diversity affects dietary quality in different contexts;
3. assessing the economic viability and environmental sustainability of dietary guidelines and recommendations.

**Research Topic 4: Developing nutrition-centered approaches in climate change**

Such approaches need to incorporate population trends, various types of food systems (production, processing, trade patterns, and consumption), access to water, sanitation, and overall environmental sustainability, with the capacity to produce various scenarios and projection of nutritional outcomes.

**Research Topic 5: Integrating individual- and household-level factors underlying economic vulnerability and food insecurity, in particular**

1. What are the incentives for individuals to spend the resources (including time) to obtain healthy diets?
2. How can one connect women's economic empowerment with enhanced nutritional status for women and children?

that can account for multiple inputs and address several important outcomes simultaneously. The main need is to build recognition that nutrition both influences and is influenced by social, environmental, and economic trends. The *ecological framework* of food and nutrition, first published more than 30 years ago, describes trends in the social environment, physical environment, technology, culture, and social organization that influence diet and nutrition in the population.[2,3] The development of the research agenda was driven by the need to better describe how environmental and societal trends influence nutrition in ways that vary by context, population, and temporal scale; and to

 


**Figure 1.** The three basic interconnected domains.

make relevant analytic tools understandable and practical for a wide range of stakeholders. Importantly, the research agenda has been defined so as to encompass the challenges posed by both undernutrition and overweight/obesity, thus guiding researchers toward developing tools and knowledge that correspond to the epidemiological situation in many low- and middle-income countries.

This paper's starting point is a Venn diagram of the three domains that unfailingly arise in any effort to understand or shift societal and environmental trends regarding food and nutrition: nutritional quality, economic viability, and environmental sustainability (Fig. 1). Trends or concerted efforts to improve any one of these domains will ultimately only be sustainable if the other two are taken into account. Policies, guidelines, and interventions move these circles closer together or farther apart, and researchers need to consider the interrelated effects of all three, at multiple spatial and time scales. The framework is placed within a larger concern of equity: that improvements in nutrition for some parts of the population should not come at the expense of other parts of the population. We present this deceptively simple framework as an overarching reminder of the core issues that surfaced repeatedly in the consultation. It is easy to call for "triple wins" among the domains, but based on the history of silos between research and development in nutrition, environment, and economics, attending to these three issues at once (ensuring maximal benefit and minimal harm to one aspect or another) has proven difficult in practice.

*Nutritional quality* of a system describes a situation in which individuals are not only food secure, in the sense that they have consistent access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for a healthy and active life,[a] but also that it is convenient and socially preferable to consume diets that support positive health outcomes. *Environmental sustainability* of a system refers to the conservation of biodiversity and ecosystems, and their impact on all life, including human well-being (ecosystem services) in the short and long run.[4] The notion that economic growth can occur without compromising environmental resources now and in the future has been described as sustainable development since the Brundtland Commission in 1987.[5] *Economic viability* of a system is a concept that combines the notion of profitability for business owners and workers resulting in economic growth, decent employment, and equitable distribution of income with a responsible use of human and natural resources.[6]

In this article, we first review gaps in the basic building blocks for doing research connecting the three domains: measurement challenges, and the potential and limitations of currently available modeling techniques to describe the interactions across the three domains. Better measurement and modeling could then be applied to analysis of three important issues affecting nutrition: food systems, climate change, and social inequity.

## Research gap 1. Measuring the three core domains: nutritional quality, environmental sustainability, and economic viability

To be able to research and model interactions across the three domains, the first step is to measure them well. Nutritional quality, environmental sustainability, and economic viability are complex constructs. How they are measured will affect results and interpretation of results. Available indicators and data do not capture all aspects of each construct, and the measurement of each depends on assumptions about timescale and which populations are included

[a] See the UN definition of food security, signed at the 1996 World Food Summit.

or excluded. The following is a brief review of available indicators.

### *Nutrition-related variables*

Population-level data relevant to nutrition come from multiple sources, and encompass indicators of nutritional status, healthcare access and disease, caregiving practices, and food security and diet. Household Demographic and Health Surveys,[7] Multiple Indicator Cluster Surveys,[8] and Living Standard Measurement Studies[9] provide nationally representative nutrition information, with variables such as age, gender, anthropometry, infant and young child feeding practices, family care of children, income, home-produced food, disease prevalence, access to safe water and health services, and disability. In some cases, a subsample will undertake measurements of biomarkers to determine micronutrient deficiencies. Nutrition indicators are periodically aggregated by the United Nations Children's Fund (UNICEF) in its flagship report, State of the World's Children,[10] and in databases of the WHO.[b,11] These reports do not currently include statistics on food access or dietary quality, and their absence represents a gap in understanding the causes of malnutrition. Some indicators of diet quality exist, such as individual dietary diversity scores, which are valid proxies of micronutrient adequacy.[c,12] The main globally collected food access indicator is the undernourishment indicator published by the Food and Agricultural Organization (FAO) of the United Nations (UN; proportion of the population unable to access adequate dietary energy), sourced from per capita food supply data adjusted for economic inequality.[d] Additional aggregate information on food quantity, quality, and safety are based on estimates of the amount of food produced, including livestock, dairy, staple, and nonstaple agriculture, and their market price. Some of this information is available in the Food Balance Sheets created by the Statistical Division of the FAO (FAOSTAT).[13] National and global datasets such as the Principal Global Indicators[e] provide data on food prices, consumer confidence, stability of food supplies, category of food available and purchased, and information on export and import. Depending on the strength of surveillance and monitoring systems, data on zoonotic diseases and food microbiological and chemical contamination can be extracted at the national or regional level and from datasets such as the WHO Global Environment Monitoring System on Food Contamination Monitoring and Assessment Program, among others.

Many studies of the determinants of food choices gather household survey data specific to the study site, to examine factors such as education, individual preferences and needs, social and cultural norms, existing health disparities, and the physical environment in order to describe nutritional outcomes in their socioeconomic context.[14,15] Measures of dietary quality and food environments (involving aspects of availability, affordability, convenience, and desirability of various types of foods) are not collected internationally, although they are collected in some national datasets and individual studies. Studies of the built environment construct indicators such as accessibility to safe water and nutritious food (for the latter using data on shop density, walkability, and safety)[f] in order to establish the strength of their association with nutritional outcomes.

### *Environment-related variables*

Natural resource measurements capture soil and water quality, biodiversity, tree and vegetation coverage, and pollutants in water streams, ocean water, ground water, soil, and air, and climate variability and change. Many indicators of the sustainability of food and agriculture systems have been

[b] See the Global Database on Child Growth and Malnutrition, and the Global Health Observatory Repository data.

[c] See the new global indicator to measure women's dietary diversity: http://www.fantaproject.org/monitoring-and-evaluation/minimum-dietary-diversity-women-indicator-mddw.

[d] http://faostat.fao.org/.

[e] It includes datasets from, among others, the World Bank, the International Monetary Fund, the European Central Bank, and the Organisation for Economic Co-operation and Development (OECD).

[f] The U.S. National Cancer Institute has a database of food environment measures, which include measures of food stores and restaurants in a vicinity, the home food environment, school/worksite food environments, and macro food environment (including food supply). See the National Cancer Institute's website at http://appliedresearch.cancer.gov/mfe/.

proposed, including indicators of environmental integrity, such as greenhouse gases, water withdrawal, water quality, soil quality, land degradation, and species diversity, among others.[16] Multifaceted measures of soil health are used in agricultural extension systems and could also be used in programming.[17] Indicators of the ecosystem service impacts of production systems need to be developed further, but could include indicators such as "crop per drop" (yield per amount of water used) or carbon sequestration potential.[18] Indicators of ecological production practices such as meeting organic standards can signify the way a certain food or commodity was produced. Studies in climate change measure, for example, global greenhouse gas (GHG) emissions and $CO_2$ concentrations, and use of fossil fuels, as potential drivers, and global and regional changes in temperature, rainfall, and sea level as likely outcomes precipitating changes in derived variables such as soil moisture, water availability, and agricultural production. Monitoring systems for sustainability have been described with reference to alarm indicators (monitored routinely and addressed when levels cross an identified threshold), diagnostic indicators (used to describe the status of a resource, necessary for modeling), and response indicators (used to monitor the impact of natural resource management policy or action).[19]

### Economy-related variables

The most frequently used aggregate economic variables are the gross domestic product (GDP) per capita and growth rates in both the agricultural and nonagricultural sectors. Income inequalities are measured by the Gini coefficient and have been positively correlated with rates of overweight and obesity in high-income countries.[20,21] Income (or consumption) is often used to measure economic status at the household level, and asset indices are used where income is difficult to estimate. Prices and estimates of own-price and cross-price elasticities are fundamental to equilibrium models where prices determine supply and demand, and are usually measured by composite food baskets. Most of these variables are collected at the national level. These variables cannot on their own capture the concept of "economic viability" as described in this paper, which would require accounting for the present and future costs of inequitable income distribution, resource destruction, and disease burden. Frameworks for economic and environmental accounting, which include not only revenue but also existing natural resources and how they are managed, have been developed at the global level.[22–24] A similar conceptual structure based on true cost accounting is needed to include the negative public health consequences generated by the food systems.[25]

### Recommendations for future research

Gaps in measurement need to be filled in order to enable research on how environmental and social trends affect nutrition. There are gaps in all three of the domains in terms of measuring nutritional quality, environmental sustainability, and economic viability.

In the *nutritional quality domain*, the largest data gaps are in measuring food access, food environments, and dietary quality. In the UNICEF Framework of the Causes of Malnutrition (1990), the immediate causes of malnutrition include inadequate dietary intake and disease; the underlying causes include inadequate access to food, unhealthy environment and inadequate access to health services, and inadequate caregiving practices. Of these main causes of malnutrition, food access and dietary intake are the only ones not globally monitored (with the exception of the FAO undernourishment indicator, as noted above).[26] While some measures of food environments and dietary quality have been developed, they are not yet mainstreamed into the most widely used surveys and datasets. Consequently, many analyses and models resort to using calorie availability or access, which is a very limited measure of nutritional quality. This gap forms the basis for research questions on the measurement of nutritional quality in terms of indicators that could be used in models:

- What proxy or proxies can be used to measure dietary quality, encompassing aspects of both adequacy (getting enough of certain foods/nutrients) and moderation (not getting too much of certain foods/nutrients)?[g]
- What indicators can capture adequacy of food access, including not only adequate dietary

[g]Such research can build on existing initiatives such as the U.S. Department of Agriculture–developed Healthy Eating Index; http://www.cnpp.usda.gov/healthyeatingindex.htm.

energy, but also affordability and convenience of healthy food (i.e., food environments)?
- What is needed to enable data collection of better food and diet indicators (such as capacity development of national bureaus of statistics or ministries of agriculture, international alignment on indicators to be collected, and open data)?

A great many indicators of *environmental sustainability* exist, but prioritization of key indicators and data may be necessary to mainstream the monitoring of these indicators and their use in models and policy making. For example, the availability of decision-relevant climate information about the past climate, recent trends, current conditions, likely future trajectories, and associated impacts is a prerequisite for climate-informed decision making. However, the availability of relevant and reliable climate information, particularly throughout rural Africa, is substantially absent owing to both data availability and access challenges.[27] Where access to relevant historical climate data at the appropriate temporal and spatial scale is limited, researchers may rely on low-resolution data or use modeled climate data inappropriately.[28] To overcome such challenges, new, nationally owned climate datasets are being developed using an integration of historical satellite data (with good spatial coverage) and ground-based observations (with good local calibration).[29] Outputs from these high-resolution quality-controlled data sets are being made available to national development agencies, local research communities, and the global community via web-based tools[30] with an initial focus on malaria.[31] Climate and agro-ecological information services can be used to benefit nutrition programs.[32]

In terms of economic viability, theory and techniques for true cost accounting are being developed based on models, with significant methodological challenges. Integrated efforts to measure the environmental and public health externalities of the food systems ultimately need to be actionable in terms of policy.

## Research gap 2. Developing and adapting modeling tools across disciplines and multisectoral collaboration in research

On social and environmental factors that affect nutrition, there are so many disciplines that come to bear that integrated datasets and tools are needed to model interactions and trade-offs across nutritional quality, economic viability, and environmental sustainability. Modeling techniques typically serve to quantify the association among variables, controlling for a set of potentially confounding factors. Whether they are used in the fields of economics, public health, climate, sociology, or other disciplines, modeling is a tool to understand and describe what happens in real life when trends evolve or shocks occur. They are essential to describe how nutrition, environment, and economic outcomes covary in response to a change, and could be effectively used through research collaborations across disciplines. In addition, the availability of a valid indicator for a given construct, the availability and quality of the initial data, and the relevance of the chosen assumptions will determine the model's validity and applicability. However, the evidence used to set the model parameters and determine proxies may not be fully established. Assessing the value of scenario-analysis models in food-systems predictions and health outcomes is particularly difficult as "existing data sources often do not provide a sufficient basis for an *ex post* comparison of simulation results with historical observations."[33] These models have many applications for agents engaged in strategic planning as long as the model's specifications, assumptions, and limits are well understood.

This section focuses on four examples of modeling techniques that have been used to examine certain components of the environmental and societal trends affecting nutrition:

(1) Developing scenarios to guide long-term policy: models that serve this purpose include both agriculture and population health models. An example of the former is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI). This model explicitly seeks to identify plausible projections for a large set of variables and both demand and supply for commodities, so as to support policy decision making related to long-term goals of food security, poverty reduction, and environmental protection.[34] Population-health models infer changes in disability-adjusted life years (DALYs) related to changes in dietary

practices driven by socioeconomic factors (including taxation and climate change–related changes in costs) through direct and indirect pathways.[35]

(2) Generating simulations of individual decisions and how they evolve following iterative changes. For instance, measuring price elasticity of demand (i.e., changes in demand following a change in price) is a common step toward simulating consumption patterns, and elasticities can be used to model how consumption responds to changes in income, expectations, and information.[36]

(3) Measuring complex constructs that have composite elements and are not readily measurable. An example is the model behind the Human Development Index, launched in 1990, which incorporates elements of social and economic development comprising income, education, and life expectancy in a single statistic.[37,38] The paradigm used to measure concepts such as vulnerability, food security, and productivity, and their impact on policy guidance, must be clearly established and well understood. For policy relevance, the individual components of indexes, rather than the total index score, are most useful to specify actions that would improve outcomes.

(4) In a combination of (1) and (3) above, models are used to assess the relationship between local and national policies and complex outcomes, when randomization and controls are unavailable. This is of interest when estimating the impact of economic policies on income distribution at the population level, and has been used to evaluate the potential effect of structural adjustment policies on nutritional status in poor households.[39] The global burden of disease project measures the health impact of diseases associated with specific risk factors, many of which are related to nutrition, thus guiding public policy investment where it is most needed and will have the greatest impact, although significant limits in data availability remain.[40,41]

(5) Trade-off models, like InVEST (Integrated Valuation of Environmental Services and Trade-offs): these models are designed to enable decision makers to assess quantified trade-offs associated with alternative management choices and to identify investments in natural capital that can enhance human development and conservation.

Various types of models are used for economic and health analysis. *General equilibrium* (*GE*) models build multiple equations, including hundreds of variables where various macrolevel parameters reach a long-term equilibrium. *Partial equilibrium* models are used when the focus is on simulating the impact of a subset of variables on a single outcome or a single commodity independently from the rest of the economy. *Microsimulation models* (*MSMs*) can simulate an individual's response to policy-induced changes, and have been used to rank the ability of various tax and subsidies strategies to enhance the nutritional intake (measured by a healthy eating index) of food stamp recipients in the United States.[42] When there is a high level of observed heterogeneity, describing individuals' decisions through shifting trends in attitudes with a high degree can be addressed by *agent-based models* (*ABMs*). ABMs are descriptive rather than predictive, as they observe highly heterogeneous microbehaviors whose evolution is by definition difficult to forecast reliably.[43] Scenario analyses sometimes combine various techniques such as imbedding MSM results into computable general equilibrium (CGE) models.[44] Each model will be specified in relation to its ability to (1) include changes related to different spatial units, different prices across these units, and transport costs (most GE are nonspatial); (2) integrate random changes over a period of time (dynamic models); and (3) include the effects of changes in future expectations (recursive models).[45]

There are several examples of how these types of models have been used for multidisciplinary or cross-disciplinary research. Hammond and Dubé proposed a grand model for the interrelations between the environmental system, the health/disease system, and the agri-food system and have evaluated existing evidence about some of these interrelations.[46] Fischer *et al.* employed agro-ecological zones (AEZ) and basic linked system (BLS), and applied special report on emissions scenarios (SRES) to build a model for comprehensive assessment of the impacts of climate change on agro-ecosystems over the 21st century.[47] Valdivia *et al.* have used a spatially explicit integrated assessment model (*trade-off analysis model* coupled with *partial market equilibrium* (TOA-ME)) to study the economic and environmental impacts of climate change and socioeconomic scenarios in Kenya, and to "analyze the effects of policy and technology interventions on the spatial distribution of environmental and economic outcomes at the market equilibrium prices"[48] (health and nutritional status were not specifically considered). The CGE model used by Lock *et al.* enables the study of interactions among changing dietary practices, livelihood, food production, trade, and the environment, but was not built to explore long-term climate change effects. As the authors remarked, many trade-offs occur within the system, and "awareness and assessment of where losses and gains accrue from policy, and the magnitude and timing of these changes, is crucial to secure policy coherence around agriculture, trade, development, and health agendas."[49] The OECD and WHO used a combined microsimulation–partial equilibrium model to assess selected health and economic consequences of changes in nutrition patterns that would follow a range of government policies (including regulatory and fiscal policies, as well as health education and interventions on individuals at higher risk in primary health care).[50,51] More recently, the OECD/WHO model was linked with OECD's AGLINK model of agricultural commodity markets in order to assess the broader impacts of the above policies on demand, trade, and prices for the relevant food commodities. Emerging modeling techniques must provide a balance between addressing methodological challenges and pragmatic requirements, with a critical evaluation of the underlying assumptions and baseline data on which they depend.

Quantitative modeling approaches can be tools to facilitate communication across disciplinary boundaries and synthesis of research evidence. A major challenge to constructing such integrated models, however, is that the disciplines frequently collect data in different time and space scales and at different levels: individual-level for nutrition and health outcomes, household or national levels for economic variables, regional or global levels for environmental exposures. They also use different tools and datasets, such as 24-h recall to collect individual dietary intake, expenditure surveys to collect broader information on consumption, and life-cycle analysis of GHG to measure environmental sustainability. Integration of these data into analyses is not always straightforward. Researchers faced with data sets from disciplines outside of their core expertise may either risk inappropriate use of these data or be adverse to this risk, thus restricting cross-disciplinary research.

Finally, there is little alignment in the outcomes of interest and methods used to measure them: typically the prevalence of a clinical outcome in nutrition and health research, a cost per DALY outcome in health–economic analysis, and an environmental outcome such as $CO_2$ equivalents in sustainability research. Inconsistencies in methods and modeling approaches across disciplines reflect the limitations of individual disciplinary perspectives and their inadequacy in addressing global issues of the size and complexity of those discussed here.

A primary challenge to the building of comprehensive integrated models across nutritional quality, economic viability, and environmental sustainability is the inherent difficulty in shifting from research based in single disciplines to research that is interdisciplinary, or even transdisciplinary. A shift away from the traditional research governed by the norms of scientific disciplines toward research that is highly interactive and emerges owing to societal pressures and incentives is now being advocated as a means to tackle large complex problems.[52]

### *Recommendations for future research*

Identifying solutions for global problems linking health, economics, and the environment requires new forms of shared thinking across disciplines. The call for such mixed tools and collaborative approaches to understand complex systems is not new. There are logistical barriers and a lack of incentives for interdisciplinary work, such as sector-based funding and specialized peer-reviewed journals. It is beyond the scope of this paper to go into depth on how these barriers can be resolved, but new partnerships, publically available, quality-controlled data sets, and quantitative modeling approaches provide a possible framework for overcoming at least some of the hurdles that currently prevent research from providing robust and relevant evidence. Some specific suggestions are:

- planning for colocation of data collection from different disciplines;
- integration of multiple spatial scales, using tools such as hierarchical sampling design,

extrapolation using modeling, and remote sensing;
- integration of multiple time scales, through long-term longitudinal data collection;
- consensus on a minimum set of common indicators that can relatively be easily integrated in different studies;
- establishment of the validity of the indicators in the minimum set if validity has not already been established;
- open access to datasets; availability of relevant, quality-assured colocated data organized at multiple temporal and spatial scales and in a common format for analysis; and routine update of such data sets through appropriate data policies and data dissemination tools;
- effective use of such multisource data (with appropriate methodologies and tools) through appropriate professional and research training efforts;
- provision of guidance regarding the most appropriate and useful analytic methods for various types of analyses.

## Research gap 3. Furthering the analysis of food systems in relation to nutritional quality, environmental sustainability, and economic viability

Measurement and modeling challenges are well exemplified when discussing how food systems can adequately meet the population's dietary needs in a sustainable way, while accounting for costs, preferences, and availability. The concept of a food system refers to the "process that turns natural and human-made resources and inputs into food."[53] Production, processing, and distribution mechanisms are interconnected at the local, national, regional, and international levels. This section presents parameters that connect food systems and nutrition and reviews the potential role of policy in shifting these parameters to optimize food systems for nutritional quality, economic viability, and environmental sustainability.

Agriculture is the main producer of food and forms the basis of food systems, but agricultural production does not automatically improve nutrition. The food supply both affects and is affected by nutritional quality, or the kind of consumption likely to result from increased incomes. Traditionally, the focus of agricultural development is increased income, which is not in all cases associated with a reduction in undernutrition, and is often associated with rising overweight and obesity rates.[54–56] Multiple mechanisms appear to be involved in how economic growth reduces child malnutrition, including increased food availability, reductions in poverty, improvements in female education, increased access to health services, improved family planning outcomes, and policy strategies to enhance the quality and safety of this food.[57] Agricultural growth has been associated with faster reductions in stunting, and greater increases in obesity, than nonagricultural growth,[58] and nonagricultural growth has been associated with improved dietary diversity.[59] None of these associations have included an examination of the type of agricultural growth (i.e., what is grown, how, and by whom).

That many people have difficulty accessing diverse, healthy diets, even as incomes rise, is one of the reasons agricultural diversification has been frequently recommended as a strategy to improve nutrition.[60] The connection between agricultural diversity and dietary quality in farmer households has rarely been measured to date. Only a few studies have been designed to examine the linkage between crop diversity and overall dietary quality explicitly, at household or village level. Studies conducted in Sub-Saharan Africa[61–64] have generally found positive associations between crop diversity and dietary quality indicators. One of the studies observed a correlation between crop and diet diversity at the village level rather than the household level.[63] Environmental cobenefits are used as a secondary justification for diversification in each of these studies, but environmental indicators were not measured. At the national or international level, it is difficult to assess the connection between food-supply indicators and diet quality because of the lack of adequate, routinely collected data on either. Using three complementary diversity metrics at the national level, however, one recent analysis found strong associations between diversity of national food supplies and child undernutrition (stunting, wasting, and underweight prevalence), but not with overweight, while controlling for socioeconomic factors. The study further shows that, for low-income countries, the diversity of agricultural goods produced by a country is a strong predictor of food supply diversity;

for middle- and high-income countries, national income and trade are better predictors.[65]

The food system also influences the environment. Food systems rely heavily on fossil fuels, one reason they contribute to climate change.[66–68] According to the FAO, livestock production is responsible for 18% of greenhouse gas production worldwide.[69] Furthermore, agricultural intensification can lead to land clearance, soil degradation for food production and processing, and intensive water use.[70] While environmentally significant, the waste generated along the food production chain and packaging is not reflected in food production costs.[71]

Dietary consumption has major impacts on health, environment, and the economy. The health and economic benefits of adopting healthy diet recommendations have been measured using Brazil and the United Kingdom to compare three possible interventions (reducing consumption of all foods from animal sources, only meat products, or only dairy products), and four possible economic effect scenarios using a CGE model.[49] The model predicts substantial differences in population health and agricultural production, trade, the wider economy, and livelihoods, depending on the dietary strategy and effect scenario employed. This model interestingly highlights an uneven distribution of economic effects, which raises the question of evaluating the actual economic viability and equity aspects of the various interventions considered depending on the context. Similar efforts are currently being conducted using System Dynamic Modeling in Canada.[h] These models did not include environmental indicators, but environmental impacts of diets are increasingly discussed in terms of sustainable development. Diets affect what is consumed and have environmental impacts, such as GHG, water and land use, and impacts on biodiversity. Metrics of sustainable diets are being developed,[72] although simply following dietary guidelines would be more sustainable than the average diets consumed in high-income countries.[73]

Economic development alone has not proven to maximize nutritional quality and sustainability, calling for policies to correct market failures in those domains. Government policies and regulations, including subsidies for production, internal trade, and import/export on both the supply and demand sides can help mitigate negative impacts of food systems on nutrition and the environment and encourage positive trade-offs. For instance, the Livestock, Environment and Development Initiative (LEAD) has suggested addressing environmental problems related to livestock production using economic tools such as removing damaging subsidies and establishing correct pricing of water, grazing, and waste, as well as payment for environmental services levels.[69] LEAD proposed using the Clean Development Mechanism to finance the spread of biogas and silvopastoral initiatives involving afforestation and reforestation. This requires the development of adequate institutional and policy frameworks at the local, national, and international levels.[69]

Understanding how subsidies or removal of subsidies may affect the three domains of nutritional quality, environmental sustainability, and economic viability together is not straightforward. One example is input subsidies, a common component of traditional Green Revolution programs since the 1960s and 1970s, which was followed by two decades of a generally negative attitude toward the effectiveness and efficiency of subsidy programs.[74] Regardless of current debates over how to make best use of subsidies as a policy tool, particular targeting of input subsidies toward specific farms and products is usually difficult, for example, because of leakage of subsidized materials from small to large farms or across national borders. This can be a major challenge if any subsidy program is to be instituted for supporting production of specific micronutrient-rich crops.

Context (including environmental and societal trends) strongly influences the outcomes of agriculture policies and programs. The distinctive experiences of Asia and Africa in the Green Revolution indicate how major initiatives with the same goal can end in different outcomes depending on the context.[75] In addition, factors such as international trade and globalization of markets, low world food prices, high energy prices, and agricultural policies can affect agricultural change.[74] At the country level, factors including per capita income and urbanization, changing market chains, and shifts

[h] See the presentation by Paul Thomassin, McGill University, during the UN SCN Annual Session 2013; http://www.unscn.org/files/Annual_Sessions/UNSCN_Meetings_2013/Thomassin_MoM_March_2013.pdf.

in public policy have been shown to influence agricultural productivity. Poverty, population pressure, community health status, technology design, property rights, infrastructure and market access, and nonfarm income opportunities can all affect agricultural change at the local level. Assessing that context is a critical step in identifying the major nutritional issues as well as the potential agricultural, livelihood, and environmental interventions and extension approaches to generate synergies between nutritional quality, economic viability, and environmental sustainability. The rapid growth in electronic agro-ecological and health data for Africa has not yet been effectively tapped to improve agriculture–nutrition programs. The use of these electronic systems for capturing and disseminating information and recommendations makes it now possible to add the context specificity required for effective, targeted approaches that leverage agriculture's potential for nutrition in an economically viable and environmentally sustainable way.

### *Recommendations for future research*

Further research is needed to evaluate the impact on dietary quality from policy changes or interventions that increase agricultural diversity and lower the price of diverse diets at national, community, or household levels. Such analyses are limited by the scarcity of data sets that include information on both dietary quality and access to diverse foods. Modeling why certain locales have greater access to diverse food than others could serve to focus research and resources on how barriers to accessing high-quality nutritious diets could be overcome. It would also be useful to build evidence on where, and for whom, diets are inadequate, and on the consequences of poor diets on health, productivity, and environmental sustainability.[76]

A successful integrated model would measure economic and environmental viability of diversification interventions and policies. Diversification is often associated with improving ecosystem services, and building the evidence on these associations would be useful. It will also be important to understand where diversification, or targeting specific micronutrient-rich crops, is economically beneficial, because profitability is a key incentive for farmers. To ensure short- and long-term economic and environmental viability, it is crucial to evaluate the potential health, trade, agriculture, and environmental implications of any such program on both research and policy.[49]

Evaluating how food systems affect nutrition has been hampered by a lack of rigorous tracking, monitoring, and evaluation tools for such complex processes. Econometric analyses would seem to be a useful analytical tool, but are only as good as the data in the models. Indicators of nutritional quality of food environments need to be developed, and better systems to collect them are needed.[26] A major question is how to evaluate policies that affect the supply, affordability, convenience, and desirability of diverse, nutritious foods. A so-far underutilized tool is case studies (ideally involving multiple disciplines) of various country or local experiences implementing a single or set of agriculture or food policies, related to trend data on diets and nutrition, as well as short- and long-term economic implications for agricultural producers and the general population. Applying a global value-chain approach can allow researchers to observe where economic and nutritional quality are generated or lost.[77,78] Finally, it would be useful to establish how policies can align food prices with externalized environmental and health costs of production and distribution.

## Research gap 4. Connecting climate variability and change to nutritional quality

Many aspects of environmental sustainability relate to nutrition, including water availability and quality, soil health, biodiversity, and climate. This section focuses on climate variability and change because it magnifies the importance and challenges of water and biodiversity for nutrition. Climate variability and change is one of the most pressing environmental issues. So far, discussions of climate change and future food have mostly focused on staple grains and aggregate food supply. Its effect on nutrition is much larger. Climate change is likely to have far-reaching effects that shape agricultural potential, disease risk, and livelihoods.[79] Existing studies indicate three major pathways between climate and nutrition-related indicators,[80] in line with the conceptual framework on causes of malnutrition developed by UNICEF in 1990:[81] (1) the food security pathway, in which climate influences farm productivity and available food quantity as well as the nutritional composition of crops, food biodiversity, food safety, storage, and price volatility;[82] (2) the maternal and child-caring pathway, in which climate and environmental setting particularly affect women's time dedication, empowerment, labor conditions, and education;[80] and (3) the health pathway, in which environmental health, the prevalence of several infectious diseases (e.g., malaria, diarrhea), and food safety (e.g., aflatoxin contamination, food-borne, and zoonotic infections) are prone to climatic conditions and can have a huge impact on nutritional outcomes.[80,83]

The impacts of climate variability and change on different aspects of food security have been assessed using four scenarios known as the SRES provided by the Intergovernmental Panel on Climate Change.[84] While changes such as increased $CO_2$ and temperature might lead to better agricultural conditions in temperate latitudes,[85] they will likely cause reduced livestock productivity, increased livestock mortality, lower soil moisture levels, and increased survival of many pests in other latitudes, leading to an overall negative impact.[86] Elevated $CO_2$ results in a reduction in protein concentration in many plant crops, and it is likely to have a greater impact on grain protein levels under warmer and drier conditions.[87] Food energy availability in 2050 is likely to decline in developing countries, resulting in approximately 20% more undernourished children relative to a world with no climate change.[88,89] Models also predict a substantial price rise following further warming predicted after 2050,[84] and biofuels production can have a negative impact on food and nutritional quality by leading to shortages and associated food price increases.[82]

Climate variability can contribute to increased risk of infectious diseases, causing or complicating hunger and malnutrition, which in turn will increase vulnerability to infections.[82,83] This pathway has been extensively studied for enteric infections across developed and developing countries using health outcomes such as incidence of diarrhea,[90] water-borne diseases,[91] and food safety and food-borne diseases.[83,92,93] All these observations support the model relating climate variability and change to malnutrition via increasing the risk for infections. The burden of childhood morbidity and mortality attributable to climatic change occurs and will continue to occur primarily through the nutrition and infectious diseases pathways. Changes brought about by urbanization and infectious disease interventions may alter this as noncommunicable diseases begin to dominate the health challenges of the urban poor over the coming decades.[94] Food-safety issues related to environmentally harmful practices have also received some attention, notably in China.[95]

Climate change, variability, and shocks (disasters) often affect further underlying determinants of nutrition that interact with each of the above pathways:[80] impact on overall income of a household and society, changes in behavior and cultural practices, demographics (urban–rural, household size, population growth), conflict, infrastructure, and economic, political, and social structures.[82] Undernutrition, in turn, undermines the resilience of vulnerable populations, decreasing their ability to cope and adapt to the consequences of climate variability and change and their ability to grow economically.[82]

### *Recommendations for future research*

While research has provided much evidence about the critical relationship between climate and basic staple grain productivity, precise measurements of other pathways to nutritional quality are not available. In particular, there is a need to assess the impact of climate on food quality, including micronutrient and protein content[96] and food safety, dietary diversity, and maternal and child care and feeding practices. There is also a need to assess the interlinks between climate, diseases (particularly water- and food-borne diseases), and nutrition.[80,83] Furthermore, the negative impact on nutrition of certain climate-change adaptation and mitigation strategies, including the growing of drought resistant crops of low nutritional value and growing food crops for biofuel production, need to be better understood.[82]

Understanding nutritional quality in a changing climate requires a comprehensive approach in which the different causal pathways described above are being considered together. A multisectoral framework for analysis of observed and predicted climate change–related impacts and vulnerabilities and the specific causal pathways is a critical step. Several conceptual frameworks have recently been suggested[80,82,97] and now need to be applied and validated to concrete situations. The necessary analytical tools and metrics to do so should be developed and tested for different representative geoclimatic locations, ecosystems, and socioeconomic and urbanization contexts. Particularly important will be the ability to identify which nutrition metrics are most sensitive to climate variability and change, and at what points intervention is most effective.

Changes in the climate occur across a continuum of timescales from natural climate variability (at seasonal and decadal timescales) to anthropogenically driven century-long processes. This makes the development of effective adaptation policies particularly difficult, as observed global and regional changes may not be experienced at the local level. As a consequence of this uncertainty, some experts have advocated that general reductions in vulnerability to climate variability and change will be more important than targeted responses to specific predicted climate phenomena.[98] Vulnerability is here defined as the degree to which geophysical, biological, and socioeconomic systems are susceptible to, and unable to cope with, adverse impacts of climate-related hazards (shocks, seasonality, trends, and gradual changes).[99] The use of climate information (past, present, and future) to better manage climate-related risks in the short term may in itself be considered a climate adaptation strategy.[100]

Multivariable regressions that analyze trends and different determinants of nutrition outcomes usually do not take into account climate information,[101] with a few exceptions.[97,102] The few existing models that predict the impact of climate change on undernutrition only use energy availability as the changing factor under climate change in predicting effects on child stunting.[88] This identifies a need for models that predict the future impact of climate change on nutrition trends beyond energy availability, under different future scenarios. This is challenging, since determinants of climate-related undernutrition are complex and the inclusion of extreme weather events' impacts in current models has been a major gap. Particularly important is risk mapping to analyze which regions and populations are most nutrition-vulnerable to climate-related hazards and why, and to include diversity in food crops, livestock, and management systems in projections rather than just the few major staple crops.

To reduce vulnerabilities to climate variability and change, a knowledge base on successful adaptation strategies and lessons learned for nutritional quality in a changing climate needs to be generated. Such a knowledge base would aim for identification, validation, and costing (i.e., cost–benefit analyses) of sets of interventions to protect nutritional quality from climate-related hazards and climate change in a diversity of contexts. Some specific questions arise around adaptation to ensure nutritional quality. How can we combine multiple traits in crops so that they are nutrient-dense and tolerant to drought and flooding? How can climate information services serve nutrition programs (i.e., their design, adaptive management, and evaluation), to enhance their resilience? How can we ensure that agricultural policies regarding climate variability and change adaptation include better nutrition as well as increased production as the desirable outcome?

Mitigation strategies in the food and agriculture sectors can reduce carbon footprints through sustainable food production and consumption and food waste reduction—including food sourcing from low-carbon production systems. Nutrition-sensitive, agriculture-based mitigation includes climate-smart approaches such as agro-forestry, agro-ecology and the promotion of sustainable diets. It is important to understand how changes in diet can still meet nutrition requirements while aiming for a reduction in GHG, land use, and water requirements. The Livewell project used modeling techniques to test whether it was possible to construct realistic and acceptable diets for the U.K. population that would meet dietary requirements for health and achieve a significant reduction in GHG.[73] Similar research efforts will enhance our understanding of what sustainable diets mean in terms of food choices for health, climate variability and change (e.g., reduction of GHG, water, and land use), and social and ethical reasons. The recent focus on insects as a source of high-quality nutrition at a low carbon price is one opportunity (already popular in many countries) that can be further exploited.[103] Analyzing potential trade-offs and synergies between nutritional quality and climate-change mitigation will be critical to identify or create win–win options.

While most research at the nexus between climate and nutrition focuses on undernutrition, the increasing prevalence of overweight and obesity calls for a better understanding of the interaction between climate and overweight. Examples of potential research questions include the following. Do climate variability and change influence the type of food production (more or less diversified)? Is diversification adaptive? Do climate variability and change influence overweight trends? Do climate variability and change (e.g., increasing heat extremes) affect the prevalence and/or symptoms of noncommunicable diseases related to overweight? Do dietary patterns that contribute to overweight contribute more to GHG than healthy diets? That is, is what is good for the environment also good for human well-being in the long run? A main challenge to measure the impact of climate variability and change on nutrition and related health outcomes in indigenous peoples' communities has been the lack of disaggregated longitudinal data on health and its determinants.

### Research Gap 5. Increasing attention to inequities among population groups in relation to the three domains (nutrition, environment, and economics)

Understanding the interaction across nutritional quality, environmental sustainability, and economic viability cannot be based solely on aggregated population data. In particular, the effect of the food systems and of food and agricultural policies and market forces and the consequences of climate change presented in the previous two sections must be analyzed in the context of disparities within population groups, such as those based on geography, socioeconomic status, livelihood (such as agricultural smallholders or laborers), ethnicity, and gender. Disparities within these groups translate into unequal levels of poor nutrition, poverty, and the adverse effects of climate change. Food systems themselves can generate inequities in the way cheap labor is an integral element of low-cost food production, processing, and distribution. Climate change generates inequities, as the poorest groups are often the first and worst hit by its effects.

Therefore, attention must be paid to the differential effects of the linkages and trade-offs across the three domains on specific population groups. An example of geographic disparities related to poor nutritional quality is provided by the study of inadequate food access, or *food deserts.* This term refers to places where healthy food is not easily physically or economically accessible.[104] In general, healthy food is less accessible to the poor: healthier food baskets are significantly costlier than less healthy options,[105] and higher relative prices of nonstarch foods cause them to take up large shares of food expenditure of the poor.[106]

The analysis of exposure to environmental threats across socioeconomic groups provides another illustration. Households with low socioeconomic status have been found to be more at risk of environmental exposure to air and water pollutants than other households.[107] High-income households' consumption patterns cause greater waste generation, water resource depletion, and contribution to GHG than lower income ones,[107] but are unlikely to bear the consequences directly in terms of health and economic costs. Environmental degradation increases the poverty of poor farmers, particularly in areas where the cost of adopting climate-change adaptation and mitigation practices is prohibitive and the outcome is uncertain. Furthermore, some adaptation strategies, such as water harvesting, may increase the risk of other negative outcomes such as malaria or dengue fever.[108] The ecosystem between farming, food production, food consumption, and land and water availability is affected by multiple factors, including asset ownership, trade, climate shocks, and incentives. This ecosystem needs to be better described in the context of poor rural smallholders in order to be preserve the environment and enable development.[109,110]

Gender inequities are widespread and are reflected in poorer nutritional outcomes. Women's empowerment to control income and assets, to have autonomy over the use of their time and labor, and to make decisions can positively influence the economic situation of the household and its members' nutritional status.[111,112]

While factors related to the environment and poverty may aggravate the household vulnerability to poor nutritional outcomes, disparities may be mitigated by access to safety nets (e.g., food aid, social protection), safe drinking water, and health care. It is established that safety nets can affect food security,[113] but they need to be carefully assessed in order to mitigate any unintended effects. For instance, a program in rural Mexico that provides cash and in-kind transfers has increased household energy consumption and increased weight among women that were already overweight or obese at enrollment without affecting child linear growth.[114,115] The assumption was that, for households that already had adequate energy, the program would provide incentive for consumption of healthy food of quality and variety, resulting in better nutritional status.[114] This example shows that social protection interventions need to be designed and measured not only in terms of undernutrition, but also with a view to complete nutritional quality, and in relation to the food environment in which they are implemented. Analysis of how the poor or other population groups respond to the food system and climate change can be used to inform social protection programs and policies to reduce disparities.

### *Recommendations for future research*

One step in the research agenda involves disaggregating nutrition, environmental, and economic data to understand and monitor inequities among subgroups, taking into account geography, socioeconomic status, type of livelihood, and gender. A second step involves using this disaggregated data to model the effect of policies and interventions. Inequities and lack of empowerment cannot always be captured in quantitative measures; however, participatory and qualitative measures may be crucial for understanding the nature of inequities. Women's empowerment is critically important to nutrition and economic viability but difficult to measure. While indicators are being developed to measure this complex construct, more needs to be done in order to understand the effect of various systems, policies, and interventions on gender equity.

Ultimately, part of the research agenda is to understand how to reduce harms to certain groups of various policy options, including the status quo, and to evaluate the effect of tools to reduce inequities. These tools may include social-protection interventions and analysis of food and agriculture policies in relation to disparities in economic, environmental, and nutritional risks. Research on the specific disparities generated throughout the food systems and the effects of food production on workers along the value chain is necessary to ensure that strategies to reduce cost of nutritious food do not result in poorer health or economic conditions for those who produce it, or environmental risks generally.

How poor households currently react to environmental risks or changes (for instance, engaging in low-return yet more drought-resistant farming or diversifying income sources) and how this response may be optimized is also a research need. For instance, while price elasticity and substitution mechanisms may have been measured, their variability across subgroups in the population is less well established. Responses to information (such as nutrition guidelines) and incentives are also not well described across subgroups.

Tools to address disparities must be evaluated using a broad perspective across the three domains. The measurement of impact of cash transfer and employment raises methodological questions in the assumptions that are made in terms of targeting, distribution, and duration of interventions.[116]

## Conclusions

This paper calls for interdisciplinary research designed to serve real-world policy and practice to address priority research gaps in knowledge and methods (Box 2). The traditional structure of universities, and challenges to career progression and funding silos, relentlessly steers researchers back to core disciplinary areas. However, the nutritional, environmental, and equity problems with food systems and climate change are increasingly recognized. As they are problems that do not fall into any single discipline, they present an opportunity to move forward with a research approach based on problem solving, which will necessitate the breakdown of silos. The proliferation of interdisciplinary centers or networks in academic settings helps in creating the research opportunity envisaged, and, more importantly, represents the recognition of the need to transcend traditional boundaries to solve increasingly pressing global problems.

The development of policy-relevant evidence for improved nutrition outcomes in the context of environmental sustainability and economic viability will require a concentrated effort to build new sources of information while better exploiting what is currently available in terms of data, methodologies, and tools—including the ever-increasing opportunities for improved development outcomes created by so-called big data. It will also require grounding research, given that constructs of most interest cannot always be measured well and that delivery of policies and interventions moderates their effect—two factors that can limit the strength of experimental or modeling results. This research agenda calls for a comprehensive approach to research that connects nutrition, economics, and environment; takes account of measurement and delivery limitations; places biology within the social, economic, and natural environment; and capitalizes on the strengths of many disciplines through collaboration and communication.

**Box 2.**

## Measurement

*Nutritional quality*

Global and nationally representative data are scarce on dietary quality and access to nutritious food, disabling analyses that seek to understand impacts on nutritional quality. Research questions on the measurement of food indicators for nutritional quality include:

- What proxy or proxies can be used to measure *dietary quality*, encompassing aspects of both adequacy (getting enough of certain foods/nutrients) and moderation (not getting too much of certain foods/nutrients)?
- What indicators can capture adequacy of food access, including not only adequate dietary energy, but also affordability and convenience of healthy food (i.e., food environments)?
- What is needed to enable *data collection* of better food and diet indicators (such as capacity development of national bureaus of statistics or ministries of agriculture, international alignment on indicators to be collected, and open data)?

*Environmental sustainability*

Prioritize key environmental sustainability indicators and data to mainstream their monitoring and use in models and policy making. For example, increase the availability of relevant and reliable climate information, through nationally owned climate data sets being developed using an integration of historical satellite data (with good spatial coverage) and ground-based observations (with good local calibration).

*Economic viability*

Model environmental, public health, and social externalities of food production and consumption in order to understand their present and future costs.

## Developing and adapting modeling tools

- Develop models integrating nutrition, economic, and environmental data.
- Enable collaborative approaches and models through:
  - planning for colocation of data collection from different disciplines;
  - integration of multiple spatial scales, using tools such as hierarchical sampling design, extrapolation using modeling, and remote sensing;
  - integration of multiple time scales, through long-term longitudinal data collection;
  - consensus on a minimum set of common indicators that can be easily integrated in different studies;
  - establishment of the validity of the indicators if validity has not already been established;
  - open access to datasets; availability of relevant, quality assured colocated data organized at multiple temporal and spatial scales and in a common format for analysis; and routine update of such data sets through appropriate data policies and data dissemination tools;
  - effective use of such multisource data (with appropriate methodologies and tools) through appropriate professional and research training efforts;
  - provision of guidance regarding the most appropriate and useful analytic methods for various types of analyses.

*Continued*

**Box 2.** ***Continued***

### Food systems in relation to nutritional quality, environmental sustainability, and economic viability

Key research questions that could be addressed with better data and integrated models:

- How do policies affect the type of agricultural growth and how does the type of agricultural growth affect nutritional quality, economic viability, and environmental sustainability?
- In addressing the global nutrition transition, what are the determinants of changing dietary habits and food choices? What are incentives for economically vulnerable groups to spend the resources (including time) to obtain healthy diets? Modeling why certain locales have greater access to diverse food than others could serve to focus research and resources on how barriers to accessing high-quality nutritious diets could be overcome.
- How do policies and interventions affect agricultural diversity, food supply diversity, and dietary patterns?
- How do changes in the environment (e.g., land degradation, loss of biodiversity, climate change) influence dietary patterns, caring practices, nutrition health delivery services, and nutrition outcomes?
- Improve evidence on where, and for whom, diets are inadequate, and the consequences of poor diets on health, productivity, and environmental sustainability.
- What is the true cost of different dietary patterns? How context-dependent is the relationship? How can these costs be internalized in the cost of food? How do consumer choices affect environmental change?
- How does agricultural diversification, or targeting specific micronutrient-rich crops, affect ecosystem services and economic viability for smallholders and laborers?
- How can barriers to market participation for smallholders be addressed? In what way does market participation of smallholders affect the local food environment?

### Challenges of climate change and variability

- Develop analytical tools and metrics for different representative geoclimatic locations, ecosystems, and socioeconomic and urbanization contexts. Particularly important will be the ability to identify which nutrition metrics are most sensitive to climate variability and change and at what points it is most effective to intervene.
- Use risk mapping to analyze which regions and populations are most nutrition-vulnerable to climate-related hazards and why, and to include diversity in food crops, livestock, and management systems in projections rather than just the few major staple crops.
- Specific questions around adaptation to ensure nutritional quality include: How can we combine multiple traits in crops so that they are nutrient-dense and tolerant to drought and flooding? How can climate information services serve nutrition programs (i.e., their design, adaptive management, and evaluation) to enhance their resilience? How can we ensure that agricultural policies regarding climate variability and change adaptation include better nutrition as well as increased production as the desirable outcome?
- How can changes in diet still meet nutrition requirements while aiming for a reduction in GHG, land use, and water requirements?
- Does climate change influence the type of food production (more or less diversified)? Is diversification adaptive? Does climate variability and change influence overweight trends? Does climate variability and change (e.g., increasing heat extremes) affect the prevalence and/or symptoms of noncommunicable diseases related to overweight? Do dietary patterns that contribute to overweight contribute more to GHG than healthy diets? That is, is what is good for the environment also good for human well-being in the long run?

*Continued*

**Box 2.** ***Continued***

**Increasing attention to inequities in the three domains**

- Collect disaggregated nutrition, environmental, and economic data to understand and monitor inequities among subgroups taking into account geography, socioeconomic status, type of livelihood, and gender. Use this disaggregated data to model the effect of policies and interventions.
- Improve measurement of women's empowerment, and build evidence on the effect of various systems, policies, and interventions on gender equity.
- Develop and use joint information services that can inform and help contextualize environment, livelihood, or nutrition-focused intervention programs.
- Analyze harms to certain groups of various policy options, including status quo, and evaluate the effect of tools to reduce inequities (including policies and programs).

## Acknowledgments

We gratefully acknowledge Dr. Francesco Branca (the World Health Organization) and Dr. Alan Dangour (the London School of Health and Tropical Medicine) for their useful inputs in the early stages of the development of this paper, and to Mary Azarm (independent) for assisting with research and citation. We deeply thank the anonymous reviewers for their very insightful comments. The opinions expressed and arguments employed herein do not necessarily reflect the official views of OECD member countries.

## Conflicts of interest

The authors declare no conflicts of interest.

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