FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Theme 5: Metrics for Food Systems for Nutrition

Scoping Exercise Report

Food Systems for Nutrition Innovation Lab

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Acronyms

CEC	Cation Exchange Capacity
COAHD	Cost and Affordability of a Healthy Diet
COCA	Cost of Caloric Adequacy
CONA	Cost of Nutrient Adequacy
DQQ	Diet Quality Questionnaire
EED	Environmental Enteric Dysfunction
FAO	Food and Agriculture Organization of the United Nations
FIES	Food Insecurity Experience Scale
FSN-IL	Food Systems for Nutrition Innovation Lab
GDQS	Global Diet Quality Score
GPS	Global Positioning System
HEI	Healthy Eating Index
HLPE-FSN	High Level Panel of Experts on Food Security and Nutrition
HWISE	Household Water Insecurity Experiences
ICT	Information and Communication Technology
IFPRI	International Food Policy Research Institute
JMP	Joint Monitoring Programme
KAP	Knowledge, Attitude, and Practice Survey
LMICs	Low- and Middle-Income Countries
MEEDAT	Micronutrient and Environmental Dysfunction Assessment Tool
NCD	Non-communicable Disease
OECD	Organization for Economic Cooperation and Development
PoU	Prevalence of Undernourishment
R&D	Research and Development
RFAs	Requests for Applications
SOFI	State of Food Insecurity
USAID	United States Agency for International Development
RFS	USAID Bureau for Resilience and Food Security
SDG	Sustainable Development Goal
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WHO	World Health Organization

Summary of Findings

Introduction and Summary of Scoping Exercise

Food systems are composed of the processes and activities related to the production, processing, storage, distribution, and consumption of food. Poorly performing food systems are contributing to the triple burden of malnutrition: undernutrition, micronutrient deficiencies, overweight and obesity and related chronic diseases. Food systems exert an impact on nutrition through their impact on diets, which have been recognized as a major contributor to the significant burden of mortality and morbidity globally. Additionally, food systems are a factor in climate change and are simultaneously affected by many climate-related issues. Given these numerous challenges related to poorly functioning food systems, it is critical to be able to measure the impacts of food systems on nutrition and health, while implementing monitoring and evaluation programs for continued systems-level improvement. The development and refinement of metrics for food systems is an important factor in addressing gaps in our understanding of food systems and related pathways and to track their impacts on nutrition and health.

Methods and Approaches

The United States Agency for International Development (USAID) Feed the Future Food Systems for Nutrition Innovation Lab (FSN-IL) commissioned a scoping review of nutrition metrics for food systems. The Harvard T.H. Chan School of Public Health (Harvard Chan) led the scoping activity for *Theme 5: Nutrition Metrics*. Project partners from Johns Hopkins University, International Food Policy Research Institute (IFPRI), Michigan University, Boston Children's Hospital, and Tufts University collaborated to inform the design and implementation of the scoping exercise. The purpose of the scoping activity was to support the FSN-IL to a) generate a preliminary census (identifying and listing) of metrics relevant to Theme 5; b) assess the strengths and limitations of each metric with regards to the feasibility of use in the field, potential for broad reach and adoption, novelty and innovation; c) identify gaps where metrics require further development; and d) offer a framework for prioritizing "best bet" metrics for possible funding under upcoming FSN-IL calls for proposals.

The steps taken by the team in consultation with partners included:

1. Developing an organizational typology of metrics, differentiating the types of metrics needed to measure food systems innovations, and clarifying the purpose of these metrics.
2. Conducting a literature review and leveraging expert knowledge in each food system domain to develop a table of metrics covering all areas of the food system.
3. Developing a compendium of metrics for food systems including currently used and innovative metrics in line with proposed domains of the food systems. The compendium provides information on the constructs used in the theories of change, the innovation metrics, novel components, and the strengths and weaknesses of each metric. We also identified gaps for each domain area.
4. Developing food systems metrics tables through an iterative process with meetings organized by the working group lead, the Harvard School of Public Health, and partners.

Findings

The scoping exercise identified several food systems frameworks including the High Level Panel of Experts on Food Security and Nutrition (HLPE-FSN) framework (HLPE, 2017) and the USAID Bureau for Resilience and Food Security (RFS) framework (USAID, 2021) to guide the development of the food systems metrics. Based on these frameworks, the following domains were identified.

Production Systems

Table 1 presents the metrics for production systems. The gaps identified in this domain include the limited availability of metrics for crop and livestock nutritional functional diversity and related cut-off points. These metrics are important for identifying gaps in species richness and diversity of food systems. This domain has a key role in assuring the production of crops to meet the needs for a healthy diet. There is a need for the development of food composition tables to facilitate the evaluation of nutrient adequacy of production and developing metrics that go beyond assuring the availability of food to consumption of healthy diets. Additionally, including wild or indigenous species in production metrics will be beneficial. Finally, establishing databases for land rights and tenure and facilitating land ownership is crucial to ensure the full participation of vulnerable population groups in food systems.

Storage and Distribution

Table 2 presents the metrics for storage and distribution. Research gaps identified in this area include a lack of field-friendly, cost-effective, and effective metrics for food safety. Innovation is required in metrics to assess contamination including those that can assess multiple contaminants at the same time. Other gaps include metrics for assessing innovations in food preservation and nutrient retention or loss during storage. Another critical area identified is the limited availability of consistent metrics for assessing food loss, especially as differing approaches have previously been used. Gaps are also evident in data available to assess food loss in LMICs.

Processing and Packaging

Table 3 presents the metrics for processing and packaging. Gaps were identified in metrics for nutritional enhancement and processed foods. It was evident that there were limitations of metrics for private sector influence on food systems, as well as metrics for linking private sector activities to nutrition and health outcomes. Another area of consideration is the potential to enhance the nutritional benefits of food through processing (e.g., fermentation). Finally, the issue of consumer attitudes towards processed and packaged foods must be evaluated through metrics as this can aid in the development of interventions to address poor consumption practices.

Retail and Markets

Table 4 presents the metrics for retail and marketing. Gaps identified in this domain include metrics to access the policy environment, particularly for retail and food marketing. The inclusion and validation of market surveys on perishable foods, including surveys conducted in rural LMICs, will provide valuable information. Finally, we identified the opportunity for further research on consumer preferences in markets and how convenience influences the production of available products in the markets.

Food Availability and Access

Table 5 presents the metrics for food availability and access. Among other things, the metrics in this domain assess availability and access to a healthy diet and access to markets. The FAO measures global food security

using three indicators: caloric undernourishment (measured using Prevalence of Undernourishment (PoU)), the experience of food insecurity (measured with the food insecurity experience scale (FIES)), and access to a healthy diet (measured with the Cost and Affordability of a Healthy Diet (CoAHD) index), as presented in the State of Food Insecurity (SOFI) 2022. Gaps were identified in that prevalence of undernourishment only considers calories and does not consider overall diet quality (e.g., micronutrient availability from fruit, vegetable, and animal source foods). Further, there is no globally applied measure of overall diet quality that had been scaled up to track progress across countries. Another area warranting future development, particularly in LMICs, is the lack of current policies which support the availability of and access to healthy foods while disincentivizing the consumption of unhealthy foods.

Promotion and Advertising

Table 6 presents the metrics to assess the promotion and advertising domain. Major gaps identified were within the policy environment to support healthy diets. For example, gaps were identified in the lack of policies to limit the promotion of unhealthy food (for example, to children), food labeling, and food standards. Appropriate definitions and guidelines must guide the enactment of such policies.

Food Quality and Safety

Table 7 presents the metrics for the food quality and safety domain. In this domain, which encompasses the contamination of food and biomarkers for contaminants, gaps were evident in community approaches to control contamination. Metrics to assess this would be informative. Other gaps were in field-friendly metrics for the detection or quantification of multiple microbes, as well as those which address multiple sources of contamination.

Consumer Behavior

Table 8 presents the metrics for consumer behavior. There were notable gaps in the measurement of food waste, with divergent definitions by different agencies. There is a need to harmonize definitions and increase the availability of data from LMICs. Additionally, linking research in food loss and waste to allow countries to conduct combined analysis would be useful. Another gap identified was limited knowledge around drivers of food choices, particularly for different geographies and populations and concerning the consumption of healthy foods.

Diets, Nutrition, and Food Security

Table 9 presents the metrics for diets, nutrition, and food security. Gaps in diet quality assessments were noted, particularly regarding the availability of validated and field-friendly metrics. Another gap was the lack of validated metrics for assessing overall diet quality for special groups (adolescents, children, and pregnant women). There is also a lack of metrics to assess consumption of ultra-processed foods, as well as to assess fruit and vegetable consumption.

Nutrition and Health Outcomes

Table 10 presents the metrics for nutrition and health outcomes. The gaps in this area are related to assessing the impacts of food systems on nutrition, health, and neurocognitive outcomes. The issue of attributing food system factors to nutrition outcomes is also of concern.

Gut Function

Table 11 presents the gut function domain including metrics for intestinal damage, permeability, microbial translocation, inflammation (EED), and the microbiome. The gaps identified were around the lack of validated

metrics and the need for evaluating associations with nutritional outcomes. The use of metrics for the evaluation of multiple biomarkers is required. Additional gaps were identified for screening and diagnostic biomarkers and those that are field-friendly, less invasive, and inexpensive for use in LMICs.

Hygiene Behaviors

Table 12 presents the metrics for the hygiene behaviors domain. Major challenges identified include that commonly-used metrics, such as the hygiene score, require validation and that standard questions used for assessment are subjective or not informative. There was a need identified for additional biomarkers for contamination. Finally, the need to consider contextual and cultural factors in assessment was also noted.

Socio-Cultural Drivers

Table 13 presents the metrics for socio-cultural drivers. This domain considers issues of women's empowerment, social support, child labor, and intrahousehold dynamics. Gaps in metrics were identified in metrics to assess women's empowerment, including those independent from agriculture. Validation of metrics in LMICs was also needed for psychosocial scales, as well as the development of metrics that rely on quicker data collection processes.

Biophysical and Environmental Drivers

Table 14 presents the metrics for the biophysical and environmental drivers of food systems. These metrics include natural resource management, land quality, water access, availability and quality, and livestock contamination. Gaps in this domain include assessing the knowledge, attitudes and practices regarding the biophysical and environmental food systems drivers.

Resilience

Table 15 presents the metrics for food systems resilience. There were gaps identified in data availability that limited the assessment of resilience and the evaluation of ecological footprints of consumption of diverse dietary patterns. Additional limitations were noted in data availability on the adoption of innovative plant breeding techniques in LMICs.

Conclusion

In this scoping report, we identify a broad range of food systems metrics, detail their strengths and limitations, and highlight gaps where no appropriate metrics are available. This compendium of metrics focuses on the most innovative and novel approaches to food systems measurement and is organized to facilitate the selection of appropriate metrics for institutions' policies, programs, and projects aimed at food systems transformation.

Background and Introduction

There is a renewed focus on food systems globally, expanding beyond the focus on agricultural production and encompassing actors and activities relating to the production, processing, distribution (including value-chains), and consumption of food (HLPE, 2017; Neufeld et al., 2021). This is based on the realization that food systems remain sub-optimal, contributing to increasing numbers of undernourished people, persistent micronutrient deficiencies, and growing levels of overweight, obesity, and chronic diseases, especially in parts of Africa and Asia (Madzorera et al., 2021; Tzioumis and Adair, 2014; W. Willett et al., 2019). For example, we know that food systems are failing to provide fruits, vegetables, legumes, and nutrient-dense animal foods at an affordable cost (Bai et al., 2021a) or to provide healthy diets in an equitable manner (Dangour et al., 2017). Further, food systems policies and inefficiencies have contributed to the increasing availability and consumption of unhealthy foods and cheaper calories (Hawkes, 2006). Low- and middle- income countries (LMICs) have faced dietary and nutrition transition as a result, with communities undergoing changes in dietary preferences towards fast, processed, and sugary foods and drinks. Urbanization has led to the need for convenience and changes in other lifestyle factors, all contributing to this transition (Popkin et al., 2012; Ronto et al., 2018). Food systems have also emerged as having a dual and cyclical role as both the primary contributor to climate change, as well as a major casualty of its effects, especially in the global south (Fanzo et al., 2018).

In view of these challenges and the importance of diet as one of the most influential contributors to morbidity and mortality globally (Afshin et al., 2019), it is important to measure the efficiency of food systems, track changes and progress over time, monitor and evaluate food systems programs and policy for impacts on nutrition and health, and develop new metrics to address gaps in our understanding of food systems and related pathways.

Success in changing the current trajectory of poorly performing food systems depends on careful consideration and decisive intervention targeting drivers of food systems, including climate and health systems. It will require supporting productivity gains, as well as innovations and changes in consumer behavior (von Braun et al., 2021). Our understanding of the interactions among food systems, nutrition, and health has deepened over the past few years due to increasing research, yet significant gaps remain. For example, understanding how food systems affect nutrition and health requires an understanding of the numerous pathways through which food systems operate to impact food environments (both external and personal) and how these, in turn, affect diets, consumption, and health outcomes. However, progress in learning how the food system impacts nutrition through its impact on diet has been constrained by the numerous definitions of healthy diets, and debates about how to measure diet quality appropriately (Madzorera et al., 2021; Neufeld et al., 2021; W. Willett et al., 2019), and limited understanding of how to intervene in the area of personal food preferences to promote healthier diets. Additionally, while there is recognition that agricultural practices contribute to environmental degradation and climate change, which in turn affects food systems by impacting agricultural production (Gornall et al., 2010), research in this area remains limited. Strategies and interventions to mitigate climate change and its effects are thus underdeveloped.

Several conceptual frameworks have been proposed to highlight interactions between food systems and nutrition (Fanzo et al., 2020; HLPE, 2017; Kanter et al., 2015; Raza et al., 2020; C. Turner et al., 2018; USAID,

2021). While there are overlaps between proposed frameworks, there are also different perspectives on these interactions, precipitating the need for further research to elucidate optimal pathways and approaches. Finally, research has consistently shown small effect sizes between food systems interventions and nutrition and health outcomes (Webb, 2013). Whether these observed effects are due to limited associations, complexities in pathways between food systems and nutrition, or to confounding factors remains to be evaluated through research. Better metrics, research tools, and approaches can help answer these questions.

The availability of appropriate metrics is essential for evaluating the impact of policies and projects, monitoring implementation progress, tracking changes over time, and answering key research questions regarding the efficiency and sustainability of food systems (McDermott et al., 2015). While metrics exist spanning all areas of food systems, many currently in use have weaknesses that limit their utility. Some are difficult to use in the field, are costly, provide unreliable measurements, or are not sensitive or specific enough to measure the effects of food systems. Additionally, there are recognized gaps in metrics to assess the extent of food loss and waste, mycotoxin (e.g., aflatoxin) levels, as well as for research on women's empowerment and enteric dysfunction (Madzorera et al., 2021). Measuring the impact of food systems on diet quality is hindered by the lack of validated, user-friendly metrics. Finally, while there have been innovations in developing metrics, tools, and approaches, many have yet to be validated in LMICs, and some have been applied in rural areas and not urban areas (and vice versa).

Aims and Objectives of the Scoping Exercise

The purpose of this scoping exercise is to support the USAID Feed the Future Food Systems for Nutrition Innovation Lab (FSN-IL) to a) generate a preliminary census (identifying and listing) of metrics relevant to *Theme 5 (Metrics for Food Systems for Nutrition)*; b) assess the strengths and limitations of each metric with regards to feasibility of use in the field, potential for broad reach and adoption, novelty and innovation; c) identify gaps where metrics require further development; and d) offer a framework for prioritizing "best bet" metrics for possible funding under upcoming FSN-IL calls for proposals.

This work aims to identify appropriate food systems metrics and highlight gaps where available metrics are insufficient. There have been several recent efforts to compile compendiums of food systems metrics. We build on this work by presenting an expanded compendium that highlights the strengths and weaknesses of each proposed metric, features recent innovations in metrics, and enumerates gaps in these metrics. The proposed operational typology, which displays the metrics within each area of the food systems framework by their innovative status and identified strengths and weaknesses, will allow for the development of Requests for Applications (RFAs) that call for research on improved metrics and identify which metrics are most useful for each type of innovation.

Outline of the Scoping Report

This scoping report first provides the *Scoping Approach and Methods,* outlining the approach of the literature review and validation of information, synthesis, and compiling of metrics. It then provides the results of the scoping exercise including a comprehensive table of metrics accompanied by a short narrative to guide interpretation of the metrics. The narrative outlines the overall strengths, weaknesses, and gaps identified for the metrics identified. The report concludes with a short paragraph encouraging the use of the metrics table

to determine the most suitable metrics for evaluation of an entities' specific projects and to inform areas of focus for further development of appropriate food systems metrics.

Scoping Approach and Methods

Overview of Scoping Approach and Methods

The thematic area of *Metrics for Food Systems for Nutrition* required a significant departure in methods from the remaining four thematic areas, which focused directly on innovations in each area of the food system. To identify metrics for food systems for nutrition, the team first developed an organizational typology of metrics and differentiated the types of metrics needed to measure food systems innovations (those to measure impact vs. track changes over time, for example). In addition to the metrics themselves, we included novel data collection approaches for the data necessary to calculate metrics. Next, a literature review using key terms was combined with expert knowledge in each domain of the food system to develop a table of metrics covering all areas of the food system. The table includes detailed information on the constructs used in the theories of change (i.e., how the metric or novel data collection approach will help measure the manner in which specific aspects of the food system can eventually impact nutrition), the innovation in the measurement approach or the metric and any novel components, and the strengths and weaknesses of each metric. Finally, the scoping report provides a narrative to describe and characterize the evidence on different types of metrics and their applicability to innovations in food systems interventions. Instead of presenting a strict prioritization schema for the identified metrics, we present the operational typology of food systems metrics and data collection approaches to categorize innovations in food systems metrics, identify gaps, and guide RFAs that will call for research on further development of metrics that could improve measurement of the impacts of many kinds of innovations. We thus present the results of the scoping review as a table of metrics accompanied by an informative narrative describing the broad metrics categories, defining the innovative metrics in each category, discussing overall strengths and weaknesses in each category, and identifying gaps where appropriate metrics either do not exist or require additional validation prior to scale-up. To the extent possible, we anchor the metrics we have identified to innovations identified by the remaining four thematic areas of the scoping exercise.

Development of Metrics Typology

The format and composition of the metrics table, including the final organization and typology of metrics, was ultimately determined through a series of meetings with the metrics for food systems working group. As the working group lead, the Harvard TH Chan team proposed an initial framework, which included division of metrics by food systems domain. The food systems domains were identified using several food systems frameworks, including the High Level Panel of Experts on Food Security and Nutrition framework (HLPE, 2017), and the USAID Bureau for Resilience and Food Security (RFS) framework (USAID, 2021).

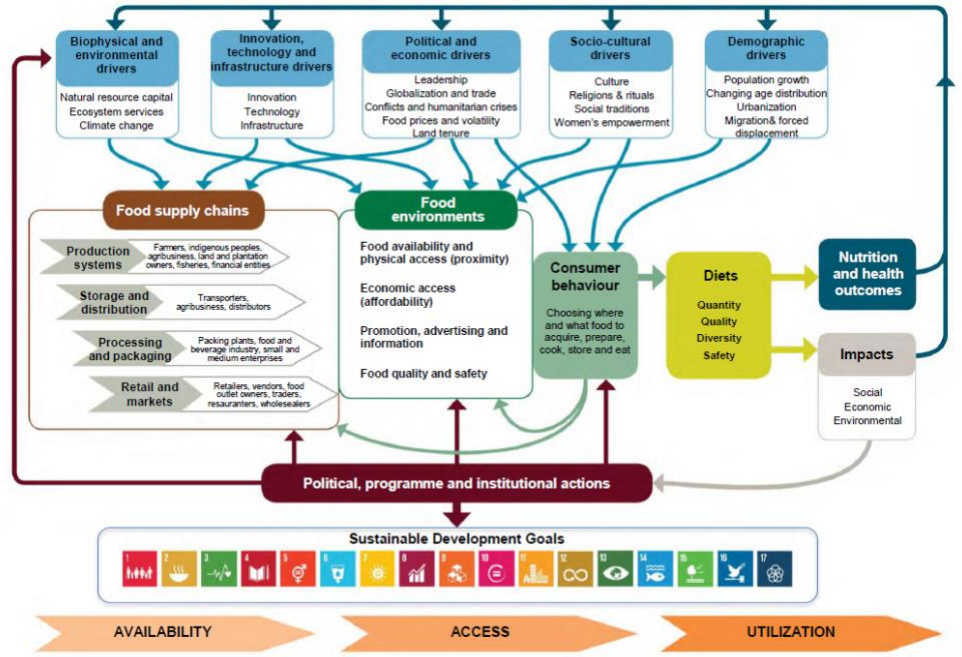

Figure 1. HLPE Framework for food systems (HLPE, 2017)

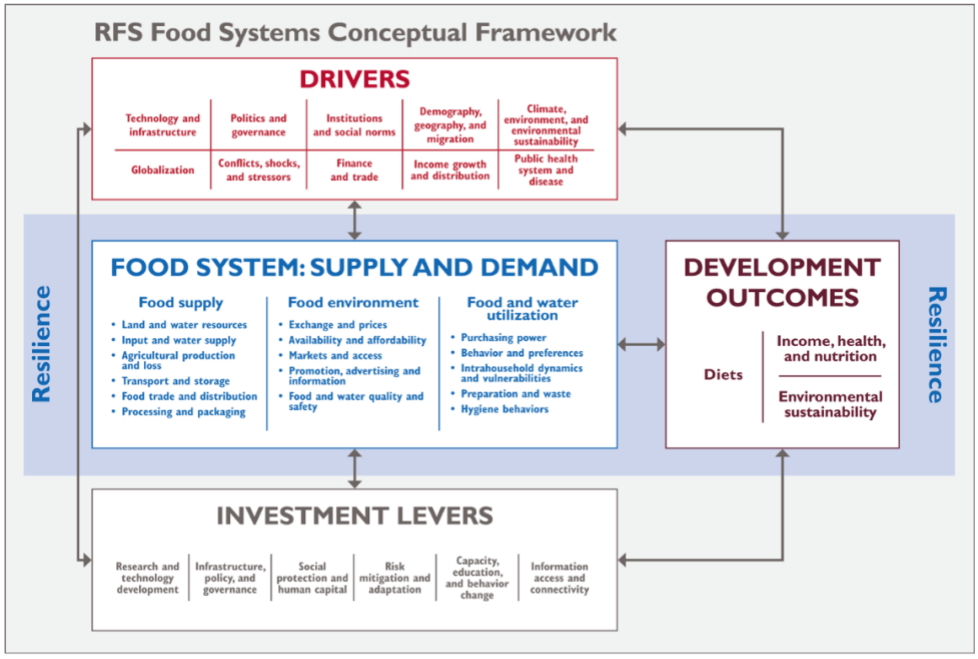

Figure 2. USAID Food Systems Conceptual Framework (USAID, 2021)

The working group was composed of partners from academic and research institutions with collective expertise covering all areas of the food systems, as well as expertise in development of measurement approaches and metrics. After several discussions with the working group, and an iterative process through which metrics in each domain of the food system were proposed and re-organized as appropriate, the team landed on a final typology that includes all areas of the food system but avoids repetition of metrics by

domain, includes cross-cutting metrics such as food safety as separate domains, and presents the metrics such that they are immediately usable to measure program or policy impact, especially on innovations for food systems presented in the reports from the scoping exercise's other four thematic areas.

The final list of food systems domains is provided below:

1. Production systems
2. Storage and distribution
3. Processing and packaging
4. Retail and markets
5. Food availability and access
6. Promotion and advertising
7. Food quality and safety
8. Consumer behavior
9. Diets, nutrition, and food security
10. Nutrition and health outcomes
11. Gut function
12. Hygiene behaviors
13. Socio-cultural drivers
14. Biophysical and environmental drivers
15. Resilience

The information recorded about each metric includes the sub-domain, the constructs used in the food systems for nutrition theory of change, the innovations in the measurement approach or metric, the novel component, the data collected (what is observed or measured), the scale of observation, the variables and units of measure of the metric, and the final derived metric or closely related variables. In addition, any search terms and sources were noted, as well as the purpose of the metric or approach (e.g., to be used for tracking change over time, evaluating impact, targeting, etc.), whether the metric is widely applied in the published literature, and any strengths and limitations of the metric (e.g., validation level, reach, field-friendliness).

Literature Review Approach

A first pass at filling in the metrics table was done through expert contributions of the working group. In the second step, a literature review was conducted using key terms relevant to each domain to identify additional metrics. Search terms by domain were combinations of "food systems" + "metrics" + "low- and middle-income countries" + "[domain name]", where the domain name was one of the 15 domains identified and listed above.

Validation of Information

Use of many of the core search terms turned up the same few compendiums of food systems metrics and indicators. Each of these compendiums of indicators had slightly different typologies for metrics, as well as different metrics highlighted. Some included metrics in similar food systems domains, though none provided extensive lists of metrics for all the domains we identified as important. Nevertheless, these compendiums were essential in the development of our own table of metrics; we made sure that we did not miss essential metrics in each domain by cross-referencing with these compendiums.

Identification of Metrics Gaps

Throughout the process of identifying food systems for nutrition metrics, we took note of any gaps in available or validated metrics to measure important food systems innovations, interventions, or policies. We present these gaps in the narrative report by overall food systems domain.

Findings of Scoping Exercise

Table of Metrics and Narrative

The detailed table of metrics for food systems for nutrition is broken down into 15 separate tables by food systems domain. These tables are meant to be consulted for an in-depth look at the variety of metrics identified in each area, and their corresponding strengths and weaknesses. Each table is presented below, accompanied by a brief narrative explaining the broad categories included, the innovations identified, overall strengths and weaknesses by domain, gaps in appropriate metrics, and research priorities and opportunities.

1. Production Systems

Production system metrics, presented in Table 1, concentrate on measuring the diversity and resilience of crop and livestock outputs, use of improved input technologies including seeds and fertilizers, measurements of soil quality and fertility, reach of agricultural extension programs, and assessment of land rights and tenure.

Overall strengths: Innovations in measurements and metrics for production systems involve the use of novel technologies such as image capture and geotagging, which have the advantage of providing high resolution and greater sensitivity and specificity for analyzing food production data, and of being low-cost. Other low-cost technologies have evolved that allow for increased feasibility of fertilizer and pesticide testing in the field. Many of the metrics in the production systems area will not only provide information about the function of production systems and whether they are likely to meet the nutritional needs of the population and climate-sensitive, but will also allow for assessment of the level of planetary health of our diets. Lastly, metrics of land rights and tenure are important in evaluating production systems, as inequitable distribution of land is a major driver of food insecurity and their measurement is essential to inform policy.

Overall weaknesses: The downsides of using newer technologies to evaluate production systems are that they often require expertise in remote sensing and geospatial analyses, and the precision and accuracy of the newer low-cost technologies for testing fertilizer and pesticide levels in the field require further study. In addition, data and documents on land rights and tenure may be difficult to come by in some regions where records are not necessarily kept up to date.

Gaps, research priorities, and opportunities: While production systems metrics are relatively comprehensive, criteria for rating adequacy of nutritional functional diversity of the crop and livestock species produced at any given location are yet to be established. Once criteria are established, appropriate cut-points to measure the adequacy of nutritional functional diversity can be defined. Other opportunities in production systems metrics include the development of food composition tables in regions where they have not been developed to be able to better determine the nutrient adequacy of production, establishing data sources for land rights and tenure in any context, and including wild or indigenous species in production metrics.

Table 1. Metrics for Production Systems

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Crop and livestock output	Crop and plant-based food growth, diversity and resilience	Image capture and processing from satellite and ground observations, use of drones	Use of novel technologies (image capture and geotagging) in collection and analysis of food production data	Area planted and harvested	Remote sensing datasets (e.g., Landstat, Sentinel)	Grid cell or plot of land	Area (ha)	Land use (e.g., %. planted)	Tracking change over time; impact evaluation; comparison within and between populations	Higher resolution and greater sensitivity and specificity when analyzing food production data; relatively low-cost	Methods may require expertise in remote sensing and geospatial analyses; geotagging and genotyping may be resource intensive	(Dimov et al., 2019; Group on Earth Observations, 2017)
				Crop growth and yield			Yield (kg/ha)	Vegetation (e.g., NDVI)				
				Genotype and health of plants			Various	Potential (e.g., yield gap)				
	Livestock and animal-source food growth, diversity and resilience	Geotagging animals, remote sensing for fish		Number and location of animals	Farm surveys; remote sensing datasets for fish	Grid cell, herd/flock or other livestock enterprise	Animals (#)	Tropical Livestock Units	Impact evaluation; comparison within and between populations			(Béné et al., 2019)
		Geotagging animals, remote sensing for fish					Index	Livestock diversity score				
		Genotyping and biomarkers		Genetics and health of livestock			Various	New variety adoption				
		Reporting of meat, milk, eggs and fish harvested	None	Production of animal-sourced foods; FAOSTAT			Yield (kg/yr)	Offtake, yield of animal-sourced foods		Simple and easy to interpret; animal sourced foods contribute to economic and social development and are necessary for population health; can also be a measure of planetary-healthy diets, depending on context	Requires collection of data from surveys; surveys may not cover large geographic areas	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Combined crops + livestock	Species richness and diversity	None	Degree of specialization at each location	Household surveys	Farm or region (e.g., district, state, or country)	Index	Nutritional Functional Diversity	Tracking change over time; impact evaluation; comparison within and between populations	Can be used to identify gaps in improving species richness and diversity in food systems	Not shown to be related to food security, anthropometry, and other nutritional outcomes; purchased food may play a larger role in household nutritional functional diversity than production in some areas; cut points for rating adequacy of NFD need to be better defined	(Luckett et al., 2015; Sheikhi et al., 2022)
			None	Number of species	Farm surveys; LSMS		Index	Crop species richness (Number of crop species grown on farm; average number of crops per unit of land)		Associations observed between crop species richness and dietary quality	Wild or indigenous species may be neglected in surveys; metric to be used for population or community-level estimation, not applicable to individuals	(A. Herforth et al., 2022)
			None	Number of crops			Index	Crop Production diversity (Number of crops grown on farm based on MDDW food groups, other diet diversity scores)				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Resilience and growth of output	None	Differences in output (without controls for inputs)	Farm surveys; LSMS; FAOSTAT		Index	Production of target nutrient-rich foods (vegetables, fruits, legumes, small livestock)		Simple and easy to interpret; widely applied in literature	Production does not necessarily translate to consumption by the population	
		Nutrient density of production	Nutrient composition of each food	Nutrients/kcal of energy	FAOSTAT; food composition tables; direct sampling and measurement from farm surveys		Index	Nutrient adequacy of production		Important to measure if food production system is aligned with population nutritional needs; nutrient composition of foods may change over time due to climate and environmental factors, and should be tracked closely	Food composition tables unavailable for many geographic regions; direct measurement may be resource intensive	(Sparling et al., 2021)
Land policy	Women's empowerment, incentives for sustainable and efficient land use, land rental opportunities for new farmers	Land rights and tenure	GIS for land boundaries, electronic records of ownership	Plot boundaries, ownership	Remote sensing datasets and satellite imagery for land boundaries; electronic record databases; other government-kept land tenure databases; LSMS	Matching plots of land to individual owners or renters	Plot size (m2)	Land owned or rented per person, esp. women		Inequitable distribution of land can lead to food insecurity and an important indicator of food systems function; no overlap with other metrics or indicators; included in SDG indicators	Data availability and quality	(Dachaga and de Vries, 2021; Higgins et al., 2018, p. 2018; UNDP, 2010)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Inputs	Overcoming labor bottlenecks at specific stages of crop and livestock production	Improved technology (electro-mechanization)	None	Adoption of specific technologies such as water pumps, harvesters etc..	Farm surveys; LSMS	Individual farmer, plot of land or quantity of crop or livestock for which the technology is used	Units per farm, kg of product or ha of land	Adoption rates (also disadoption when other technology proves to be better)	Targeting, impact evaluation; comparison within and between populations	Uptake metrics needed for targeting of interventions and formulating policy	Definitions of what constitutes improved technologies need to be well-established; may be high variation in types of new technologies available in different regions	(Khan et al., 2021)
	Reduced land and labor use per unit of plant nutrients	Percentage of cultivable land for crop production	Satellite observation of climate and vegetation, matched to soil sampling for geochemistry	Grid cell suitability for each kind of crop or livestock	Remote sensing datasets (e.g., Landstat, MODIS); soil sampling surveys	Grid cells	Index	Land suitability indexes, by purpose	Tracking change over time; impact evaluation; targeting	Higher resolution and greater sensitivity and specificity when analyzing production input data; uptake and adoption metrics needed for targeting of interventions and formulating policy	Methods may require expertise in remote sensing and geospatial analyses; geotagging and genotyping may be resource intensive	(Dimov et al., 2019; Group on Earth Observations, 2017; I. Y. Rabbi et al., 2015)
		High yielding seed varieties	Genotyping, AI recognition from photos	Area planted and harvested	Remote sensing datasets (e.g., Landstat, MODIS); genotyping and geotagging from farm surveys	Grid cells or plots	Units/ha	Adoption rates (also disadoption when other technology proves to be better)				
		Biofortified seeds	Genotyping, nutrient composition testing	Area planted and harvested		Grid cells or plots	Units/ha					
	Reduced methane emissions, land and feed use per unit of ASF	Improved breeds (livestock)	Geotagging, AI image recognition	Number and size of animals		Headcounts	Animals/farm					

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Soil enhancement and sustainability, incl. biofortification (e.g., Zn or Se fertilization)	Fertilizer type	Chemical testing	Nutrient composition (% of weight)	Farm surveys	kg of fertilizer	Nutrient (%)	Nutrient application rates for plant macronutrients (N, P and K) and micronutrients (esp. Zn and Fe, but also manganese etc..)	Impact evaluation; comparison within and between populations	Low-cost technologies have increased feasibility of fertilizer and pesticide testing in the field	Precision and accuracy of measurements using new technologies requires further study	(Melesse et al., 2020)
	Soil enhancement and sustainability	Fertilizer use per unit of land	Precision application	Nutrient application		Grid cells or plots	kg/ha					
	Crop protection and resilience	Pesticides/herbicide use/type	Precision application	Chemical application		Grid cells or plots	kg/ha	Application rates, timing and risk of operator poisoning or water runoff, airborne spread and residues in food				(Sarkar et al., 2021)
	Sustainability and resilience	Agricultural water withdrawal	Satellite imagery, electronic sensing	Water use	Remote sensing datasets; farm surveys; AQUASTAT	Grid cells up to surface watersheds or underground aquifers	m^3/day (or year)	Depletion and renewal rates, water use efficiency		Higher resolution and greater sensitivity and specificity when analyzing production input data	Methods may require expertise in remote sensing and geospatial analyses	(Melesse et al., 2020)
Soil quality and fertility	Sustainability and resilience	Organic carbon content	Soil sampling, testing and imagery	Soil organic matter (SOM)	Remote sensing datasets; farm surveys	Grid cells or plots	%	SOM levels, depletion and renewal rates		Low-cost technologies have increased feasibility of fertilizer and pesticide testing in the field	Precision and accuracy of measurements using new technologies requires further study	(Béné et al., 2019; Vanham et al., 2018)
	Sustainability and resilience	Total nitrogen	Soil sampling, testing and imagery	Soil nitrogen		Grid cells or plots	mg/kg	Total nitrogen				(Pozza and Field, 2020; Wagg et al., 2014)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Nutrient geochemistry	Soil-plant micronutrient testing	Soil sampling, testing and mapping	Soil (and plant) micronutrients, e.g. zinc, iron, selenium, iodine		Grid cells or plots	Unit/kg e.g. mg/kg	Micronutrient deficiencies in soils, plants, and foods				
	Sustainability and resilience	Soil potential hydrogen (pH)	Soil sampling, testing and imagery	Soil acidity		Grid cells or plots	pH	Soil potential hydrogen				
	Sustainability and resilience	Cation exchange capacity (CEC)	Soil sampling, testing and imagery	Soil geochemistry		Grid cells or plots	Cation exchange capacity (CEC)	Cation exchange capacity (CEC)				
Agriculture extension and support	Extension services improve agricultural yield	None	Consideration of agriculture extension programs	Access to extension agent	Farm surveys	Household/individual	Y/N	% Of population with access to agricultural extension services		Access to extension services is critical to farmer adoption of technologies and improved food systems function; measurement is simple and cost-effective	Not very useful as a stand-alone metric; should be combined with other metrics in order to be useful in policy and programming decision-making	(FAO, 2019)
	Extension services improve livestock yield	None	Consideration of agriculture extension programs	Access to livestock extension agent		Household/individual	Y/N	% Of population with access to livestock extension services				

2. Storage and Distribution

The metrics for storage and distribution are shown in Table 2. The topics included are safety and food loss. Metrics in this domain consider safety during storage, distribution of food, preservation of nutrient content of food, and minimizing food loss and deterioration of quality.

Overall strengths: The metrics presented encompass objective measures of contamination control in all forms, and a wide array of metrics are presented including metrics for aflatoxins, biological contaminants, and adulterants. We further consider metrics for nutritional loss, preservation and innovation in storage, and food loss. This compendium is deliberate in including, in detail, these areas that are critical for maintaining the nutritional quality of food and addressing issues that limit the availability of food, including food loss, particularly for nutrient-rich, but perishable fruits and vegetables, as well as legumes- which is a major challenge in LMICs.

Overall weaknesses: The food safety measures presented through the objective require specialized equipment, which is limited in availability in LMICs. These metrics also require training and many are not cost-effective, which is a barrier to their adoption. There is a limitation in the availability of metrics to assess food loss, with differences in definitions and approaches being a significant barrier.

Gaps, research priorities, and opportunities: For food safety, there is a need for field-friendly and effective metrics that are affordable and easy to assess without a significant burden for training. Further, the availability of metrics and methods that can account for multiple causes of contamination would be transformative. We recognize that there is a gap in metrics for assessing innovations in food preservation (including nutrient retention) during storage as these are important for decreasing food loss, a critical issue on which research is limited (particularly in LMICs). Further, there are clear gaps in the availability of data and streamlined metrics to assess food loss, with multiple agencies using differing approaches. These challenges make the generalizability of findings from food loss difficult and are an impediment to developing interventions and policies to address the problem.

Table 2. Metrics for storage and distribution

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Safety	Contamination control	Health surveillance systems	Data comprise the gold-standard metrics to evaluate whether food safety programs have been effective and to track their impact over time and in different regions or populations	Number of illness, cases and deaths per year in a defined population, and Disability-adjusted life years (DALYs), for a specific hazard or aggregated over hazards, and summarized at different geographical scales; cases of emerging/zoonotic diseases; chemical marker's concentration in a tissue or body fluid sample	Surveys	Country-level	Cases, deaths, DALYs, individual exposure levels in the case of chemical contaminants	Cases, deaths, DALYs, individual exposure levels in the case of chemical contaminants	Monitoring, tracking change	Objective measures if based on chemical assessment or biomarkers	Limited data available (reporting voluntary, sporadic), difficult to attribute cases to food, not all endpoints considered, economic burden not captured	(Fung et al., 2018; Gao et al., 2015; L. A. Thompson and Darwish, 2019)
		Aflatoxin and other mycotoxin levels (trichothecenes, zearalenone, fumonisins, ochratoxins, and patulin)	Numerous validated (laboratory) methods for detection; rapid test kits/strips have also been developed	Contamination levels from a representative sample	Surveys	Food sample from household, farm, market, slaughterhouses	µg/kg	% of samples over permissible limits	Monitoring	Important to assess aflatoxin levels as a possible factor in nutritional outcomes as levels tend to be high in many stored food products.	Very difficult to obtain a representative sample, also a number of analytical challenges (difficulties in detecting low-level contamination, great diversity of mycotoxin chemical structures, co-occurrence of	(Chavez et al., 2020; Reddy et al., 2010)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
											mycotoxins, etc..)	
		Presence of biological contaminants	Low-cost, field-deployable analytical techniques to enable rapid testing are in development (e.g., Biosensors)	Contamination levels (e.g., Of salmonella, Escherichia coli (E. coli), listeria, etc..)	Surveys	Food sample from household, farm, market, slaughterhouses	CFU/gram	% of samples with biological contaminants	Monitoring	Important to assess as factors are associated with poor health outcomes, potential for contamination is high due to poor storage conditions in many LMICs. Low-cost field deployable techniques will increase access in LMICs.	Labor-intensive, time consuming, requires laboratory-based analytical techniques which may not be available or cost-effective	(Azinheiro et al., 2020; Thakali and MacRae, 2021)
		Presence of unauthorized food adulterants		Detection/levels of adulterant	Surveys	Food sample from household, farm, market, slaughterhouses	Y/N or amount/gram	% of samples that have been adulterated	Monitoring			(Bansal et al., 2017)
		Conditions which can promote saprophytes	None	Moisture content, water activity	Surveys	Market/warehouse	%, scale 0-1	Appropriate storage for product (Y/N)	Targeting	Accurate methods available	Requires laboratory assessment (moisture); existing low-cost methods may have low accuracy, and higher accuracy methods require specialized equipment making them inaccessible in LMICs; qualitative methods may not provide sufficient information	(Mannaa and Kim, 2017; Vera Zambrano et al., 2019)
				Storage temperature and humidity	Surveys	Market/warehouse	Celsius, qualitative assessment (e.g., cool temperature)	Appropriate storage for product (Y/N)		Simple to assess		
				Storage duration	Surveys	Market/warehouse	Time (days)	Appropriate storage duration (Y/N)				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Food and nutrient preservation	Metrics of food preservation/deterioration	Measurement of nutrient content throughout storage and distribution	Changes in nutritional properties	Surveys	Food sample from household, farm, market, slaughterhouses	Nutrient density/content (amino acid, fat and crude protein, contents, etc..)	Nutrient density/content (amino acid, fat and crude protein, contents, etc..)	Evaluate the effectiveness of new innovations and monitoring	Objective measures if based on chemical assessment or biomarkers	Require extensive laboratory analyses or specialized equipment to fully evaluate; some tests are expensive, sensory approaches may be affected by subjectivity.	(L. Liu and Kong, 2021)
			Measurement of functional properties throughout storage and distribution	Changes in functional properties	Surveys	Food sample from household, farm, market, slaughterhouses	Bulk densities, water absorption indices, water solubility indices, oil absorption capacities, emulsion activities, emulsion stabilities	Bulk densities, water absorption indices, water solubility indices, oil absorption capacities, emulsion activities, emulsion stabilities				
			Measurement of physical properties throughout storage and distribution	Changes in physical properties (from various chemical and biochemical reactions)	Surveys	Food sample from household, farm, market, slaughterhouses	Magnitude of discoloration, changes in texture/flavor/smell, changes in pH levels	Sensory changes, magnitude of discoloration, changes in texture/flavor/smell, changes in pH levels				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Nutritional loss (not expressing loss in terms of nutrients but actual measurements/estimation of loss)	Probably the least measured type of loss in practice	Represents loss in terms of nutrients as a result of spoilage or processing. Most often studied through lab simulations, seldom in the field. Could be done alongside measurements to assess contaminants in dried fish for example.	Surveys	Food sample from household, farm, market, slaughterhouses	% of nutrient loss	Loss by the nutrient of interest (protein, fiber, lipids, minerals, vitamins, carbohydrate).	Monitoring	Important as not commonly studied	Requires technical expertise	(Kruijssen et al., 2020)
		Adoption of innovations in practices and techniques	Measurement of environmentally sustainable storage approaches	Use of improved harvesting and drying technology (robots, aerial images, moisture sensors, mechanical, gas-based, desiccant beads, dry bags, batch dryers/solar dryers, continuous flow dryers, etc..)	Surveys	Household	Y/N	Use of improved technology (Y/N)	Targeting, tracking change	There is limited research and innovation in this area, which is important for preventing contamination and deterioration of food (nutritionally, quality) and food loss. The use of metrics to track this is useful for informing interventions and policy.	Metrics may not address issues of lack of access to innovations by smallholder farmers, cost of technology	(Arshad et al., 2021; Bradford et al., 2018; Fernandez et al., 2021)
				Use of improved storage technology [hermetic storage, desiccant beads, dry bags, (climate-controlled) metal silos, cold storage units/refrigeration, etc..]	Surveys	Household		Use of improved technology (Y/N)				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
				Use of food preservation techniques [chemical/naturally occurring preservatives, biological processing (fermentation), cold treatment (freezing/refrigeration/chilling), pasteurization/sterilization/hurdle technology, irradiation/ultraviolet radiation, etc..]	Surveys	Household		Use of improved technology (Y/N)				
				Use of sustainable energy sources for food storage and preservation technologies (solar, wind)	Surveys	Household		Use of improved technology (Y/N)				
Food loss	Minimizing food loss increases availability of food, enhances sustainability, may increase access for poorer populations	Percentage of total food lost and wasted in food system from food production to consumption	Accounting of total food losses throughout the food supply chain	Food produced and lost; typically assessed using weights for many commodities. It is unusual to see assessments examine the entire food production chain; more commonly expressed for specific parts of the chain /levels as in the indicator below.	Surveys	Food supply chain for a commodity	Typically expressed as a % of total weight. Sometimes expressed as % of other units.	Total food lost and wasted throughout food supply chain	National tracking	Documenting rates of waste and loss can be used for advocacy and national tracking.	Challenges exist related to the generalizability of findings (also see narrative piece). Gaps in the availability of data required for estimates, particularly in LMICs.	(UNECE, 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Percentage of food lost (at a given level).	Accounting of food lost at each level of supply chain	Food produced; food lost; typically assessed using weights for many commodities.	Surveys	Depends on approach and commodity (described in narrative)	Typically expressed as a %	Cereal losses, pulse losses, fruit losses, vegetable losses	National tracking	Documenting rates of waste and loss can be used for advocacy and national tracking.	Challenges exist related to the generalizability of findings (also see narrative piece). Gaps in the availability of data required for estimates, particularly in LMICs.	(FAO, 2021)
		Loss percentage by commodity (also disaggregated by nodes of the value chain)	Accounting of food loss by specific commodity	Food produced; food lost (kg/ha)	Surveys	Commodity	kg/ha	Food produced; food lost	National tracking	Documenting rates of waste and loss can be used for advocacy and national tracking.	Challenges exist related to the generalizability of findings (also see narrative piece). Gaps in the availability of data required for estimates, particularly in LMICs.	(FAO, 2022)
		UNECE food waste and loss methodologies at each stage- harvest yield efficiency, etc..	Approach to quantification is relatively simple to quantify food loss at different stages including value lost.	Observations include actual harvest, expected harvest, removals due to processing and infestation, mostly using measurements by weight.	Surveys	Applicable at 28 stages of the food production chain.	Mostly % (efficiency) monetary value is not considered	Harvest yield efficiency	National tracking	Documenting food loss concentrations at the supply chain (grower/harvest level), a result of inadequate storage, adequate cooling systems, bad infrastructure and limited transportation	Challenges exist related to the generalizability of findings (also see narrative piece). Gaps in the availability of data required for estimates, particularly in LMICs.	(Gutiérrez-Delgado et al., 2020; UNECE, 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Tracking food losses over time by country to monitor progress towards food loss reduction	Food Loss Tracking (SDG Indicator). SDG 12.3.1(a) The Food Loss Index: Losses for key commodities in a country across the supply chain up to but not including retail (FAO is custodian)	Globally relevant to SDG's, relatively new metric	For 10 commodities, measures changes in % losses by country compared with baseline (calculated as a ratio of Food Loss Percentage in current period compared with the base period multiplied by 100. The actual data collected varies by method (see writeup by ATL).	Surveys	Collected at 29 levels (so hard to answer this) with a goal of estimating at national level	Ratio (no units)	Food loss percentage is needed to calculate the indicator	Tracking change for the SDG's	Important indicator for tracking SDGs, important to assessing loss which is informative for tracking food availability	Described in narrative; by itself does not say where loss is coming from, only for tracking	(Mingione and Jona Lasinio, 2018)
	Monetary consequences of food loss or market inefficiency	Market for loss (expressed in terms of monetary value lost)	Assigning monetary value to food loss	Different types of loss attributable to market behavior or management. Does not involve change in quality attributes; example might be selling in season vs. out of season; expressed in monetary terms	Surveys	Food	Currency	Monetary value lost	National tracking	Important metric to use for advocacy to mitigate food loss, useful for cross country and trend assessment	Complex methodology for underlying estimates of food loss; limited data in LMICs impacts estimates	(UNEP, 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Deterioration of quality throughout the food value chain	Nutrient density (market/point of consumption) for fresh foods	Quantifying food loss at each segment of the food value chain	Nutritive value of food at different time points	Sample survey data at each stage of the food value chain for specific foods	Food	Nutrient density/content (amino acid, fat and crude protein, micronutrient contents, etc..)	Changes in the nutritive value of foods from production to market/purchase (using nutrient profile model ratings)	Identification of problem areas along the food value chain	Multiple validated models for nutrient profiles exist – evaluating the change among food system stages will identify areas where improvements are needed	Resource intensive to collect data	(Delgado et al., 2021; Drewnowski and Fulgoni, 2014)
	Changes in primary production due to food loss	Food loss and waste flow model (MAGNET modeling approach)	Simulates how changes in primary production might occur for different commodities given loss reductions including modeling the impact of reducing loss of different commodities on micronutrient availability (And emissions) in this paper	A global general equilibrium model with a modular structure that is used to simulate impacts of agricultural, land, bioenergy policies on the global economy.	Surveys	Commodity	Modeling approach	Modeling approach	Identification of problem areas along the food value chain	Models estimate changes needed in food production after decreasing food loss	Application and validity in multiple contexts needs	(Gatto et al., 2022)

3. Processing and Packaging

Processing and packaging metrics, presented in Table 3, measure the effects of transforming foods through processing on the health effects of foods, the influence of private food processing enterprises on the availability of and access to healthy and unhealthy packaged foods, assessment of packaged food prices, the contribution of the food processing sector to employment and income generation, and the energy efficiency of food processing.

Overall strengths: In general, the strength of the metrics for processing and packaging are that they can provide the necessary context for policy decisions around food packaging and processing, including regulation of the processing agencies, marketing, and import or trade policies. The metrics that include measurement of the relative prices of healthy versus unhealthy packaged food also provide an essential lens to formulating policies, since price is a major driver of food choice. Using low-cost techniques such as web scraping and approaches such as Nutrition Sensitive Value Chain assessments can also facilitate the data collection process for many metrics of food processing and packaging and identify areas for improvement.

Overall weaknesses: The major weakness of processing and packaging metrics is that there is no universally accepted classification of the healthiness of processed or packaged foods. Though the NOVA classification system is the only one in widespread use, many experts do not agree on the fundamental components of this system. Thus, any metrics that distinguish between healthy and unhealthy processed or packaged foods, or determine their share of the market, are inherently defined by a classification system that has not been endorsed by all. Additionally, identification of small-scale food processing and packaging plants may be difficult, even with the use of technologies such as web scraping.

Gaps, research priorities, and opportunities: Definitions of nutritional enhancement and processed foods are constantly in flux and need more consensus. In addition, there are currently no metrics that allow comparison of private sector influence on food systems across contexts, or studies connecting specific types of products produced by the private sector to nutrition and health outcomes. It would be beneficial to develop a system to classify types of processing (i.e., fermentation, drying, canning, pasteurization, additives, etc.) by their potential for health benefits and/or detrimental effects. Last, metrics need to be developed to measure consumer attitudes towards processed and packaged foods.

Table 3. Metrics for processing and packaging

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Retail food environments	Health effects of foods transformed by processing	Classification systems for types of foods	Share of ultra-processed foods among foods available in markets; Classification of ultra-processed foods	Harmful loss of healthy attributes or addition of harmful compounds	Market surveys	District	NOVA classification for ultra-processed food	Proportion of available foods in each classification category	Tracking change over time; assessment to inform policy; measuring overall economic health of food system components	One of the only widespread classification systems for processed foods; useful for informing and monitoring policy decisions around processed food	Classification system/definitions for processed foods not universally accepted and opinions on classification vary widely	(Astrup and Monteiro, 2022; Monteiro et al., 2019; Monteiro and Astrup, 2022)
		Functional classification by processing type (e.g., fermenting, hermetic packaging, freezing, milling and fractioning etc..)	Considering food processing contributions to nutrition	Specific food attributes gained or lost	Market surveys	Food assessed	Various (micronutrients retained/kg, contains probiotics (Y/N), fermented (Y/N))	Does the processing enhance digestibility (Y/N), Does the processing preserve/micronutrients (Y/N)		Allows for assessment of potential processing contributions to nutrition, which can guide policy or consumer decisions	Processing methods and techniques may vary widely, making comparisons difficult; no well-defined definitions of nutritional enhancement	(Melesse et al., 2020; Weaver et al., 2014)
	Role of private sector in food value chains	Influence of private food processing enterprises on availability of healthy and unhealthy packaged foods	Tracking influence of private sector on food systems	Type, number and size of food processing and marketing enterprises	Enterprise surveys, food environment assessments, market visits, web scraping of online vendors, value chain analysis	District	Number of processors, size	Availability of food processing enterprises by type and size		Provides context for policy decisions around food processing entities; combining market visits and food environment assessments with web scraping of online vendors will provide more accurate data	Identification and inclusion of small-scale food processing enterprises may be difficult	(Augustin et al., 2016; Fardet, 2018; Knorr et al., 2020; Marrero, 2022)
				Product availability and nutrition attributes		Market	Y/N by product; combined index	Products produced by private sector actors (nutrient enhanced, previously unavailable healthy products, previously unavailable			No established validated index to show how types of products produced by private sector or degree of processing are related to nutrition or health outcomes	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
								unhealthy products, percent whole grains processed to a variety of consumer food products)				
		Nutrition Sensitive Value Chain (NSVC)	Approach that identifies opportunities to improve nutrition across the value chain	Nutrition Sensitive Value Chain	N/A	Food product evaluated in value chain	Number of value chains	Results from Nutrition Sensitive Value Chain assessments	Identifying opportunities for improvement across food value chain	Results from NSVC approach can be used to evaluate and improve food value chains, especially among smallholder farmers; approach was developed in a participatory manner using field input and testing	No current data repository or sources for monitoring NSVC projects; approach is new and still developing through further research and experience	(de la Pena and Garrett, 2018)
		Production and sales for local small- and micro-entrepreneur food processors	Inclusion of small- and micro-entrepreneur food processors	Production volume; sale volume	Food processor survey	Food processing entrepreneur	Metric tons/food product, annual revenue/food product	Production volume; sale volume	Tracking change over time; assessment to inform policy; measuring overall	Provides context for policy decisions around food processing entities and import/trade policies	Production and sales volume may not translate to consumption	(Moodie et al., 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Access to healthy foods (intact or packaged and processed), and to unhealthy processed foods	Influence of private food processing enterprises on access to healthy and unhealthy foods	Tracking influence of private sector on food systems	Product availability and nutritional attributes	Market visits, web scraping of online vendors	Market	Y/N by product; combined index	Products available in the market (nutrient enhanced, previously unavailable healthy products, previously unavailable unhealthy products, percent whole grains processed to a variety of consumer food products)	Economic health of food system components	Provides context for policy decisions around marketing of processed foods; combining market visits and food environment assessments with web scraping of online vendors will provide more accurate data	Product availability does not measure consumer attitudes towards products or translate to consumption	(Augustin et al., 2016; Knorr et al., 2020; Marrero, 2022)
		Assessment of price of packaged foods	Considering price in food processing and packaging policy	Price	Market visits, web scraping of online vendors	Food	Price per unit	Price of packaged foods (nutrient enhanced, previously unavailable healthy products, previously unavailable unhealthy products, percent whole grains processed to a variety of consumer food products)	Tracking change over time; assessment to inform policy	Price is a primary influence on food purchase choices; can be used to calculate relative prices of healthy vs unhealthy packaged food; can inform policy decisions regarding food prices	Defining processed and packaged foods, healthy packaged foods, and unhealthy packaged foods is a challenge; prices will vary widely over time and space	(Dominguez-Viera et al., 2022; Headey and Alderman, 2019; Muhammad et al., 2017)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Relative importance of ultra-processed foods in diets		Retail value of UPFs		National	Retail value (USD/capita/ year)	Retail value of ultra-processed foods		Price is a primary influence on food purchase choices; relative contribution of unhealthy packaged food can inform policy decisions regarding food prices and availability		
Employment and value addition	Employment and value added in food processing, distribution and retail	Contribution of food processing sector to employment and income generation	Linking food system to economic growth and health	Type and number of workers, earnings and expenditure of enterprises	Enterprise budgets, employment surveys, national accounts	District	Jobs per year, income generated per year	Number of jobs created per year by food processing sector; Income generated		Measure of food system influence on job creation and income generation can highlight areas for growth; indirect indicator of demand for processed and packaged products; important metric related to the sustainability of food system	Would need highly disaggregated data to measures equity or equality in food processing sector jobs and income generation	(Davis et al., 2022; Townsend et al., 2017)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Micronutrient levels (removal, enrichment and fortification, excesses)	Remedying micronutrient deficiencies and excesses	Food testing, processing and management of micronutrient levels	Validated nutrient profile models	Micronutrient density of foods (e.g., folate in flour)	Sampling from processing plants and markets	Each food, national level	Micronutrient density (e.g., mg/kcal or mg/g)	Appropriate micronutrient threshold achieved (Y/N); Nutrient profile model rating	Monitoring; tracking change over time; identifying policy and programming targets	Using nutrient profile rating shows whether multiple nutritional attributes are present in the right quantities; multiple validated models for nutrient profiles exist	May be resource intensive to get representative samples from food processing plants	(Drewnowski and Fulgoni, 2014)
Sustainability and climate impact	Limiting energy consumption, using green energy sources and limiting greenhouse gas emissions	Consideration of energy efficiency in food processing	Contribution of food processing sector to GHG emissions	Energy consumption, energy sources, greenhouse gas emissions	Emissions Database for Global Atmospheric Research EDGAR-FOOD; processing facility surveys	Processing plant/facility	Energy consumed (kilowatt hours kWh); energy efficiency (%)	How much energy is consumed during food processing; Clean energy used in food processing (Y/N); Energy saving technologies used in food processing (Y/N); Initiatives to use green energy sources/reduce GHG in food processing established (Y/N); energy efficiency (Y/N)		Important to inform decision-making and policy; can be disaggregated by processing type	Complex to collect data and calculate; data availability; requires many assumptions	(Clark et al., 2022; Crippa et al., 2021; A. Herforth et al., 2022; WWF, 2020)

4. Retail and markets

In the area of retail and markets, displayed in Table 4, metrics cover the overall nutrient availability of foods available in markets (including small-scale and informal markets), assessment of market regulations and the policy environment, level of market integration and therefore price stabilization and product variability across markets, connectivity of producers and consumers to markets, access to information about market prices, and how market infrastructure is related to the hygiene and sanitation environment of markets and contamination control.

Overall strengths: Included in the retail and markets domain are several areas that have not often been considered and had been identified as gaps in previous reporting on food systems for nutrition, such as influences of market infrastructure and hygiene and sanitation environment, and market integration. Regarding the metrics themselves, the overall strength of metrics in this area is that they measure concrete areas that need to be understood to inform policy adaptation.

Overall weaknesses: Much of the data needed for the metrics in retail and markets comes from market surveys, which may not be representative of all types of markets. While the inclusion of small-scale and informal markets will improve generalizability, it is not evident that small-scale markets will be identified or that it is feasible to conduct such surveys in remote or hard-to-reach areas. Data on the fortified foods available in markets also will not provide any information about the quality of the fortification process. Assessment of policy environments in this area is important, but it is difficult to find metrics that will be comparable across geographies as there is wide variation in the types and severity of policies.

Gaps, research priorities, and opportunities: Historically, market surveys in low- and middle- income countries have not included perishable foods and lack standardization; establishing more standardized versions of these surveys will facilitate comparisons and generalizability in the evaluation of retail and markets metrics. There is also no validated index or score to be used for measuring the hygiene and sanitation environment of markets, and this needs to be established as well. There is a gap in metrics evaluating preferences in markets and the convenience of the different products available in markets, which is a big research opportunity area. Finally, while metrics have been established to study the policy environment of retail and markets, there are currently no validated metrics to evaluate the effects of these policies.

Table 4. Metrics for retail and markets

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Quality	Enhanced micronutrient profile of foods	Availability of micronutrient fortified foods	Assessing availability of fortification in smaller-scale or informal markets	Number of different products available on the market that are fortified/Fortification available for Vit A (Y/N) (Vit D, folic acid, iron etc.)	Market surveys, vendor audit, inventory	Market	Number of fortified foods (with various fortificants)	Number of different products that are fortified/Fortification available for Vit A (Y/N), Vit D, folic acid, iron, etc.	Tracking change over time; assessment; identification of areas for improvement	Can be easily adapted by context and implemented in informal markets; provides essential information on quality of foods available in local markets	Fortification labels do not reveal anything about the quality of fortification; data collection may be resource intensive or lack feasibility in remote areas	(Ahmed et al., 2021)
	Diversity of available foods in markets	Assessing nutrient availability and commerce environment	Assessing nutrient availability in smaller-scale or informal markets	Types of different products available			Index	Market food diversity scores (e.g., Market Food Diversity Index, MFDI)			Data collection may be resource intensive or lack feasibility in remote areas; data may not be representative of typical markets	
Market Regulations	Policies for limiting harmful nutrients	Assessment of the food policy environment	Consideration of the importance of science-policy interface for food systems transformation	Policies enacted	National policies and process documents; FAO LEX database	National	Policy (Y/N)	Presence of policies limiting harmful ingredients (e.g., trans fats, added sugars, sodium)	Policy environment assessment	Macro-level policies may have potential for widespread impact on improving food systems function and are important to measure	Variation in policy type and severity make cross-country comparison difficult; presence of policies does not guarantee effectiveness of policy in transforming food systems or impacting outcomes	(Singh et al., 2021)
		Effectiveness of the food policy environment in changing consumption		Amount of ingredient in unit (e.g., grams) per serving			Unit (e.g., grams) per serving	% Reduction in market availability of unhealthy ingredients (e.g., trans fats, added sugars, sodium)				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		National dietary guidelines linked to execution of food policy		Policies linked to food policy			Policy (Y/N)	Existence of policies derived from national dietary guidelines				
	Enforcement of policies to limit harmful nutrients	Written guidelines on enforcement of policies	Consideration of potential for policy impact on food systems	Existence of written guidelines on food policy				Existence of written guidelines on food policy				
Market integration	Pathways linking market price stabilization across markets to nutritional outcomes	Assessing price stabilization across markets	Use of new food price data sources	Prices for particular products in different markets	World bank Microdata Library; consumer price index data (disaggregated); international agencies Early Warning Systems (EWS) data; market surveys	Market	Prices	Pricing discrepancy across markets (e.g., correlation coefficients)	Tracking change over time; assessment; identification of areas for improvement	Can be used as concrete metrics of price volatility; important to measure to understand potential for food price crises or potential impacts of food price interventions, which depend in part on market integration and efficiency; greater market integration helps consumers make decisions and anticipate needs	Data availability – for many low- and middle-income countries, market surveys have not included perishable foods and surveys are not standardized; necessitates new market surveys	(Varela et al., 2016)
	Pathways linking product availability across markets to nutritional outcomes	Assessing variation in product availability across markets	Understanding market integration across smaller-scale or informal markets	Availability of foods in different markets	Market surveys, vendor audit, inventory		Number of foods in different categories (e.g., fruits, chips)	Variation in available foods across markets (e.g., number of foods per food category in each market)				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
							Purchases of specific foods available in each market (kg or MT or dollars spent)	Variation in food purchased across markets (e.g., purchase data for foods at various markets)				
Market connectivity	Access to information	Assessing adoption of innovative information and communication technology (ICT) technologies and opportunities	Consideration of information asymmetry in modern food systems function; use of mobile phone coverage data to assess connectivity	Availability and uptake of ICT	Household surveys; mobile phone coverage data (phone companies)	Household	Y/N	Use of information and communication technology (ICT) (e.g., SMS messaging/radio/tv access to information about weather forecast, market prices, crop and livestock diseases)	Monitoring; impact evaluation; assessment; identification of areas for improvement	Important to increase understanding of access of small-scale farmers to ICT to help address crop yields, climate adaptation, food price stability, etc..; mobile phone coverage data is low-cost and widespread	Use of cell phone coverage data is cost-effective but does not assess uptake; surveys needed to assess uptake	(Mehrabi et al., 2021)
Storage and market facilities	Contamination control	Food warehousing access	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control	See storage and distribution tab section on contamination control

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Market hygiene and sanitation environment influence on access to goods in the market	Market infrastructure availability and use (shaded areas, toilets and other sanitation services etc..)	Measurement of hygiene and sanitation facilities in markets	Photos and scoring of facilities	Market visits, surveys	Market	Y/N, Index	Availability and use of hygiene and sanitation services, Hygiene and sanitation score, Market infrastructure (shaded areas, toilets, etc..); sale of expired foods	Monitoring; impact evaluation; assessment; identification of areas for improvement	Represents an under-studied area – can be used to fill research gaps in market functionality and food systems	No existing validated index or score specific to market hygiene and sanitation	(I. Cliffer et al., 2019)

5. Food availability and access

Food availability, markets and access, policy environment, trade metrics, food prices, and food affordability metrics are presented in Table 5. The metrics presented are useful for tracking progress in availability and access to healthy diets, foods (e.g., fruits, vegetables and legumes) and nutrients, access to functional markets, and relevant policy and trade environments.

Overall strengths: The metrics provided include more explicitly the factors that contribute to the consumption of healthy diets including the availability of nutrient-rich foods, the availability of adequate micro- and macro-nutrients, and the food environment represented by markets. We consider the distance to, time to markets and diversity of foods sold in the market, as well as market functionality. We also consider several metrics of the cost of healthy diets.

Overall weaknesses: The metrics presented cover the availability of nutrients, foods and healthy diets, but are not able to capture the actual consumption of healthy diets. While several market metrics are presented, the literature shows that there are varying definitions for several constructs including the measurement of diversification of foods sold in the markets, market functionality, and access.

Gaps, research priorities, and opportunities: The gaps identified include measures of undernourishment. The FAO currently measures world food security using three indicators, with caloric undernourishment measured using Prevalence of Undernourishment (PoU), the Experience of Food Insecurity measured with the Food Insecurity Experience Scale (FIES), and access to a healthy diet measured with the newly established Cost and Affordability of a Healthy Diet (CoAHD) index which was included in the State of Food Insecurity (SOFI) 2022 report. In assessing the prevalence of undernourishment, only caloric availability is considered, and the metric does not consider diet quality (for example, micronutrient availability from fruit, vegetable and animal source foods). This limits the extent to which this metric provides information on the state of undernourishment globally. Further, there is no globally applied measure of overall diet quality that had been scaled up to track progress across countries. Additionally, there is limited research on the policies to support the production of healthy foods and limit unhealthy foods, as these are key to changing the external food environment in LMICs.

Table 5. Metrics for food availability and access

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Food availability	Access to healthy diets is a basic human need	Cost and affordability of healthy diets (COAHD)	New data on food availability and prices, matched to item composition and requirements to meet dietary guidelines for diet costs, matched to income for affordability	Whether local food environments provide physical and economic access to a healthy diet	Surveys	Populations (individuals or households matched to markets)	Cost/day (USD), people (number and % of population)	Cost of a healthy diet (COHD) is difference between least-cost healthy diets and actual production or consumption	Global definition of food security (3rd main metric, after POU and FIES)	Innovative measure of access to healthy diets, allows cross-country comparisons. Added for tracking access to healthy diets by FAO (SOFI 2022) report	Measures only access, not utilization, etc..	(Bai et al., 2021b; A. Herforth et al., 2020)
	Stockholding to smooth consumption between harvests	Assessing stability of food availability	None	Household stocks of grain or other foods	Surveys	Household	Kg (in stock / used per month)	Months of adequate household food provisioning (MAHFP)	Assess improved household food consumption	Simple and easy to assess. If measured over time, captures changes in the household's ability to address vulnerability.	Needs further validation, application to urban settings requires further research	(FANTA, 2010)
	"undernourishment" in calorie terms	Daily per capita energy supply (domestic production + imports- exports per capita)	None	National food balance sheets	Surveys	Country	Kcal/person/day	Prevalence of undernourishment (POU) (percentage of population below minimum energy requirements)	Measure used for SDG2	Allows for national estimates and comparisons. Used a global metric to assess undernourishment by SOFI. Used as an SDG metric.	Based on caloric availability, which may not indicate consumption. Also doesn't consider other nutrients e.g., micronutrients	(FAO, 2021; Food and Agriculture Organization of the United Nations, 2022)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Diet diversity, micronutrient availability	Vegetable availability	None	National food balance sheets	Surveys	Country	grams/person/day	Vegetable availability	Tracking	Easy to assess, important to evaluate availability of healthy foods	Assesses availability not actual consumption	
	Diet diversity, micronutrient availability	Fruit availability	None	National food balance sheets	Surveys	Country	grams/person/ day	Fruit availability	Tracking			
	Diet diversity, micronutrient availability	Pulse availability	None	National food balance sheets	Surveys	Country	grams/person/ day	Pulse availability	Tracking			
	Diet diversity, micronutrient availability	Fruit and vegetable availability	None	National food balance sheets	Surveys	Country	grams/person/ day	Minimum individual intake of 400g (or the equivalent of 5 servings) of fruit and vegetables per day for the prevention of chronic diseases	Tracking	Easy to assess, important to evaluate availability of healthy foods	Assesses availability not actual consumption	(Food and Agriculture Organization of the United Nations, 2022) FAOSTAT
	Macronutrient availability	Daily per capita protein supply (animal)	None	National food balance sheets	Surveys	Country	grams/person/ day	Daily per capita protein supply (animal)	Tracking	National level estimate of supply, easy to assess	Assesses availability not actual consumption by vulnerable groups	(Food and Agriculture Organization of the United Nations, 2022; Grace et al., 2018)
	Macronutrient availability	Daily per capita protein supply (plant)	None	National food balance sheets	Surveys	Country	grams/person/ day	Daily per capita protein supply (plant)	Tracking	National level estimate of supply, easy to assess	Assesses availability not actual consumption by vulnerable groups	(Andreoli et al., 2021; Food and Agriculture Organization of the United Nations, 2022) FAOSTAT

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Macronutrient availability	Daily per capita fat supply	None	National food balance sheets	Surveys	Country	grams/person/ day	Daily per capita fat supply	Tracking	National level estimate of supply, easy to assess	Assesses availability not actual consumption by vulnerable groups	(Food and Agriculture Organization of the United Nations, 2022; Swarnamali et al., 2022)
	Nutrient adequacy	Population share with adequate nutrients	None	Household consumption or individual dietary recall survey; food balance sheet	Surveys	Household or individual, as % of surveyed pop	% of population	Population share with adequate nutrients	Tracking	Estimates consumption of key nutrients. Allows national level comparisons	Based on available calories, may overestimate actual consumption and population meeting requirements	(Gustafson et al., 2016)
	Nutrient adequacy	Non-staple food energy	None	National food balance sheets	Surveys	Country	% of kcal	Non-staple food energy	Tracking	Estimates available calories from non-staples as a proxy for energy supply; easy to compute from food balance sheet, country comparisons possible	Based on calories, and provides no estimate of actual intake and also by vulnerable groups	
	Nutrient adequacy	Staple food energy (cereals, roots and tubers)	None	National food balance sheets	Surveys	Country	% of kcal	Staple food energy	Tracking	Estimates available calories from staples as a proxy for energy supply; easy to compute from food balance sheet, country comparisons possible	Based on calories, and provides no estimate of actual intake and also by vulnerable groups	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Diversification to reduce risk, provide synergies (but loses gains from specialization)	Shannon diversity (measure of food supply diversity)	None	Quantity shares by category (e.g., Species)	Surveys	Farm household, district, country	in each category	Shannon diversity (measure of food supply diversity)	Tracking	Used to assess the diversity of national food supplies	Focuses on availability not consumption	
	Diversification to meet health needs from a balanced diet	Modified functional attribute diversity (diversity of nutrients in the food supply)	None	Quantity and nutrient composition of each food	Surveys	Farm household, district, country	Index	Modified functional attribute diversity (MFAD, diversity of nutrients in the food supply)	Tracking	MFAD assesses variety of nutrients using number of different food items, and amount of each item; proposes as a way to measure food nutrient adequacy	Focuses on availability not consumption	
Markets and access	Nutrient adequacy	Nutrient density score	None	Quantity and nutrient composition of each food	Surveys	Individual or household, country, world	Index	Nutrient density score	Tracking	Considers bioavailability of foods and energy density	Complicated methodology limits us in LMICs	(Drewnowski et al., 2019; Gustafson et al., 2016)
	Access to diverse foods for a balanced diet	Market food diversity	None	Quantity shares by category (e.g., Species)	Surveys	Individual vendor or marketplace	Index	Market food diversity	Tracking	Easy to compute and understand	Multiple approaches for assessment, need validation	(Ambikapathi et al., 2019; Pingali and Ricketts, 2014; Sibhatu et al., 2015)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Nutrient adequacy	Nutritional functional diversity score	None	Quantity shares by category (e.g., Species)	Surveys	Individual or household, country, world	Index	Nutritional functional diversity score	Tracking	Assesses nutritional diversity through the value chain (from farm to consumption), and can provide information on every level	Does not capture information on individual's nutrient requirements, absorption and utilization which are important for adequate nutrition	(Nandi et al., 2021)
	Access to goods in the market	Time to travel to market	None	Travel speeds; GIS location of households, roads and markets	Surveys	Household	Time (hrs.)	Time to travel to market	Tracking	Easy to assess	Does not provide information on quality of market and the foods sold.	(Nandi et al., 2021)
	Competition to lower price/raise quality	Number of food vendors	None	Market visits	Surveys	Marketplace	Number of vendors	Number of food vendors	Tracking	Easy to compute metric	Do not provide information on types of foods sold and access by vulnerable groups	(Ahmed et al., 2021)
	Access to goods in the market	Market type (informal/formal/supermarket)	None	Market visits	Surveys	Marketplace	Type of market	Market type (informal/formal/supermarket)	Tracking			
	Access to goods in the market	Market participation	None	Household surveys	Surveys	Household	Market food purchases	Market participation	Tracking	Proxy for household access to food/markets	Varying definitions, metrics require validation	
	Access to goods in the market	Access to market information	None	Household surveys	Surveys	Household	Market prices	Access to market information	Tracking	Can be easy to assess	Limited information and research on the area	(Clancy et al., 2017)
	Commercialization helps farm households meet their needs, by selling some things so they can buy others	Market production index	None	Household surveys	Surveys	Farm household	Index	Market production index	Tracking	Measure of household sales compared to total production, provides information on production for sale	Does not provide information on whether household needs are met or the types of crops sold	(Nandi et al., 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Access to goods in the market	Market food availability index	None	Market visits, food environment assessments	Surveys	Marketplace	Index	Market food availability index	Tracking	Provides an estimate of regional availability of a basket of food items regularly consumed, as a proxy for usual food availability	Does not include pulses in assessment	(Nandi et al., 2021)
	Commercialization helps farm households meet their needs, by selling some things so they can buy others	Transportation costs to market	None	Household surveys	Surveys	Farm household	Cost ($)	Transportation costs to market	Tracking	Assesses access to market	Does not provide information on other aspects of market	(Wudad et al., 2021)
	Commercialization helps farm households meet their needs, by selling some things so they can buy others	Road access (distance to nearest paved road)	None	Household surveys, GIS mapping	Surveys	Farm household	Distance (km)	Road access (distance to nearest main/paved road)	Tracking	Assesses access to market	Does not provide information on other aspects of market	(Wudad et al., 2021)
	Physical barriers/facilitators to access markets	Using satellite and GPS to assess road type/density	Satellite imagery/GPS	GIS location of households, roads and markets, type of road (improved/tarred etc.), time to travel, cost to travel	Surveys	Community level	Index	Market accessibility score	No, proposed metric	N/A	N/A	(Dimov et al., 2019)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Physical barriers/facilitators to access markets	Using satellite and GPS to assess road type/density	Satellite imagery/GPS	GIS location of households, roads and markets	Surveys	Community level	Km	Distance to market	Tracking	Easy to interpret	Multiple approaches for assessment	(Koppmair et al., 2017)
	Access to locally produced food products and access to direct-to-consumer pricing	Number of direct marketing channels from producers to consumers	Availability of locally produced foods	Food products with one or two stages between producer and consumer	Surveys	Household	Percentage of products	Number or % of food products with direct marketing, total sales of directly marketed products	Tracking	Direct marketing is a proxy of fewer middlemen, and better prices for farmers	Limited research on this in LMICs	(McFadden, 2017)
Policy environment	Policies that encourage or discourage production and availability of specific crops and livestock	Agricultural policies (subsidies, incentives, taxes, energy policies)	None	Policy exists	Surveys	National	Policy (Y/N)	Existence of policies promoting healthy food production, policies promoting excess unhealthy food production (e.g., Cereal and input subsidies)	Tracking	Policies supporting production of healthy foods and limiting unhealthy foods can change the food environment in LMICs	Limited policy research in LMICs	(Abay et al., 2022)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Trade metrics	Freer access to trade helps communities meet their needs, by selling some things so they can buy others	Trade policies (tariffs, non-tariff measures)	None	Administrative data from customs service, reported via monitoring services	Surveys	Tariff line, aggregated to commodity categories	Percent (%) commodities, exports for GDP etc.	Example metrics % of food commodities imported and exported (formal and informal), measures of trade protection (e.g., % exports for GDP, % imports for GDP, balance of trade)	Tracking	Proxy for access to markets	Research to establish links to local food systems and nutrition outcomes	(World Bank, 2022)
Food prices	Cost of all foods, in proportion to actual consumption	Food price index	None	Consumer price inflation	Surveys	National (sometimes subnational)	Index	Food price index	Tracking	Can provide information on local and international markets, which have a bearing on domestic food prices and is important for food security. Can provide useful information for local policies	Information to often used to inform local markets	(FAO, 2021)
	Cost of food commodities in bulk, for international trade	FAO food price index	None	Commodity price levels and volatility	Surveys	"World" markets (e.g., Rice exports from Bangkok, wheat into Rotterdam)	Index	FAO food price index	Tracking			

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Food affordability (note this is measured using only foods that are available, so it is also an availability metric)	Least-costs foods in sufficient quantities to meet nutrient needs; whether local food environments provide physical and economic access to a healthy diet	Cost of nutrient adequacy (CoNA)	New data on food availability and prices, matched to item composition and nutrient requirements	Cost of foods; nutrient composition of foods	Surveys	Populations (individuals or households matched to markets)	Cost/day (USD), and people (# or % of a population) who cannot afford that cost	For global food security monitoring, CoNA has been superseded by CoHD (cost/day) and AOHD (% or # of people). The FAO collectively refers to these metrics as COAHD.	Policy uses so far include SOFI 2020, 2021 and 2022, the UNFSS healthy diets coalition plus national initiatives in Nigeria, Pakistan and elsewhere; also, several recent academic articles on how this innovation works. The basic innovation is the use of least-cost diets to track food access, allowing for local substitution to meet international diet quality standards.	Innovative metrics to assess cost of and affordability of healthy diet	Population-level metric, not feasible for individual targeting; Evaluate if CoNA diet palatable	(Bai et al., 2021b)
	Least-costs foods in sufficient quantities to meet energy needs; whether local food environments provide physical and economic access to a healthy diet	Cost of caloric adequacy (CoCA)		Cost of foods, energy content of food	Surveys	Individuals						(Bai et al., 2021b)
	Least-costs foods in sufficient quantities to meet dietary guidelines; whether local food environments provide physical and economic access to a healthy diet	Cost of a healthy diet (CoHD)	New data on food availability and price, matched to item composition and dietary guidelines	Costs of foods, nutrition composition of food and adherence to dietary guidelines	Surveys	Individuals						(A. Herforth et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Adequacy of household income to acquire foods with adequate nutrients; whether local food environments provide physical and economic access to a healthy diet	Affordability of nutrients (CoNA/ available income)	CoNA, matched to income for affordability	As above for CONA; household total expenditure	Surveys	Individuals						(Bai et al., 2021b)
		Affordability of a healthy diet (CoHD/ available income)	CoHD, matched to income for affordability	Costs of foods, nutrition composition of food and adherence to dietary guidelines, household total expenditure	Surveys	Individuals						(Bai et al., 2021b)
	Financial burden of healthy diet	Relative cost of adequate fruits and vegetables	None	Costs of foods and recommended intake of foods	Surveys	National	Cost per person per day	Relative cost of adequate fruits and vegetables (ratio of the cost of the recommended amount of fruits and vegetables to the cost of the recommended amount of starchy staples per person per day)	Tracking	Informative for cost of healthy diets	Complicated methodology limits use in LMICs	(FAO, 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Relative cost of adequate legumes, nuts and seeds	None	Costs of foods and recommended intake of foods	Surveys	National	Cost per person per day	Relative cost of adequate legumes, nuts and seeds (ratio of the cost of the recommended amount of legumes, nuts and seeds to the cost of the recommended amount of starchy staples per person per day)	Tracking			(FAO, 2021)
		Relative cost of a healthy diet	None	Cost of foods and recommended intake of foods	Surveys	National	Cost per person per day	Relative cost of a healthy diet (ratio of the cost of a healthy diet to the cost of caloric adequacy)	Tracking			(FAO, 2021)

6. Promotion and advertising

Metrics for promotion and advertising are presented in Table 6. These are all metrics that evaluate the policy environment for promotion and advertising of different types of foods, including the tracking of food and nutrition labeling policies, food-based dietary guidelines, and school-based nutrition standards.

Overall strengths: Metrics in this area are all important to inform and assess concrete policy options to influence consumer behavior and minimal resources are required to collect the necessary data and information.

Overall weaknesses: The variation in types and severity of policies across different environments makes it difficult to establish metrics that can be used for cross-country comparisons.

Gaps, research priorities, and opportunities: Areas for future development include establishing universal definitions of appropriate labels, advertisements, and guidelines by which to define policy environment metrics. While universal definitions of healthy and unhealthy food may be possible to some extent, flexibility should be retained in the actual guidelines that could vary by context. However, metrics by which guidelines and policies are evaluated can be made more universal.

Table 6. Metrics for promotion and advertisement

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Food labeling and marketing	Policies for limiting advertising of unhealthy foods and harmful nutrients	Assessment of the food advertising policy environment	Consideration of the importance of science-policy interface for food systems transformation	Written policies	National policies and process documents; FAO National dietary guidelines tracker; FAO LEX database	National	Policy (Y/N)	Presence of policies limiting the advertising of unhealthy foods and harmful ingredients (e.g., sugar-sweetened beverages (SSB's), added sugars, sodium); Presence of policies limiting advertising of unhealthy foods to vulnerable groups (e.g., children)	Policy environment assessment	Important metrics to inform and assess concrete policy options to influence consumer behavior; simple to collect data with minimal resources	Definitions of unhealthy foods is not agreed upon; great variation in policy type and severity make cross-country comparison difficult	(Singh et al., 2021)
	Policies for limiting misleading food labeling claims	Assessment of misleading food labeling policies				National	Policy (Y/N)	Presence of policies limiting misleading food claims (e.g., health claims such as inappropriate foods advertised as healthy complementary foods, low sodium foods)				
	Policies requiring nutrition labeling	Assessment of nutrition labeling policies				National	Policy (Y/N)	Presence of policies promoting nutrition labeling				
	Promotion of healthy diets through national guidelines	Existence of food-based dietary guidelines		Written and published guidelines		National	Guidelines (Y/N)	Presence of food based dietary guideline				
		Assessment of the scientific merit of food based dietary guidelines		Documentation of process for developing guidelines		National	Guidelines based on scientific evidence (Y/N)	Guidelines based on latest scientific evidence (e.g., last 5 years)				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	School-based promotion of healthy diets	Assessment of nutrition standards for schools		Written and published policies		National	Policy (Y/N)	Presence of nutrition standards for schools (what can be sold, or distributed in schools, school feeding)				

7. Food quality and safety

Table 7 presents the metrics for the food quality and safety domain. Metrics in this area include those focusing on contamination of food and biomarkers for bacterial pathogens, parasites, viral pathogens, chemicals, toxins, community-wide metrics of contamination, microbial contamination of water, and regulation of food contaminants and adulterants.

Overall strengths: Metrics identified include several that focus on the identification of food contaminants and their biomarkers. The metrics proposed are objective and may be validated. Metrics for assessing community approaches and contamination of water are suggested, and this is informative for programs where community initiatives may play a critical role in addressing the problem. Finally, metrics for policy and regulation are suggested, as the implementation of policies to control contaminants and adulterants and monitoring their enforcement are often limited in LMICs.

Overall weaknesses: Most of the metrics for assessment of contaminants presented require laboratory equipment and are expensive. They also require significant training.

Gaps, research priorities, and opportunities: There have been limited studies conducted, as well as a lack of metrics to evaluate community-level approaches to control wastewater, surface water, or soil microbial or chemical contaminants. Additionally, there are limited metrics for the detection or quantification of multiple microbes. The development of new approaches and metrics in this area will be a significant contribution to this domain of food systems.

Table 7. Metrics for food quality and safety

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Contamination of food with bacterial pathogens (e.g., salmonella, e. Coli, listeria, campylobacter, vibrio)	Food contaminants as a source of disease	Detection (cell culture assays) or quantification (PCR)	None	Please see "variables" column	Food samples from surveys	Microscopic	CFUs (colony forming units)	Prevalence of contaminated food samples (percentage of positive samples)	Detection, quantification, risk assessment, tracking change, targeting, monitoring	Simple, easy to interpret; rapid tests available for some measures	Food is not the only source of these pathogens; water and environment also contribute. Also, people respond very differently to the same doses.	(Crépet et al., 2007; Schmelcher and Loessner, 2014)
Contamination of food with parasites (e.g., taenia solium, trichinella, giardia, cryptosporidium, toxoplasma)		Detection of parasites, eggs, cysts, or oocysts; detection of eggs in stool samples	None	Please see "variables" column	Food samples from surveys	Microscopic	Eggs, cysts, oocysts	Prevalence of contaminated food samples (percentage of positive samples)	Detection, quantification, risk assessment, tracking change, targeting, monitoring	Simple, easy to interpret	Food is not the only source of these pathogens; water and environment also contribute. Also, people respond very differently to the same doses.	(Koutsoumanis et al., 2018)
Contamination of food with viral pathogens (e.g., norovirus, hepatitis a virus)		Detection (cell culture assays) or quantification (PCR)	None	Please see "variables" column	Food samples from surveys	Microscopic	Viral particles	Prevalence of contaminated food samples (percentage of positive samples)	Detection, quantification, risk assessment, tracking change, targeting	Objective measure	Food is not the only source of exposure; norovirus is very easily transmitted via surfaces, shared environments, etc..; detection of viruses in food is harder	(O'Shea et al., 2019)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Contamination of food with chemicals and toxins (e.g., aflatoxin, fumonisin, don, arsenic, lead, mercury, cassava cyanide)		Detection and quantification of pure or methylated forms of these toxins	None	Please see "variables" column	Food samples from surveys	Microscopic	Concentration (e.g., mg/kg food)	Proportion of samples contaminated; concentration of contaminant	Detection, quantification, risk assessment, tracking change, targeting	Objective measure	Testing may be extremely expensive, not all detection methods are harmonized, not all biomarkers measure for effect as well as exposure.	(Żukowska and Biziuk, 2008)
Biomarkers of contamination with bacterial pathogens (e.g., salmonella, e. Coli, listeria, campylobacter, vibrio)	Biomarkers of food contaminants	Detection or quantification in stool samples (or blood if systemic infection)	None	Please see "variables" column	Stool or blood samples from surveys	Microscopic	CFUs (colony forming units)	Proportion of samples contaminated; concentration of contaminant	Detection, quantification, risk assessment, tracking change, targeting	Simple, easy to interpret	Testing may be expensive	(Schmelcher and Loessner, 2014)
Biomarkers of contamination with parasitic pathogens (e.g., taenia solium, trichinella, giardia, cryptosporidium, toxoplasma)		Detection of eggs in stool samples	None	Please see "variables" column	Stool samples from surveys	Microscopic	Eggs, cysts, oocysts	Proportion of samples contaminated	Detection, quantification, risk assessment, tracking change, targeting	Simple, easy to interpret	Testing may be expensive, not all biomarkers measure for effect as well as exposure.	(Rosado-García et al., 2017)
Biomarkers of contamination with viral pathogens (e.g., norovirus, hepatitis a virus)		Virus-specific Immunoglobulins e.g. IgM or IgG in blood (antibody tests), PCR of blood or stool	None	Please see "variables" column	Blood samples from surveys	Microscopic	Viral particles	Prevalence or incidence in population	Detection, quantification, risk assessment, tracking change, targeting	Simple, easy to interpret	Testing may be expensive, not all biomarkers measure for effect as well as exposure.	(Victor et al., 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Biomarkers of contamination of food with chemicals and toxins (e.g., aflatoxin, fumonisin, Deoxynivalenol (DON) (don), arsenic, lead, mercury, cassava cyanide)		Multiple different biomarkers (e.g., afm1 in urine, aflatoxin-albumin in blood, fumonisin B1 (UFB1), urinary DON (UDON), inorganic arsenic (iAs) or methylated forms in urine-blood-hair-nails, urinary thiocyanate)	None	Please see "variables" column	Biological samples (e.g., Urine and blood) samples from surveys	Microscopic	Urinary, blood, fecal, hair, or nail concentration (e.g., ng/ml)	Proportion of samples contaminated	Detection, quantification, risk assessment, tracking change, targeting	Body fluids or tissues capture concentration of parent toxins and metabolite from multiple sources, and thus potentially provides a better estimate of exposure	Testing may be extremely expensive, not all detection methods are harmonized, not all biomarkers measure for effect as well as exposure.	(P. C. Turner and Snyder, 2021)
Foodborne zoonoses	Food-borne diseases	Detected cases, possibly with multipliers applied for underreporting and underdiagnosis	None	Please see "scale" column	Blood samples form surveys	Individuals	Cases (per unit population)	Prevalence or incidence in population	Detection, quantification, risk assessment, tracking change, targeting	Objective measure	Underreporting, underdiagnosis, complicated methodology	(Zaidi et al., 2012)
Community-wide metrics of contamination	Community approaches	Waste water, surface water, or soil measurements of microbial or chemical contaminants	None	Please see "scale" column	Community surveys of water contamination	Community	Depends on medium, e.g., if water, mg/l, etc..	Measure above threshold (Y/N), prevalence /incidence in community	Detection, quantification, risk assessment, tracking change, targeting	Community approach may be more informative	Few studies have been conducted	(Jakubowski and Frumkin, 2010)
Microbial contamination of water	Contamination of water	Detection or quantification of multiple microbes	None	Please see "scale" column	Water samples from surveys	Community	CFUs, cysts, mg/l	Measure above threshold (Y/N), prevalence of contaminated water sources in community	Detection, quantification, risk assessment, tracking change, targeting	Simple, easy to interpret	Few studies have been conducted	(Ramirez-Machorro et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Regulation of food contaminants and adulterants	Policy and regulation	Existence of written regulations for thresholds for contaminants and adulterants (e.g., Microbial, viral, environmental)	None	Policy documents	Policy surveys	National	Policy	Written regulations (Y/N)	Regulating food contaminat ion levels	Simple, easy to interpret	Policy existence may not translate to implementation and monitoring	(Gahukar, 2014)

8. Consumer behavior

The metrics for desirability and personal preferences, systemic drivers of food choice, food preparation, waste, and food and nutrient preservation are shown in Table 8. The metrics are used to evaluate the individual and community-level drivers that inform individual food choices as well as the effects of exposure to advertising for unhealthy foods. The systemic drivers of food choice metrics encompass the underlying factors such as economic development, urbanization, and globalization that inform the availability of foods. Food waste metrics assess the factors that increase waste at the consumer level.

Overall strengths: The domain includes a comprehensive list of metrics measuring individual factors that influence food choices. This is an often-neglected area as programs and derived metrics in this area prioritize the external environmental factors as the most important drivers of consumption. Similarly, the importance of community factors and systemic drivers that often influence the food environment is also often underestimated or unmeasured. Finally, the inclusion of several food waste indicators highlights this important area that is a contributor to the low availability of perishable and other foods.

Overall weaknesses: The metrics for food waste indicate that there are inconsistencies in the measurement and data available in this area. Additionally, there is limited information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets, etc. in LMICs. The complexity around decision-making, for example, the interaction between food prices, affordability, socio-economic factors and the drivers of food choice is not considered in analyzing this area.

Gaps, research priorities, and opportunities: The gaps in the area of food waste can be addressed through the collection of additional data in LMICs. There is also a need for harmonized approaches, definitions, and simpler methodologies for field use for the collection of food waste data. Because of their overlap, there is also a need for combined assessment of food loss and waste within country assessments. Regarding drivers of food choice, there is limited information and knowledge available from LMICs, and metrics are required that can be applied across different ages and geographies. Additionally, most of the research is limited to urban areas, therefore there is a need for additional research in rural contexts.

Table 8. Metrics for consumer behavior

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Desirability and personal preferences	Individual and community level drivers of food choice	Socio-economic factors	None	Surveys	Surveys	Individual	Various or index	Socio-economic status (e.g., income, education, gender dynamics, age)	Assesses the role of demographic and socio-economic disparities in food choices	Easy to assess and interpret	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs	(Karanja et al., 2022)
		Psychological factors	None	Surveys	Surveys	Individual	Various or index	Psychological factors (food preferences, familiarity, aversions, appetite, palatability, habit)	Assesses the influence of psychological factors in food choices	Easy to assess and interpret	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs	
		Socio-cultural factors	None	Surveys	Surveys	Individual	Various or index	Socio-cultural factors (food traditions, cultures, gender dynamics, food taboos, religion, beliefs)	Assesses the influence of socio-cultural factors as drivers of food choices	Consistent research on topic in rural areas	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs	
		Sensory	None	Surveys	Surveys	Individual	Various or index	Sensory (taste, color, smell, texture)	Assesses the influence of sensory factors as drivers of food choices	Easy to assess and interpret	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Health and nutrition perceptions	None	Surveys	Surveys	Individual	Various or index	Health and nutrition perceptions (perceived health benefits, impact on body weight, nutrition composition)	Assesses the influence of health and nutrition perceptions on food choices	Easy to assess and interpret	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs	
		Convenience	None	Surveys	Surveys	Individual	Various or index	Convenience (cooking time, travel time and distance)	Assesses convenience as a factor influencing food choices	Easy to assess and interpret	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs	
		Social interactions	None	Surveys	Surveys	Individual	Various or index	Social interactions (community, peer, child, parent influence)	Assesses the influence of social interactions as drivers of food choices		Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs; not easy to assess	
		Food affordability	See food availability and access section	See food availability and access section	Surveys	See food availability and access section	See food availability and access section	Food affordability	Assesses the influence of food affordability as a driver of food choices	Metrics are validated	Little information on the influence of drivers on specific food groups e.g., fruits and vegetables, unhealthy foods, not overall diets etc. in LMICs; complex methodology	See food availability and access section

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Influence of exposure to advertising on consumption behaviors	Assessment of exposure to advertising for unhealthy foods	Consideration of advertising environment	Exposure to advertisement of unhealthy foods	Surveys	Household	Number	Number advertisements of unhealthy food in specified time period (radio, tv, billboards, social media)	Assesses the influence of advertising on consumption of unhealthy foods	Easy to assess and interpret	Limited studies in LMICs	(Buijzen et al., 2008; J. L. Harris et al., 2009; Zimmerman and Shimoga, 2014)
		Assessment of exposure to advertising for healthy foods	Consideration of advertising environment	Exposure to advertisement of healthy foods	Surveys	Household	Number	Number advertisements of healthy food in specified time period (radio, tv, billboards, social media)	Assesses the influence of food affordability as a driver of food consumption	Easy to assess and interpret	Limited studies in LMICs	(Buijzen et al., 2008)
Systemic drivers of food choice	Food preferences shift as countries become richer	Economic development	None	GDP	World Bank database	National	GDP per capita	Growth rate of GDP per capita	Increasing income as a possible influencer of consumption	Allows cross country comparisons	Does not consider the interplay of key drivers of food demand, supply and prices	(Buijzen et al., 2008; Burggraf et al., 2015; Fukase and Martin, 2020)
	Influence of globalization on access and availability of food	Level of globalization	None	Level of global market integration (e.g., Tariffs)	Organization for economic cooperation and development (OECD), FAOSTAT	National	Index	Globalization index (e.g., KOF index, OECD measure of protection)	Evaluate the extent of globalization as a possible factor in food availability and utilization	Allows cross country and regional comparisons	Lagged effect may be expected in effects of globalization on nutrition; effects of social globalization have to also be considered; complicated methodology	(Costa-Font and Mas, 2016)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Research and development influence on availability and cost of foods	RandD in the food production and processing sector	None	R and d expenditure	Organization for economic cooperation and development (OECD); world bank; UNESCO institute for statistics	National	Per capita expenditure (dollars per capita)	Annual per capita expenditure in r and d in food production and processing; intensity ratio (IR)—the percentage of agricultural gross domestic product invested in agricultural RandD	Estimates the benefits of increasing research and development in food production and processing on food availability and cost	Allows cross country and regional comparisons	Lagged response to increase in research and development; affected by market size and population size (annual per capita expenditure in research and development)	(Nin-Pratt, 2021)
	Urbanization as driver of consumer access to healthy and unhealthy foods	Urbanization	None	Population growth	Surveys	National	% Change	Change in % of population in urban areas	Can be used to estimate how change in urbanization can influence access to healthy or unhealthy foods	Allows cross country or regional comparisons	Does not provide additional information on the interaction with socio-economic status and access to food	(Fox et al., 2019; Hawkes et al., 2017; Karanja et al., 2022)
	National policy to promote increased consumption of healthy foods and decrease consumption of unhealthy foods	Assessment of taxes and subsidies to discourage consumption of unhealthy foods and promote the consumption of healthy foods	None	Written policies	Surveys	National	Policy (Y/N)	Presence of taxes to discourage consumption of unhealthy foods; pass through rates to consumer (how much tax affects what consumer actually pays); presence of subsidies to encourage consumption of healthy foods	Assess the presence of tax and other policies to increase consumption of healthy foods or decrease consumption of unhealthy foods	Easy to assess	Presence of policy does not indicate implementation of policy	(Thow et al., 2018)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Food preparation and waste	Recycling food waste to minimize environment impact of food consumption	Percentage of food waste recycled	Measures minimization of environmental effects of food waste	Total food waste, total food waste recycled	Surveys	National	%	Percentage of the total food waste that is recycled to recover resources and/or to minimize negative environmental effects of the waste	Determine trends in recycling of food waste	Informative for decreasing effects of food waste on environment	Limited by lack of data	(Melesse et al., 2020; Thi et al., 2015)
	Reducing food waste increases availability of food, enhances sustainability, may increase access for poorer populations; tracking food waste over time by country to monitor progress towards food waste goals	Food waste index (developed by UNEP as a sustainable development goal indicator)	Systematic approach to estimating food waste at a national level enabling cross-country comparisons; globally relevant to SDG's, relatively new metric using a more structured approach	Food and inedible components wasted at retail and consumer levels. Three different levels exist depending on data availability and resources with levels 2 and 3 involving primary data collection/direct measurement of waste.	Surveys	National; Depends on collection of disaggregated data, sector by sector, at retail, food service and household levels over a timeframe with a recommended period spanning 12 months.	Index	Food waste index (measures food waste at the retail and consumer level (households and foodservice) for each country)	Tracking change in levels of retail and consumer food waste over time	Food waste index estimate consumer food waste excluding nonfood uses and enable tracking of this.	Depends on level; level 2 is sufficiently accurate for tracking; level 3 supports development of food waste prevention strategy as it can be disaggregated; complex methodology and limited data in some contexts	(UNEP, 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Reducing food waste increases availability of food, enhances sustainability, may increase access for poorer populations	Estimate of household-level food waste	Innovative approaches may be possible as part of data collection such as photos, diaries, few studies have asked for the reasons behind why food is thrown away, which may be a novel component even if not required for purposes of tracking food waste for this indicator. Globally relevant to SDG's, relatively new metric.	Household income and expenditure surveys on purchases, census data for population number and type of household, waste collection company data (where applicable to estimate waste). Surveys may also be used to understand how income, gender, other factors influence food use, waste, consumption etc.	Surveys	National	Kg per capita per year	Household per capita food waste	Tracking change in levels of household food waste over time	Informative metric for assessing household level food waste, allows cross country comparisons	Multiple reviews have noted the paucity of data on food waste from LMICs; limited data to check for trends over time; complex methodology	(Thi et al., 2015)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Reducing food waste increases availability of food, enhances sustainability, may increase access for poorer populations	The food loss and waste protocol by World Resources Institute (WRI)	Standardized method of quantitative data collection for countries, identifying where to focus in reducing food waste	Food loss and waste protocol	Surveys	National	Food loss and waste standard	Food loss and waste standard	Global standard that guides quantifying and reporting food loss and waste, clarifies reporting of weight of food and inedible parts that excluded from the food supply chain	Methodology provides additional guidance on how to quantify and report food waste and loss; allows for standardizing approaches	Limited availability of data from LMICs	(UNEP, 2021)
	Food waste index at retail level	See above. Innovative approaches might be possible within data collection (such as scanning systems or smart bins to provide data on composition of waste)	Globally relevant to SDG's, relatively new metric	Data may be collected through records of discards or through actual measurement of discards. Challenges exist to sorting out/separating different types of food if that is desired it may need to involve separate record keeping or sampling approaches for sorted samples.	Surveys	Samples taken over a specified period at the retail level of interest; may involve stratified sampling of different types of retailers.	Often expressed as a %.	% Wasted in total (calculated as weight in kg wasted/total received)	Can be used for tracking change on food wasted, for estimating amount of food waste	Can be useful tracking differences in waste by food group at retail level	Small samples; uncertain generalizability of samples from a small number of retailers to the larger food system.	(Whitacre et al., 2019)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Food and nutrient preservation	Conditions which can promote saprophytes	Household level measures of safe preparation and storage of food	Food preparation approach (cooking time)	Time (minutes)	Surveys	Household	Y/N	Appropriate preparation for type of food (Y/N)	Tracking prevalence of recommended practices (hygiene) for household food preparation to prevent contamination and food waste	Simple measure	Not very specific	(Lagerkvist et al., 2021)
	Conditions which can promote saprophytes		Food preparation approach (e.g., Food covered and not left to stand at room temp)	Y/N	Surveys	Household	%	% of households that cover food	Tracking prevalence of recommended practices (time) for household food preparation to prevent contamination to prevent food waste	Simple measure	Not very specific	(Lagerkvist et al., 2021)

9. Diets, nutrition, and food security

Metrics for diets, nutrition, and food security presented in Table 9 focus on the areas of food security, quantity, quality, and diversity of diets, biofortification, and approaches for evaluating food consumption and diets.

Overall strengths: This table presents a wide array of metrics for assessing diets, particularly the quality and diversity of diets. One strength of the diet quality metrics is that some have been validated for micronutrient intake, and assess the consumption of unhealthy foods that are associated with non-communicable diseases (NCDs), e.g., diabetes, heart disease, stroke and cancer. Additionally, the diet diversity indices are validated for micronutrient adequacy and are simple and easy to use.

Overall weaknesses: The main weaknesses of the metrics considered include that diet quality metrics require field validation (DQQ, GDQS) in different contexts. The promising diet quality metrics (e.g., GDQS) require expertise and are cumbersome to compute, limiting their potential for adoption. The diet diversity indicators only consider one dimension of diet quality, which is nutrient adequacy, and have limited utility in the context of dietary transition and increasing consumption of unhealthy diets.

Gaps, research priorities, and opportunities: Further validation is required for diet quality indices in various contexts, including for associations with poor nutrition and health outcomes. There is also a need for field-friendly and innovative approaches for the food frequency questionnaire and 24-hour recall tools. Clarity on which tool and metric, what each measure and appropriate use is needed. There are different metrics for different needs e.g., dietary diversity scores where micronutrient intake and undernutrition are the main challenges, and overall diet quality scores where the risk of unhealthy diets is also high. There is a gap in validated dietary metrics for different age groups (adolescents, children and pregnant women). Finally, there is a need for metrics to assess the consumption of ultra-processed foods and consumption of fruits and vegetables.

Table 9. Metrics for diets, nutrition and food security

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Food security	Coping strategies during periods of food insecurity	Experiential food security measurement	None	Household food insecurity (questionnaire)	Surveys	Household	Scale	Household food insecurity access scale (HFIAS)/ Food Insecurity Experience Scale (FIES)	Developed to assess the impacts of development food aid programs on the *access* component of household food insecurity	Simple and user-friendly approach for measuring the construct of food security; captures households' behavioral and psychological manifestations including anxiety and uncertainty due to insecure food access; assesses population level household food insecurity and changes in food insecurity over time; applicable in both rural and urban areas and other contexts	Only assesses the access component of household food insecurity; some questions do not meet psychometric criteria for cultural invariance and may not be useful for diverse socio-cultural countries and contexts	(FAO, 2021; Hussein et al., 2018)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Coping strategies during periods of food insecurity	Experiential food security measurement	None	Perceived household food insecurity (questionnaire)	Surveys	Household	Scale	Household hunger scale	Includes only 3 hunger-related and most severe aspects of insecure food access, which are culturally invariant in multiple contexts	Assesses prevalence of hunger over time and across multicultural contexts/ countries	Requires further validation	(Ballard et al., 2011; Maxwell et al., 2020)
	Assess access to healthy diet	Cost of a healthy diet	See cost of a healthy diet in food availability and access tab	See cost of a healthy diet in food availability and access tab	Surveys	National	Cost of healthy diet (see cost of healthy diet metrics) and income	% of people who cannot afford a healthy diet	Assess affordability of healthy diet	Data available for cross country comparisons of access to healthy diets	Complex methodology and limited data availability may make it difficult to assess at regional level	See cost of a healthy diet in food availability and access tab
Quantity	Sufficiency of caloric intake for daily activities	Daily per capita energy supply (domestic production + imports - exports per capita)	None	National food balances, population data (census), and household consumption (household surveys)	Surveys	Country	Kcal/person/ day	Prevalence of undernourishment (POU) (percentage of population below minimum energy requirements)	Assess the prevalence of undernourishment, SDG indicator	Useful metric for assessing undernourishment and allows for cross-country and year to year comparisons	Complex methodology; caloric intake alone provides insufficient information on the availability of healthy foods; data is at national level often, insufficient data for disaggregation e.g., by gender, and geographic regions within countries	(Cafiero, 2014; Food and Agriculture Organization of the United Nations, 2022)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Sufficiency of caloric intake for growth and development	Meal frequency as a proxy for caloric intake	None	Questionnaire	Surveys	Individual	Minimum meal frequency for children	Minimum meal frequency for children	Assesses age-appropriate meal frequency for children as a proxy for sufficient caloric intake	Easy data collection and interpretation; indicator available for both breastfed and non-breastfed children	Does not provide quantitative information on quality of foods fed to children	(United Nations Children's Fund (UNICEF), 2020; World Health Organization (WHO) and United Nations Children's Fund (UNICEF), 2021)
Quality and diversity	Quality diets protect against micronutrient deficiencies, undernutrition and risk of diet-related chronic diseases	Overall diet quality index that assesses adequacy, variety/diversity, moderation in consumption of unhealthy foods	Penalizes for consumption of unhealthy foods (promotes higher consumption of foods that are healthy and moderation/ low consumption of unhealthy foods); validated for associations with diet related chronic diseases	FFQ derived quantity consumed of specific foods and food groups	Surveys	Individual	Score	Prime diet quality score (PDQS)	Classification of populations based on quality of diets consumed	Index has utility for assessing overall quality of diets for both men and women (micronutrient deficiency, consumption of unhealthy foods)	Based on FFQ, a tool that's not commonly used in dietary assessment in LMICs; validation has mostly been in us populations. A few studies have utilized or validated the PDQS in LMIC contexts; population-based metric and cannot be used for individual assessment.	(Fung et al., 2018; Gicevic et al., 2018; Madzorera et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			Globally validated score, penalizes for consumption of unhealthy foods (promotes higher consumption of foods that are healthy and moderation/ low consumption of unhealthy foods); validated for associations with diet related chronic diseases	24 hr. recall of dietary intake for specific foods and food groups (and amounts)	Surveys	Individual	Score	Global diet quality score (GDQS), GDQS+ and GDQS-	Classification of populations based on quality of diets consumed	Validated in a number of LMICs; uses 24-hour dietary recall data that is more widely available; scores for consumption of healthy (mean GDQS+) and unhealthy foods (mean GDQS–) considered independently; classification of risk of micronutrient deficiency and NCDs provided with binary indicators(GDQS ≥23 - low risk of nutrient inadequacy and NCD-related outcomes, scores ≥15 and <23 indicate moderate risk, and scores <15 indicate high risk)	Shows promise for adoption as a global dietary metric if further validation is conducted. However, data collection and interpretation still require technical expertise, which may decrease utility for use in projects; based on 24hr recall and requires quantities consumed for scoring; further, it's a population-based metric and cannot be used for individual assessment.	(Bromage et al., 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			Penalizes for consumption of unhealthy foods (promotes moderation/low consumption of unhealthy foods and rewards consumption of healthy foods)	Consumption of specific food groups (yes/no)	Surveys	Individual	Score	Diet quality questionnaire (DQQ)	Classification of populations based on quality of diets consumed	Country adopted questionnaires with lists of foods available; easy and quick data collection	No "field validation" yet; does not assess quantity of foods	(A. Herforth et al., 2019)
			Recommends portion sizes and frequency of consumption for food groups; includes cap for total energy intake from sugars	Frequency and number of foods consumed (24-hour recall, FFQ, etc..)	Surveys	Individual	Score	WHO Healthy Diet	Classification of populations based on quality of diets consumed	Provides recommendations to address malnutrition in all its forms, including for the prevention of noncommunicable diseases (NCDs), e.g., diabetes, heart disease, stroke and cancer.	Provides specific guidelines and recommendations for consumption of select healthy and unhealthy food groups and nutrients, however, how to operationalize the recommendations is not clear. Not a clear metric for evaluation of diet quality	(Kanauchi and Kanauchi, 2018)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			Benchmarked against chronic diseases	Frequency and number of foods consumed (FFQ, 24-hour recall, etc..)	Surveys	Individual	Score	Diet quality indices e.g., Healthy eating index (HEI), alternative healthy eating index (HEI) Mediterranean diet score	Classification of populations based on quality of diets consumed	Based on dietary recommendations (HEI-2015) and measures the quality of diets while accounting for energy intake (HEI-2015); associations with diet-related NCDs have been shown.	Validated in high-income contexts; based on United States dietary guidelines or traditional eating patterns of populations in southern Europe (Mediterranean diet); requires 24h recall or FFQ data and quantities consumed; population-level indicators, not used for individual assessment	(Melesse et al., 2020; Rumawas et al., 2009; USDA, 2022)
	Diverse diets increase the likelihood of meeting micronutrient requirements (micronutrient adequacy)	Diet diversity scores	Specifically validated for micronutrient requirements for women of reproductive age	24 hr. recall derived quantity consumed of specific foods and food groups	Surveys	Individual	Score	Minimum dietary diversity score for women (MDDW). (5+ food groups or ordinal)	Classification of population (women) based on diversity of diets consumed and risk of inadequate micronutrient intake	Diet diversity indices have greater potential for use in LMICs compared to diet quality scores currently, due to easier data collection approaches and interpretation.	Assesses one dimension of diet quality (nutrient adequacy), and therefore may have less utility in the context of dietary transition, increasing consumption of unhealthy foods, and the rising prevalence of diet-related chronic	(Arimond et al., 2010; Madzorera et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
											diseases; validation based on 24h recall data and mostly limited to non-pregnant women (15-45 years); binary indicator for minimum dietary diversity (at least 5 of the 10 food groups in 24-hour) may have limited utility in projects especially when low diversity diets are consumed; consumption of 5 or more foods does not mean that micronutrient adequacy is reached e.g., if quantities consumed are small; limited guidance on interpretation of ordinal score is a limitation.	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			None	Number of different foods consumed	Surveys	Individual	Score	Food variety score, global dietary recommendations (GDR) score, others	Assessment of the diversity of diets as proxy for micronutrient adequacy (FVS); assess consumption of healthy diets based on 5 global recommendations on nutritious foods for healthy diets (GDR)	FVS: has been associated with micronutrient adequacy, simple and easy to assessment in field conditions	No standard definition: interpretation of scores and cut-offs are not well established	(A. W. Herforth et al., 2020; Melesse et al., 2020; Steyn et al., 2006)
			None	Consumption of specific food groups (yes/no)	Surveys	Individual	Score	Minimum dietary diversity for young children (MDD age 6-23 months)	Assessment of the diversity of diets as proxy for micronutrient adequacy	Easy data collection and interpretation; validated for micronutrient deficiencies	Assesses one dimension of diet quality-nutrient adequacy, therefore may have less utility in the context of dietary transition and increasing consumption of unhealthy foods; various versions of metrics are proposed in the literature, although more recent work uses the UNICEF/WHO indicator	(United Nations Children's Fund (UNICEF), 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			Proxy indicator of household caloric availability	Frequency of household consumption of food groups	Surveys	Household	Score	Food consumption score	Assessment of food consumption as a proxy for household caloric availability and food quality at the household level	Assesses dietary diversity, frequency of food group consumption and the nutritional value of the food groups	Only validated against household energy availability and per capita household food and energy consumption; not validated for quality of diets; cut-offs proposed are arbitrary	(Leroy et al., 2015)
			None	Consumption of specific food groups (yes/no)	Surveys	Individual	Score	Individual/women dietary diversity score (IDDS/WDDS); household dietary diversity score (HDDS)	WDDS/IDDS assesses the diversity of women's and individual diets as a proxy for adequacy of micronutrient intake	WDDS validated for adequacy of micronutrients in the diet of women of reproductive age	WDDS has been validated against mean probability of adequacy (MPA) of nutrients; IDDS has not	(Leroy et al., 2015)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			None	Consumption of specific food groups (yes/no); frequency of feeding	Surveys	Individual	Y/N	Minimum acceptable diet (MAD) for young children	Assesses overall quality of child diets	Combines diversity and frequency; easy to measure and interpret; allows cross country comparisons	Indicator does not quantitative information about children's food and nutrient intake; does not capture excessive consumption of nutrients (e.g., energy, sugar, or fat) and unhealthy foods	(United Nations Children's Fund (UNICEF), 2020; World Health Organizatio n (WHO) and United Nations Children's Fund (UNICEF), 2021)
			None	Consumption of fruits and vegetables (yes/no); frequency of feeding	Surveys	Individual	Y/N	Prevalence of infants (6-23 months) consuming zero fruits and vegetables	Evaluates the consumption of fruits and vegetables by young children	Easy to assess and interpret	This yes or no indicator does not consider optimal consumption of animal source foods	
			None	Consumption of fish, meat, and eggs (yes/no); frequency of feeding	Surveys	Individual	Y/N	Prevalence of infants (6-23 months) consuming zero fish, meat or eggs	Evaluates the consumption of animal source foods by young children	Easy to assess and interpret	This yes or no indicator does not consider optimal consumption of fruits and vegetables	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
			None	Household consumption (yes/no) of food groups	Surveys	Household	Score	Household diet diversity score (HDDS)	HDDS: an indicator of the food access dimension of household food security	Easy to assess and interpret	Has only been validated against household energy availability; does not provide information on intra-household allocation and individual intake	(Swindale and Bilinksy, 2006; Vellema et al., 2016)
		Consumption of healthy and unhealthy food groups	None	Frequency and number of foods consumed (24-hour recall, FFQ, etc..)	Surveys	Individual	Score	Fruit and vegetable consumption	Evaluates the consumption of fruits and vegetables	Easy to assess and interpret	No standard definition	(Melesse et al., 2020)
			None	Frequency and number of foods consumed (24-hour recall, FFQ, etc..)	Surveys	Individual	Score	Consumption of ultra-processed foods	Evaluates the consumption of ultra-processed foods	Easy to assess and interpret	No standard definition	(Melesse et al., 2020)
	Nutrient-rich diets protect against micronutrient deficiencies, undernutrition and risk of diet-related chronic diseases	Assessment of nutrient composition of specific foods	Ranking of foods based on nutrient composition	Nutrient content in food (calculated separately for desirable and undesirable nutrients)	Surveys	Foods	Score	Nutrient rich food (NRF) index	Ranking of foods based on nutrient density (9 healthy nutrients to encourage and 3 unhealthy nutrients to limit)	Considers both healthy and unhealthy nutrients	Complex methodology limits adoption; validated using US dietary guidelines and requires validation in LMICs; only considers a limited group of nutrients	(Drewnowski et al., 2019; Fulgoni et al., 2009; Melesse et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Population level assessment of availability of nutrients	None	Food balance sheets and food composition tables	Surveys	Individual	Proportion	Population share with adequate nutrients	Metric estimates the proportion of the population consuming key nutrients at an adequate level	Based on estimated intake within population group	No standard definition; requires validation; if population level intake is low metric may lead to underestimation of nutrient gap	(Gustafson et al., 2016; Melesse et al., 2020)
		Assessment of probability of nutrient adequacy of different diets	None	Quantitative 24h dietary recall; micronutrient intake compared to dietary recommendation	Surveys	Individual	Probability; Y/N (does it meet a cutoff)	Mean probability of adequacy (MPA)	Assesses likelihood of meeting nutrient requirements	Considers nutrient density, defined as nutrients per calorie,	Complex methodology, difficult to adopt in field settings	(Arimond et al., 2010; Joseph and Carriquiry, 2010; G. Kennedy et al., 2011; Melesse et al., 2020; Zaki et al., 2015)
Biofortification metrics	Biofortified foods may increase likelihood of meeting nutrient requirements	Micronutrient content of biofortified food	Contribution of biofortified foods to micronutrient intake	Lab measurements (micronutrient content)	Surveys	Individual biofortified foods	Nutrient content (e.g., Micrograms of nutrient/kg)	Nutrient content	Assesses likelihood of meeting nutrient requirements	Considers micronutrient content of biofortified foods	Cost limitations of assessing micronutrient levels may limit adoption	(Bouis and Saltzman, 2017; De Moura et al., 2015)
	Consumption of biofortified foods may increase likelihood of meeting nutrient requirements	Assessment of consumption of micronutrient biofortified crops	None	Frequency of consumption of biofortified foods	Surveys	Individual biofortified foods	Frequency of consumption	Prevalence of consumption of biofortified foods	Assess utilization/consumption of biofortified foods/crops	Easy to assess and interpret	Does not provide information of levels of nutrient consumed by individual	(Petry et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Approaches	Novel approaches needed for dietary data collection and assessment	Novel approaches needed for dietary data collection and assessment	No	Frequency of consuming specific foods (+ possibly quantity)	Surveys	Individual	See column on "derived metrics"	Food frequency questionnaire	Assess usual intake of foods/nutrients	Easy to administer, assessment tools increasing available (tablets etc..)	Underutilized in LMICs, may miss foods if not locally validated and subject to recall error with longer periods of recall; usually underestimates caloric intake; may not capture seasonality	(Cade et al., 2002; Hu et al., 1999; Subar et al., 2001; W. C. Willett et al., 1987)
			Innovation in assessment including use of photos, tablets, ai	Quantity of all foods and drinks consumed in the past 24h	Surveys	Individual	See column on "derived metrics"	24-hour recall	Assesses recent intake	Assessment tools increasing available (tablets, ai, etc..); low respondent burden; list method approaches possible	Demanding method but increasingly used in LMICs; often misused as tool for assessing usual intake; requires several recalls to estimate usual intake; does not capture seasonality	(Eck et al., 1996; Freedman et al., 2017; Yuan et al., 2018)
			Innovation in assessment including use of photos, tablets, AI	Quantity of all foods and drinks consumed in the past 24h	Surveys	Individual	See column on "derived metrics"	Food diary/ diet record	Assesses dietary intake	Gold standard	Non-literate populations may not be able to use it; high respondent burden; expensive; requires several days of intake	(MacIntyre et al., 2001)

10. Nutrition and health outcomes

Nutrition and health outcome metrics are displayed in Table 10. These are mainly comprised of well-known metrics meant to measure how food systems contribute to maternal and child nutrition, non-communicable diseases, micronutrient status, and motor and cognitive development among children.

Overall strengths: For the most part, these are well-established metrics that are widely used in literature and are accepted as the appropriate metrics for determining nutritional, health, and neurocognitive outcomes.

Overall weaknesses: The major weakness of the metrics presented in this area is that they are not specific enough to truly evaluate the function of food systems in relation to nutrition, health, and neurocognition. All the metrics presented are influenced by a multitude of factors, many within the food system, but also including many within the environmental or behavioral systems.

Gaps, research priorities, and opportunities: Opportunities for continued development of these metrics lie in further determining how to properly tease out the effects of food systems on nutrition, health, and neurocognitive outcomes, or in finding metrics that appropriately measure these outcomes but that can only reasonably be attributed to food systems-specific factors.

Table 10. Metrics for nutrition, health, and neurocognitive outcomes

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Nutritional status	Food systems as a contributing factor to maternal and child malnutrition	Growth velocity (linear and ponderal)	Use of repeated measure/longitudinal approach, trajectory analysis, velocity Z score	Height, weight, age, sex	Household surveys	Individual	cm per unit time, kg per unit time	Absolute growth velocity; velocity Z scores	Impact evaluation	Longitudinal measure; can be used to identify sensitive periods for growth; timely indicator of growth-limiting conditions; suitable for making inferences about individuals within a population; useful for understanding child growth process in relation to the environment	Longitudinal data collection of Heights and weights may be resource intensive and lack feasibility; lack of specificity in evaluating food systems function	(Cliffer et al., 2021)
		Stunting	Phone image capture for heights and weights	Height, age, sex	Household surveys; DHS; FAOSTAT	Regional/ National	Height-for-age	Prevalence of stunting	Impact evaluation; tracking change over time	Widely used and accepted in literature; use of technology may greatly facilitate data collection and accuracy	Lack of specificity in evaluating food systems function	(Melesse et al., 2020)
		Wasting	Phone image capture for heights and weights	Height, weight, sex, MUAC			Weight-for-Height, Mid Upper Arm Circumference (MUAC)	Prevalence of Wasting				
		Underweight	Phone image capture for heights and weights	Height, weight, sex			Weight-for-age	Prevalence of Underweight				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Head Circumference	None	Head circumference			Head circumference-for-age	Prevalence of head circumference <-2SD		Widely used and accepted in literature; can serve as a proxy measure for cognitive function for infants and is an important indicator of infant health		(Harris, 2015)
		Underweight in adults	None	Height, weight	Household surveys; DHS; LSMS		BMI (kg/m^2)	Prevalence of maternal/ paternal underweight		Widely used and accepted in literature		(Melesse et al., 2020)
		Overweight/Obesity	Phone image capture for Heights and weights	Height, weight, sex			Children: BMI for age and sex (kg/m^2); adults BMI (kg/ m^2)	Prevalence of overweight/obesity		Widely used and accepted in literature; use of technology may greatly facilitate data collection and accuracy		
		Low birth weight	None	Birthweight	Household surveys; DHS; FAOSTAT		Birthweight (grams)	Prevalence of low birth weight		Widely used and accepted in literature; early indicators associated with life-long complications		(Christian et al., 2013)
		Small for gestational age	None	Birthweight, gestational age	Household surveys; hospital records		Birth weight less than the 10th percentile for gestational age and sex	Prevalence of small for gestational age				
		Preterm birth	None	Gestational age at birth			Gestational age <37 weeks	Prevalence of preterm birth				

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Adiposity	Field friendly measures (e.g., Bioimpedance vector analysis (BIVA))	Examples: DEXA; Bioimpedance measurements; Stable isotope (deuterium oxide dilution method)	Household surveys	Individual	Lean mass, total body fat	Lean mass, fat mass proportions	Impact evaluation	Much more specific and sensitive measure of body composition than BMI; field friendly measures allow for feasible assessment		(Branca et al., 2019)
Non-communicable diseases (NCDs)	Food systems as a contributing factor for non-communicable diseases (NCDs)	Hypertension	None	Blood pressure (mmHg)	Household surveys; hospital records	Regional/ National	Blood pressure (mmHg)	Prevalence of hypertension (adults and adolescents)	Impact evaluation; tracking change over time	Food systems are an important contributing factor to the nutrition transition and NCDs thus measurement is important	Data availability lacking in low- and middle-income countries; Lack of specificity in evaluating food systems function	
		Diabetes	None	Blood glucose			Blood glucose (mmol/L)	Prevalence of diabetes (adults and adolescents)				
		Coronary Heart Disease	None	Cholesterol, triglycerides, stress test, EKG, MRI etc.			cholesterol, triglycerides, stress test, EKG, MRI etc.	Prevalence of coronary heart disease (CHD)				
Micronutrient	Micronutrient assessment	Plasma zinc assessment	Dietary consumption estimates	Plasma zinc	Household surveys		zinc (µg/dl)	Zinc deficiency		Highly prevalent micronutrient deficiency with wide-ranging health consequences including immunity and growth; dietary consumption estimates are non-invasive and feasible	Lack of reliable measurement techniques; lack of specificity in evaluating food systems function	(Béné et al., 2019; Miller and Welch, 2013)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Iron status/Anemia	Hemoglobin measurement using skin conductance (Masimo); proxy for dietary consumption estimates	Hemoglobin (g/dL), Ferritin (µg/L)	Household surveys; Demographic Health Service (DHS); FAOSTAT		Hemoglobin (g/dL), Ferritin (µg/L)	Prevalence of anemia and iron deficiency anemia in women, adolescents and children		Widely used and accepted in literature; relatively simple to measure; one of the leading causes of death among certain sub-populations	Anemia can be caused by many factors, not only iron deficiency; lack of specificity in evaluating food systems function	
		Vitamin A status	None	Serum retinol concentration	Household surveys		Serum retinol µmol/L	Prevalence of vitamin A status		Highly prevalent micronutrient deficiency with wide-ranging health consequences and mortality	Either has to be estimated through dietary intake or assessed using invasive and costly blood draws; lack of specificity in evaluating food systems function	
		Iodine status	None	Urinary Iodine, µg/L			Urinary Iodine, µg/L	Prevalence of iodine deficiency		Common micronutrient deficiency associated with functional and developmental abnormalities	Lack of specificity in evaluating food systems function	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Motor and Cognitive Development	Motor and cognitive development assessment	Attention, visual-motor and motor measures	Eye tracking	Fine motor skills, verbal ability, attention, impulsivity, reaction time	Household surveys	Individual	Index or score	Beery visual motor integration (VMI) test, Bruininks-Oseretsky test of motor proficiency, Movement assessment battery for children MABC-2, Test of variables of attention, Eye tracking	Impact evaluation	Eye tracking data is objective, non-invasive, and can be used in young infants and is feasible in low- and middle-income settings; motor integration and movement assessment batteries are cost-efficient	Lack of specificity in evaluating food systems function; eye-tracking can be expensive	(Hessels and Hooge, 2019; Semrud-Clikeman et al., 2017)
		Comprehensive neurodevelopmental measures	None	Cognitive development			Index or score	Raven's scores, Bayley scale of infant development, caregiver-reported early childhood development (ECD) scale, UNICEF's Early Childhood Development Index, Early Development Index for school-aged children, Cambridge Neuropsychological testing automated battery (CANTAB), Griffiths mental development scales)		Low cost and non-invasive; widely used and applied in literature; some tests have been validated in low- and middle-income settings	Not all tests may be appropriate or validated for use in low- and middle-income countries; lack of specificity in evaluating food systems function	(McCoy et al., 2017)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Screening tests	None	Risk of experiencing developmental differences			Index or score	Ages and stages questionnaire, Strength and difficulties questionnaire, Developmental milestones checklist				(Semrud-Clikeman et al., 2017)

11. Gut function

Table 11 shows the gut function domain and incorporates metrics for intestinal damage, permeability, microbial translocation, inflammation (EED), and the microbiome.

Overall strengths: The table presents a suite of newer metrics to evaluate gut function such as the Multiplex assays (e.g., MEEDAT). Although the cost of the MEEDAT is still high, the metric still represents reduced costs per data point.

Overall weaknesses: Many of these metrics require specialized technologies generally not available in LMICs such as imagers and software. It was found that the MEEDAT utility is only as good as the individual markers that make it up. Thus far, MEEDAT's EED biomarkers are not associated with linear growth. Blood stool biomarkers are still invasive, logistically challenging and assess only a singular functional domain of EED. Many of the metrics included are non-specific in nature, and their correlation with EED symptoms and growth outcomes is inconsistent in the literature. ELISA kits are also generally not available in LMICs.

Gaps, research priorities, and opportunities: Further work is needed to validate the metrics for EED, particularly MEEDAT with regards to child growth and other nutrition and health outcomes. Further development of screening and diagnostic metrics is also warranted, particularly to develop field-friendly data collection strategies, more sensitive and specific biomarkers, and less invasive and inexpensive metrics that can be adopted and used in LMICs.

Table 11. Metrics for gut function

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Gut dysfunction	Intestinal damage/repair	Small bowel biopsy	Less invasive methods of small bowel biopsy currently being developed	Please see "innovations in measurement and metrics" column	Biopsies from surveys	Individual	Blunting of the villi, crypt depth, surface area, cellular infiltrate, epithelial monolayer fragility/breaks, tight junction and cell adhesion abnormalities, etc..	(1) Multiplex assays (e.g., Meedat) which measure multiple domains of EED and nutritional status (2) EED disease activity scores	Diagnostic	Provide detailed information on gut function/environmental enteropathy (EED)	Extremely invasive, infeasible as a screening tool; expensive	(Thompson et al., 2017)
		Hydrogen breath test (HBT)	Noninvasive, can detect small intestine bacterial overgrowth (SIBO)	Please see "innovations in measurement and metrics" column	Hydrogen breath test ((HBT)) from surveys		Hydrogen concentration in breath (ppm) after consuming a sugar solution (glucose, lactulose)		Screening, diagnostic	Non-invasive test	May not be well correlated with EED markers	(Lee et al., 2020)
		Intestinal fatty-acid binding protein (I-FABP)	Urine, blood, and stool markers are less invasive compared to small bowel biopsies and can be analyzed using conventional ELISAs	Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration		Screening	Possible biomarker for gut maturation	Limited published data	(Arndt et al., 2020)
		Citrulline		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration			Non-invasive marker of remnant small bowel mass and function		
		Regenerating gene 1β (reg1β)		Please see "innovations in measurement and metrics" column	Surveys		Stool concentration			Serum biomarker of intestinal damage		

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Intestinal permeability	Lactulose: mannitol (l:m) l:m/lactulose: rhamnose (l:)r test		Please see "innovations in measurement and metrics" column	Surveys		Urine l:m ratio/ l:r ratio (% l excretion, % m excretion)			Useful measure of gut permeability	Intensive to collect (time-consuming)	
		Alpha 1-antitrypsin (AAT)		Please see "innovations in measurement and metrics" column	Surveys		Fecal concentration			MEEDAT is quick and validated as effective tool for screening children for EED	Limited published data	
		Zonulin		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
	Microbial translocation	Lipopolysaccharide (LPS)		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration			Markers of systemic immune activation		
		Antibodies to LPS		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
		Antibodies to flagellin		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
		LPS-binding protein (LBP)		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
		soluble CD14 (sCD14)		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
		Endotoxin-core antibody (ENDOCAB)		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Bacterial DNA		Please see "innovations in measurement and metrics" column	Surveys		Presence in blood					
	Intestinal inflammation	Calprotectin (Cal)		Please see "innovations in measurement and metrics" column	Surveys		Fecal concentration			Not invasive	Stool samples difficult to collect, markers are non-specific	
		Myeloperoxidase (MPO)		Please see "innovations in measurement and metrics" column	Surveys							
		Neopterin (neo)		Please see "innovations in measurement and metrics" column	Surveys							
	Systemic inflammation	C-reactive protein (CRP)		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum /dried blood spot concentration			Can be assessed from small amounts of blood	Small amount of blood needed makes population screening especially possible, but non-specific nature = questionable validity	
		Alpha(1)-acid glycoprotein (AGP)		Please see "innovations in measurement and metrics" column	Surveys							
		Plasma kynurenine-to-tryptophan ratio		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
		Interleukin (il)-6		Please see "innovations in measurement and metrics" column	Surveys		Plasma/serum concentration					
		Ferritin		Please see "innovations in measurement and metrics" column	Surveys		Serum concentration					
	Growth hormone resistance	Growth hormone (GH)		Please see "innovations in measurement and metrics" column	Surveys		Serum concentration			Associated with growth failure	Non-specific in nature	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Insulin-like growth factor 1 (Igf-1)		Please see "innovations in measurement and metrics" column	Surveys							
		Insulin-like growth factor binding protein 3 (Igfbp-3)		Please see "innovations in measurement and metrics" column	Surveys							
		Fibroblast growth factor 21 (Fgf21)		Please see "innovations in measurement and metrics" column	Surveys							
	Microbiome	16S ribosomal RNA (16s rRNA)	Most established genetic marker used for bacterial identification and classification	Please see "innovations in measurement and metrics" column	Surveys		Sequencing reads which can be analyzed via bioinformatics	(1) Shannon diversity index, (2) microbiota-for-age z-score, (3) microbiome multi-omics	Research	Capture microbiome diversity	Expensive, difficult to analyze, unclear relationship to clinical metrics	(Kamng'ona et al., 2019)
		(Shotgun) metagenomics	Can read all genomic DNA in a sample, rather than just one specific region of DNA (i.e., Can profile bacteria, fungi, viruses and many other types of microorganisms at the same time)	Please see "innovations in measurement and metrics" column	Surveys							

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Metabolomics, proteomics	Can help to elucidate biological mechanisms (e.g., How EED adversely impacts child health and growth)	Please see "innovations in measurement and metrics" column	Surveys							
	Nutrient requirements	Stable isotope techniques (doubly labeled water, breath tests)	Potential to understand the impact of gut dysfunction on macro- and micronutrient absorption and utilization	Please see "innovations in measurement and metrics" column	Surveys		Oral administration of an isotopically labeled compound and subsequent monitoring of the appearance of the compound or its catabolic products in breath, feces, urine, and/or blood		Diagnostic, research		Can be invasive, expensive, analytical difficulties, official guidelines may not be established in LMICs/preparations may not be cleared for use	(Butler et al., 2017)

12. Hygiene behaviors

The hygiene behaviors domain is shown in Table 12. It includes nutrition and food safety norms (project-specific indicators) related to knowledge, attitudes, and practices (KAP) and access to improved drinking water metrics. Specifically, we consider metrics for safe food storage and preparation practices, appropriate handwashing behaviors, improved sanitation facilities, physical access to water, safe drinking water, and health outcomes. The proposed metrics are suitable for the evaluation of projects and for monitoring progress over time.

Overall strengths: Many of the metrics for food storage, handwashing and sanitation are based on self-report and are easy to measure in the field. We also include objective measures to assess safe drinking water and indicators related to the health effects of poor hygiene and sanitation.

Overall weaknesses: For the metrics that require laboratory analysis, the cost of the assessments and time requirements are limiting factors for adoption. For improved sanitation and physical water access, the metrics are proxy measures for safe water/sanitation access that guarantee better health outcomes.

Gaps, research priorities, and opportunities: Many of the metrics, however, for the hygiene score are unstandardized and often not properly validated. For example, many examples of KAP questionnaires related to food hygiene behaviors in the literature include responses of "yes" or no" with little richness in data. Additionally, reliability can be impacted by contextual/cultural factors, as well as social desirability bias. For many of these metrics, findings would be better when coupled with focus group discussions, in-depth interviews, participant observation, etc. For the JMP ladder for drinking water quality, data is best used for comparing across regions/countries and monitoring progress towards SGDs. However, this indicator requires water to be free from contamination (fecal and priority chemical) which is extremely difficult to assess in practice. Most studies rely on portable testing kits (which are often limited to the detection of E. coli contamination) and do not actually measure additional biological or any chemical water quality indicators. Water quality may deteriorate between source and consumption. Finally, many of the metrics rely on cross-sectional studies and do not provide a substitute for regular monitoring and risk assessments of water supplies or availability, especially due to seasonality. It fails to capture key metrics such as adequacy across uses, acceptability, and affordability. Reliability is a limitation and the Household Water Insecurity Experiences (HWISE) is designed to fill this gap.

Table 12. Metrics for hygiene behavior

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Nutrition and food safety knowledge and norms	Safe food storage and preparation practices	Wash hands and surfaces when preparing food	Often asked as part of KAP surveys	Survey of KAP (handwashing, hygienic preparation and storage of food)	Surveys	Individuals/ households	Self-report or direct observation (e.g., Access to cold storage facilities (refrigerator) allowing for the preservation of perishable food) (Y/N)	Hygiene score	Assess the practice of safe/recommended hygiene behaviors	Easy to assess	No standard or well-validated KAP survey, many used in the literature	(Global Alliance for Improved Nutrition, 2020; Strunz et al., 2014)
		Use separate cutting board when preparing food			Surveys							
		Cook food to a safe temperature			Surveys							
		Refrigerate food after cooking (within 2 hours)			Surveys							
		Wash fruits and vegetables with safe water			Surveys							
		Access to refrigeration at the household level			Surveys							(Cini, 2019)
		Food contamination	Objective measures of domestic hygiene and food safety, do not rely on self-report	Bacterial counts	Surveys		Bacterial counts (fecal coliforms, fecal streptococci, clostridium perfringens, etc..)	Detection of or passing thresholds for fecal coliforms, fecal streptococci, clostridium perfringens	Measuring prevalence of bacterial contamination of foods; assessing impact of interventions to improve hygiene	Objective measures, not self-reported	Costly, requires laboratory analyses	(Kennedy et al., 2011; Toure et al., 2012)
		Bacterial examination of food samples		Bacterial counts	Surveys							
		Cleanliness of utensils		Bacterial counts	Surveys							
	Appropriate handwashing behaviors	Demonstration of proper handwashing technique	Does not rely on self-report	Handwashing techniques	Observation	Individuals	Direct observation (Y/N)	Handwashing score	Tracking adherence to recommended hygiene practices	Easy to assess	Time consuming	(Rabbi and Dey, 2013)
		Knowledge and practice of handwashing at (5) critical times	Quick and inexpensive when self-reported	Practices	Surveys, observation	Individuals, population/ national surveys	Self-report or direct observation (Y/N)			Easy to assess	Self-report bias	

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Hand cleanliness	Objective, does not rely on self-report	Hands	Observation, lab assessment	Individuals	Rapid observation (Y/N) or bacterial counts			Objective	Expensive to conduct laboratory analyses	
		JMP service ladder for hygiene	Comparable across countries (and SDG tracking)	Please see "variables" column	Surveys	Households, population/ national surveys	Service ladder category (basic, limited, no facility)	Handwashing facility with soap and water on premises (Y/N)	Benchmark and compare service levels across countries	Standardized approach	Only a proxy for behavior and does not guarantee proper handwashing at key times or better health outcomes	(Wagari et al., 2022)
	Improved sanitation facilities	JMP service ladder for sanitation	Comparable across countries (and SDG tracking), builds on the established improved/unimproved classification but with additional criteria related to sharing and safe management	Please see "variables" column	Surveys	Households, population/ national surveys	Service ladder category (safely managed, basic, limited, unimproved, open defecation)	Use of a safely managed sanitation service (Y/N)	Tracking change	Standardized approach	Likewise, these are proxy measures for safe water/sanitation access that do guarantee better health outcomes	(Exley et al., 2015; Wagari et al., 2022)
		Use of improved sanitation facility	Simple, available in DHS, but has largely been replaced by the JMP classification system (above)	Please see "variables" column	Surveys		Use of an improved, non-shared toilet facility (Y/N)	Population using an improved, non-shared toilet facility		Simple measure and included in DHS		(Ali et al., 2022)
	Physical water access	Distance/time from dwelling to primary water source	Useful for rapid assessment of water quality, access, scarcity.	Distance/time travelled	Surveys	Households, population / national surveys	Km, or minutes	Household water insecurity (HWISE) scale, brief	Track changes in water quality,	Simple, easy to measure		(Nygren et al., 2016)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Average # liters of water /person/day.		Water use per person	Surveys		Liters/person/day	water insecurity experiences scale (BWISE), individual household water insecurity scale (IWISE)	access, scarcity	Simple, easy to measure		(Tamason et al., 2016, p. 201; WHO and UNICEF, 2021)
		Average liters of water collected at household level per day		Water us (per household)	Surveys		Liters/household/day			Simple, easy to measure		(Tamason et al., 2016)
		Number of persons (users) per water source (tap, handpump, well, etc..)		Number of users of water source	Surveys		# Of persons/source			Simple, easy to measure		(Young, 2021)
		Household expenditure for water per month		Household water expenditure	Surveys		$/month			Simple, easy to measure		(Stoler et al., 2020)
		JMP service ladder for drinking water quality	Comparable across countries (and SDG tracking), builds on the established improved/unimproved classification but with additional criteria related to location, availability, and safety	Please see "variables" column	Surveys		Use of safely managed drinking water services (Y/N)		Tracking change	Metric allows cross country comparisons		(Wagari et al., 2022)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Safe drinking water	Use of improved drinking water source	Simple, available in DHS, but has largely been replaced by the JMP classification system (above)	Please see "variables" column	Surveys	Households, population/ national surveys	Type of primary water source	Water quality index (WQI)	Tracking change	Simple, easy to assess metric	Not always well correlated with objective measures of water quality; improved water supplies may still not be microbiologically safe	(Shaheed et al., 2014)
		Use of recommended household water treatment technologies (e.g., Boil, bleach, filter, or solar disinfection)	Useful for rapid assessment of water safety	Use of water treatment technologies	Surveys		Y/N from self-report or direct observation		Assess water quality	Simple to assess; methods effective to improve water quality	Subject to report and recall bias	(Lantagne and Clasen, 2013)
		Practice of recommended safe water storage practices		Use of safe water storage practices	Surveys				Track use of safe water storage practices	Simple to assess; methods effective to improve water quality		(Anderson et al., 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Total coliform (TC)	Objective measures; rapid water quality testing kits are portable and do not require lab, electricity, expensive equipment	Rapid tests for TC	Surveys	Households	Plate count, most probable number (MPN), presence-absence (P-A)		Track coliform, bacteria and virus content of water	Objective measures of water quality	No single indicator represents all potential pathogens that can be present in the water only. Rapid tests are semi-quantitative (often p-a or MPN, often limited to E.coli detection, and still time consuming (24hr+ incubation))	(Hodge et al., 2016; Verhille, 2013)
		Thermotolerant coliform		Rapid tests for coliforms	Surveys							
		E. Coli		Rapid tests for E. coli	Surveys							
		Viruses, protozoa		Rapid test for viruses, protozoa	Surveys		Difficult to measure in water, not routinely done					
		Inorganic (arsenic, chromium, copper, fluoride, lead, manganese, nitrate, nitrite, etc..)	Objective measures of household water quality/safety. Can be measured via laboratory analyses, some more quickly with portable meters, sensors, direct observation	Lab assessment	Surveys	Households	Concertation (e.g., Micrograms per liter)		Tracking	Objective measures	Require centralized laboratory, not routinely tested for at household level	(Bradley et al., 2021)
		Organic (pesticides, petrochemicals, pops, etc..)		Lab assessment	Surveys							
		Ph		Lab assessment	Surveys		Acid-base scale			Objective measures	Not routinely collected, reliance on observation	(FAO, 1999)
		Total dissolved solids (TDS)		Lab assessment	Surveys		mg/L					
		Dissolved oxygen (DO)		Lab assessment	Surveys		mg/L					
		Hardness		Lab assessment	Surveys		mg calcium carbonate					

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
							($CaCO_3$) (mineral)/L					
		Temperature		Please see "innovations in measurement and metrics" column	Surveys		Celsius					
		Turbidity (tur)		Please see "innovations in measurement and metrics" column	Surveys		Nephelometric turbidity units					
		Color		Please see "innovations in measurement and metrics" column	Surveys		Observation (should appear colorless)			Easy to assess		
		Taste/odor			Surveys		Percentage	Prevalence of samples with unsatisfactory taste/odor	Tracking			
	Health outcome	Incidence of diarrheal disease	None	Cases	Surveys	Population/ national surveys	Diarrhea in the last two weeks	Percentage of children under 5 with diarrhea in the last two weeks	Assessment of trends	Allows cross country/regional comparison	Does not capture specific cause	(Karambizi et al., 2021)
		Prevalence of other water/sanitation-related health outcomes (soil-transmitted helminth infections, trachoma, hep a, typhoid, polio, etc..)		Cases	Surveys	Individuals/ population surveys	Prevalence of disease (soil-transmitted helminth infections, trachoma, hep a, typhoid, polio, etc.) In the last 2 weeks	Prevalence of disease (soil-transmitted helminth infections, trachoma, hep a, typhoid, polio, etc..)	Assessment of trends	Allows cross country/regional comparison	Often undiagnosed/ misdiagnosed	(Strunz et al., 2014)

13. Socio-cultural drivers

Metrics for the socio-cultural drivers of food systems are displayed in Table 13. Broadly, this area includes the categories of women's empowerment, social support, child labor, and intrahousehold dynamics and vulnerabilities. These metrics are mostly used for evaluating the impacts of interventions and determining how to appropriately target interventions to those most vulnerable.

Overall strengths: The metrics identified for socio-cultural food systems drivers improve on older metrics by explicitly considering how power and social dynamics within households or communities relate to food systems function and outcomes. They allow for more precise and accurate targeting of food systems interventions by disaggregating data by individual rather than making assumptions about individuals within households based on household-level data. They also include the area of child labor, an important but not often measured driver of food systems function, and data collection approaches to improve time-use measurements (such as wearable devices).

Overall weaknesses: Data collection for many of the socio-cultural drivers of food systems metrics is time intensive as it involves conducting surveys in individual households.

Gaps, research priorities, and opportunities: Areas for development include the validation of psychosocial scales for use in low- and middle-income countries, utilization of metrics that represent the full spectrum of gender identities, creation of an overall empowerment index (not tied only to agriculture), further development of metrics to measure child involvement at all stages of the food system and its effects on both the children and on food systems function and validation of metrics that require less survey time or burden on the participant.

Table 13. Metrics for socio-cultural drivers of food systems

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Women's empowerment	Consideration of women's societal position in food systems function	Women's Empowerment in Agriculture Index (WEAI)/Project Level-WEAI	Quantitative approach to measuring women's empowerment specifically in the agricultural sector; Pro-WEAI is abbreviated version, used for project evaluation	Various domains (decisions in production, control over assets, etc.)	Surveys	Individual	Empowerment in 5 domains; gender parity index	Women's empowerment in agriculture index (WEAI)/ Pro-WEAI, or other empowerment indices	Impact evaluation; targeting	Specific to agriculture so can be linked directly to other food systems metrics	Some versions of the WEAI require a lot of survey time; measures only agriculture-related activities	(IFPRI et al., 2012)
		Women's autonomy, access to resources, and control over resources	Assessment of individual constructs of women's empowerment	Various domains	Surveys	Individual	Empowerment domains (Y/N)	Decision-making autonomy (e.g., for health, agriculture, nutrition, etc..), mobility autonomy, financial autonomy, access to credit, time-use, opportunity costs, participation in key agricultural activities, etc..	Impact evaluation; targeting	Assessing individual empowerment domains allows comparison across domains	Metrics for time-use are cumbersome and time-intensive; may be difficult to tease out causal relationships regarding indicators for social norms, policies, and laws	(Lombardini et al., 2017; Vemireddy and Pingali, 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Gender equity	Assessment of gender parity	Economic participation and opportunity; educational attainment; health and survival; political empowerment	World Economic Forum surveys	Country	Index	Global gender gap index	Tracking change over time	Allows comparison across country level; includes multiple sub-indices (ex: educational attainment, health and survival, political empowerment)	Data is not available to reflect gender gaps across the spectrum of gender identities	(World Economic Forum, 2022)
Social support	Benefits of social networks and support for food security, nutrition, and health outcomes	Social support	Understanding role of societal position, influence, and support in food systems function	Social support from friends, family, and significant other/special person	Surveys	Individual	Various scales	Multidimensional Perceived Social Support Scale; Social Support Questionnaire; Size of social network; Social capital	Impact evaluation; targeting	Commonly used and applied in literature; relatively easy to interpret	Scales often not validated for use in low- and middle- income countries; scales may not be useful for all age ranges	(Dambi et al., 2018)
Child factors	Role of child labor in agriculture and food systems	Extent of child labor	Consideration of child labor in evaluating food systems function	Children 5 to 17 in employment by hrs/wk., hazardous conditions, and age	National surveys	Country	Child labor %	% Of agricultural labor provided by children	Tracking change over time	Only metric available to assess role of child labor in agriculture and food systems	Limited direct measurement of target population (children who perform labor)	(International Labour Office (ILO), 2012)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Intra-household dynamics and vulnerabilities	How individual characteristics and position within a household determine probability of meeting nutrient requirements	Nutrient intake by age, sex, economic role, and contribution	Disaggregation of nutrient intake by individual family member for comparison	Dietary recall by family member compared to dietary reference intakes (DRIs)	Surveys	Individuals within a household	Various nutrient units (e.g., grams)	Energy-adjusted nutrient adequacy by nutrient and household (HH) member	Targeting	More precise and accurate than using household dietary data to make assumptions about individuals; allows for targeting to most vulnerable household members	Nutrient intake and diet difficult to assess and time consuming, especially if assessed for each family member; need to define individual nutrient needs	(Fiedler and Mwangi, 2016; Harris-Fry et al., 2017; Schneider et al., 2021)
	How individual characteristics and position within a household determine probability of meeting dietary requirements	Household members' diet diversity and quantities by age, sex, economic role and contribution	Disaggregation of dietary diversity (or other dietary/food security scores) by individual family member for comparison	Dietary recall by family member	Surveys	Individuals within a household	Scores or indices	Dietary scores by HH member	Targeting			
	Women's empowerment influence on household resource allocation	Women's decision-making in food allocation	Consideration of women's decision-making in intra-household allocation of resources	Personal perception of decision-making power	Surveys	Individual	Score	Women's decision-making score for intrahousehold resource allocation	Impact evaluation; targeting	Can/should be asked of both women and men, to gather perspectives from both	Less generalizable; may be hard to compare across settings due to cultural differences in perception	(Doss, 2013)
	Re-allocation of time demands with introduction of new agricultural technologies	Household members' time demands by age, sex, economic role and contribution	Understanding changes in time demands with introduction of new technologies	Time-use by HH member	Direct observation, surveys, technology to record time-use	Individual	Time	Change in time spent in agricultural activities before and after introduction of new technologies, by HH member	Impact evaluation; targeting	Measure is objective/reliable if directly observed	Time use may be difficult and intensive to capture	(Shibata et al., 2020)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Re-allocation of labor and energy demands with introduction of new agricultural technologies	Household members' labor and energy demands by age, sex, economic role and contribution	Measurement of labor and energy demands using wearable devices	Calorie expenditure	Observation of activities with wearable devices	Individual	Calories expended	Change in labor demands for agricultural activities before and after introduction of new technologies, by HH member	Impact evaluation; targeting	Wearable devices make data collection more precise and accurate; may be less intrusive than long surveys or observations	Wearable devices may be expensive; potential for technology failure	

14. Biophysical and environmental drivers

Metrics of the biophysical and environmental drivers of food systems are presented in Table 14. These metrics cover contributions of natural resource management, land quality, water access, availability and quality, and livestock contamination to food systems function. Most provide measurement at the community or national level and are useful for tracking changes over time and detecting and quantifying food systems risks.

Overall strengths: The innovative use of satellite images and remote sensing to facilitate data collection for metrics of biophysical and environmental food systems drivers allows for widespread use of publicly available data at virtually any scale, and across many time periods, to evaluate how these drivers change over time and how they differ geographically.

Overall weaknesses: The use of remote sensing and satellite imagery requires expertise in the methods and geospatial analyses, which may not be immediately feasible for all research groups.

Gaps, research priorities, and opportunities: Future work could target metrics in the area of knowledge, attitudes, and practice regarding the biophysical and environmental food systems drivers.

Table 14. Metrics for biophysical and environmental drivers of food systems

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Natural resource management practices	Impact of natural resource management on food system functions	Sustainable land management	Satellite imagery	Satellite images, household/community surveys	Remote sensing datasets (e.g., Landstat, Sentinel)	Community	Adoption (Y/N); area under conservation (ha)	Adoption of land and water conservation practices (e.g., soil bund, stone bund, stone-faced soil bund, loose stone and brush-wood check dams, hillside terrace, and bund stabilized with vegetation); % of land under conservation techniques	Tracking change over time; monitoring	Remote sensing data can be used at any scale; largely publicly available, free and open data; longitudinal data; can be used to cross-check in situ measurements; important metrics for evaluating sustainability of food systems	Methods may require expertise in remote sensing and geospatial analyses	(Group on Earth Observations, 2017)
Land quality	Relationship between food systems, agriculture and land quality	Loss of arable land	Satellite imagery	Satellite images, household/community surveys	Remote sensing datasets (e.g., Landstat, Sentinel)	Community	Arable land area (ha)	Loss of arable land (between time periods)				(Group on Earth Observations, 2017)
	Relationship between food systems, agriculture and land quality	Land slope	Remote sensing and satellite imagery	Surface topography	Remote sensing datasets (e.g., Landstat, Sentinel)	Community	% Slope	% Slope				(Group on Earth Observations, 2017)
Water access and availability	Water availability and water use efficiency measures	Water stress	Remote sensing and satellite imagery	Gross or net water abstraction from fresh surface water	FAO Aquastat; remote sensing; OECD	National	Percent freshwater withdrawal	Level of water stress (Freshwater withdrawal as a proportion of available freshwater resources), water use efficiency				(Group on Earth Observations, 2017; Vanham et al., 2018)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Relationship between agriculture, food systems and water scarcity	Water scarcity	Remote sensing and satellite imagery	Blue water (m^3/month), green water (m^3/month), Evapotranspiration and crop coefficients	FAO Aquastat; remote sensing; OECD	National	Blue water (m^3/month), green water (m^3/month), Evapotranspiration and crop coefficients	Water scarcity index (ratio of water demand to water availability in crop production taking into consideration of blue water, green water, environmental flow requirement (EFR)), Water depletion, Water footprint assessment, Household water supply				(Hoekstra et al., 2011; X. Liu et al., 2022)
Water quality	Agriculture, food systems and water contamination	Contamination from water or environment in the food supply	None	Levels of contaminants	Multiple Indicator Cluster Surveys (MICS); Living Standards Measurement Study (LSMS); household surveys	Community	unit/L	Measure above threshold (Y/N), Prevalence/Incidence in community (e.g., pesticides, nitrates, plastics, arsenic, mercury, microbial etc.)	Detection, quantification, risk assessment, tracking change, targeting	Essential to measure water quality in assessing food systems function	Contamination of water may be due to a multitude of factors, making it difficult to identify the source	(Bain et al., 2020)
Contamination from livestock	Contamination from livestock	Contamination in the food supply from animal feces due to proximity to livestock	Focus on transmission of zoonotic pathogens within the food system	Levels of contaminants in drinking water; proximity of livestock to household; presence of livestock feces in water	DHS; Household surveys	Household	unit/L	Measure above threshold (Y/N), Prevalence/Incidence in community (e.g., microbial etc.)	Detection, quantification, risk assessment, tracking change, targeting	Allows consideration of risks of livestock operations for nutrition and health outcomes	Livestock presence around household is not the only one source of water contamination	(Kaur et al., 2017)

15. Resilience

Table 15 shows food systems resilience metrics. To measure food systems resilience, metrics are presented that use latent variables to measure capacity to evade long-term consequences from stressors and shocks and that also measure climate resilience and adaptation. The latter category includes greenhouse gas emissions throughout the food system, and the contributions of food production and consumption to climate stress, such as levels of eutrophication and biodiversity loss. Metrics are also presented that assess the food systems climate policy environment.

Overall strengths: Innovative use of methods to measure resilience as a latent variable allow for timely assessment of resilience in a way that is sensitive to the transitory nature of shocks. In general, the resilience metrics provide important information for decision-makers to use in determining how to best transform food systems to be well-adapted to climate change and ensure that populations will have sufficient food for the future. Several can be assessed using publicly available longitudinal data, meaning changes can be relatively easily tracked over time. In addition, newer techniques such as using nuclear dating provide opportunities to assess soil degradation levels and loss of arable land at relatively low costs.

Overall weaknesses: We define resilience as the ability of communities to mitigate, adapt to, and bounce back from shocks and stressors, and thus present metrics related to this definition. However, resilience is notoriously difficult to define and measure, and with alternate definitions, there may be alternate appropriate metrics. In addition, because resilience is a latent variable and must be measured by other influencing or related variables, many of the resilience measures may have poor internal and external consistency and have not been shown to be associated with well-being outcomes. The metrics that measure the more concrete resilience areas such as contributions of the food system to climate stress often require resource-intensive or complex data collection, and their calculations involve several assumptions, making estimates potentially imprecise.

Gaps, research priorities, and opportunities: The gaps in resilience metrics are mainly tied to data availability to assess the important resilience indicators. Data to calculate the ecological footprints of consumption and production of specific food groups or dietary patterns is largely unavailable and would be useful to be able to assess the potential for improving biocapacity deficits or reserves under different production and consumption conditions. Data on the adoption of innovative plant breeding techniques in low- and middle-income countries is also unavailable, and the use of nuclear techniques to monitor soil and water management requires scale-up.

Table 15. Metrics for food systems resilience

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Resilience	Resilience: Capacity to evade long term consequences from stressors and shocks	Use of latent variables to measure resilience	Measures sensitive to transitory shocks	Access to Basic Services (ABS), Assets (AS), Social Safety Nets (SSN), and Adaptive Capacity (AC)	Household and community survey data	Household and community	Index	Resilience capacity index (RCI); realized resilience (non-negative change in well-being indicator of over consecutive measurements)	Monitoring; impact evaluation	Sensitive to transitory shocks	Poor internal and external consistency, require improvement, not consistently related to well-being outcomes (e.g., food security); realized resilience uses only observed changes over time without accounting for the level of measure, thus may not be correlated with the level of well-being.	(Upton et al., 2022)
		Normative measure of resilience with a cut-off indexed to specific development outcomes (e.g., food security, poverty)	Use of a threshold-based approach to measure resilience	Resilience latent variables (e.g. Access to Basic Services (ABS), Assets (AS), Social Safety Nets (SSN), and Adaptive Capacity (AC)); development outcomes e.g. food security, nutrition outcomes)	Household and community survey data	Household and community	Resilience score	Probability of a resilience score below threshold	Monitoring; impact evaluation	Can be anchored to normative well-being standards or food systems outcomes; thresholds can be adjusted based on context and assessment goals		

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Climate resilience and adaptation (reducing exposure and sensitivity to climate hazards, reducing vulnerabilities and enhancing capacities to respond to them, exploiting any beneficial opportunities presented by changing climates, climate smart agriculture)	Pest and disease resilient crops	DNA genotyping	Pest and disease resistant crop varieties	Household and community survey data	Household and community	Y/N	Proportion of households adopting of pest and disease resistant crops	Tracking change over time; monitoring	Leads to data-driven breeding approaches; more accurate than farmer interviews and plant descriptors; tracking and monitoring using genotyping may increase accuracy of reports and encourage further innovation	DNA genotyping may be resource intensive and difficult to implement in the field	(Elshire et al., 2011; Glaubitz et al., 2014; I. Y. Rabbi et al., 2015)
		Use of innovations in plant breeding		Number of crop varieties	IAEA Mutant Variety Database (MVD)	National	Number of crop varieties	Number of new climate-resistant or pest resistant varieties of crops developed per year			Lack of comprehensive datasets covering diverse geographic areas	
		Adoption of climate resilient crop varieties		Climate-resilient crop varieties	Household and community survey data	Household and community survey data	Y/N	Proportion of households adopting of climate resilient crops			DNA genotyping may be resource intensive and difficult to implement in the field	
		Use of innovative techniques to measure land degradation (e.g., loss of arable land, soil erosion)	Nuclear techniques (e.g., Fallout Radionuclides (FRN)) for soil erosion and compound-specific stable isotopes (CSSI) for areas affected by soil erosion	FRNs (e.g., caesium 137); CSSI-carbon 13 stable isotope	FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture; community surveys; soil sampling	Community farms	Levels of caesium 137, or carbon 13	Level of soil erosion	Tracking change over time; monitoring; impact evaluation	Novel technique can determine rate of soil erosion; identification of appropriate soil conservation and management practices can minimize soil erosion; technique has been applied with success in LMICs	Restricted size of areas that can be tested; rely on assumptions about uniform initial spatial distribution of radioactive elements; requires substantial training and expertise	(IAEA, 2021; Mabit et al., 2018)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Adoption of practices to prevent land degradation (e.g., loss of arable land, soil erosion)	None	Practices to prevent land degradation and soil erosion	Household and community survey data	Household and community	Y/N	Proportion of households adopting recommended practice (e.g., appropriate conservation practices such as intercropping, growing green-manure plants, creating basins near coffee trees, contour cropping and terracing)	Impact evaluation	Feasible and cost-effective data collection	Does not necessarily provide information on effectiveness of different interventions, unless combined with metrics to track land degradation	(IAEA, 2021)
		Land use per capita as a measure of agriculture intensification	Geospatial approaches to measure land use	Land area under agricultural use	FAOSTAT	National	ha per person	Land use per capita	Tracking change over time	Publicly available data	Non-specific	(Chaudhary et al., 2018)
	Policies to limit the impact of food production and consumption on climate change	Assessment of food systems climate policy environment	Consideration of the importance of science-policy interface for food systems transformation	Written policies	National policies and process documents; Climate Action Tracker	National	Policy (Y/N)	Presence of policies limiting the impact of food production and consumption on climate change	Policy environment assessment	Important metrics to inform and assess concrete policy options for food systems transformation and mitigation of climate change	Great variation in policy type and scope; comparison across countries may be difficult	(Singh et al., 2021)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
Climatic resilience and ecosystem stability	Food system climate stress	Greenhouse gas emissions throughout the entire food system (production, processing and packaging, storage and distribution and consumption)	Assess contribution of different dietary patterns	GHGe by food	Various (ex: EDGAR-FOOD; FooDB for food composition data; HESTIA for environmental data, Blue Food Assessment for environmental data)	Food	Greenhouse gas emissions per capita	GHGe of individual foods throughout the food supply chain per capita (kg CO2 equivalent per capita) for each food or dietary pattern	Monitoring; tracking change over time; identifying policy and programming targets	Important to inform decision-making and policy; can be disaggregated by food system stage as well as food or dietary pattern	Complex to collect data and calculate; data availability; requires many assumptions	(Clark et al., 2022; A. Herforth et al., 2022; WWF, 2020)
	Consumption level influence on climate stress	Blue water consumption per capita	Assess contribution of different dietary patterns	Liters by food	Waterstat	National	Liters per capita	Water use linked to food consumption (liters/capita)		Important to inform decision-making and policy; can be disaggregated by food system stage as well as food or dietary pattern; data available in repositories	Disaggregated data limited to food products from agricultural sector (industrial commodities treated as one category); year-specific data not available so tracking change over time difficult; calculations rely on many underlying assumptions	(Mekonnen and Hoekstra, 2011)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Contribution of food consumption patterns to eutrophication	Contribution of different dietary patterns	Excess nutrient flows by food throughout the food value chain	Various individual studies; farm surveys that have measured eutrophication	Food	Eutrophying emissions per kilogram of food product (grams of PO_4 eq per kg)	Eutrophication of food consumption (g PO_4-equivalent/capita) (i.e., nitrogen and phosphorus eutrophication of water bodies)		Important to inform decision-making and policy; can be disaggregated by food system stage as well as food or dietary pattern	Availability of data; complex methodology	(Poore and Nemecek, 2018)
		Contribution of food consumption patterns to biodiversity loss	Contribution of different dietary patterns; life cycle assessment (LCA) based impact assessment	Species lost (Potentially Disappeared Fraction (PDF) of species), per capita food consumption patterns, agricultural emissions	Life Cycle Inventory data sources (ex: Agrifootprint); individual LCA studies	Food	Extinctions per species year $*10^{12}$/capita; agricultural emissions (e.g., NH_3, N_20); per capita food consumption by product (kg/person-year)	Biodiversity impact of food consumption (extinctions per species year $*10^{12}$/capita)		Important to inform decision-making and policy; can be disaggregated by food system stage as well as food or dietary pattern	Availability of data; complex methodology; spatial and temporal differences	(WWF, 2020)
		Contribution of food consumption to climate stress	Reveals biocapacity deficits or reserves	Footprint of apparent consumption: Area needed to produce the materials consumed (global ha) and the area needed to absorb the carbon dioxide emissions (global ha), footprint of food imports minus exports	Foodprint Data Foundation (Fodaf)	National	global ha/ capita	Total ecological footprint of consumption (global ha/ capita)		Publicly available longitudinal data	Data for specific foods or food groups not readily available	(York University Ecological Footprint Initiative and Global Footprint Network, 2022)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
	Production level influence on climate stress	Contribution of food production to climate stress		Footprints for all resources harvested and all waste generated in a defined geographical region (area within a country necessary for supporting the actual harvest of primary products (cropland, pastureland, forestland and fishing grounds), the country's built-up area (roads, factories, cities), area needed to absorb all fossil fuel carbon emissions generated within the country				Total ecological footprint of production (global hectares/capita)				
		Contribution of food production to soil biodiversity	Variation by farming approaches; introduction of comprehensive index	Measures of richness (bacterial richness, fungal richness); the relative abundance of groups of soil organisms (number of nematodes, root colonization by fungi, estimate of soil microbial biomass); farming approaches and techniques	Survey (soil biodiversity data collected using a range of methods measuring biomass, activity, diversity/community structure)	Farm	Shannon-Wiener Index of Diversity	Soil biodiversity index (e.g., by farming approach)		Soil biodiversity maintains ecosystems and is important to measure and track; index corresponds with ecosystem function	Data collection methods may be resource intensive	(Wagg et al., 2014)

Domain	Constructs used in theories of change	Innovations in measurement and metrics	Novel component	Measurements (what is observed)	Data sources	Scale	Variables	Derived metrics	Purpose	Strengths	Limitations	Sources
		Intrinsic value of native species for maintaining biodiversity	None	% Of agricultural land composed of native species	Remote sensing and satellite imagery; land cover maps	National	% Of agricultural land composed of native species	Proportion of agricultural lands embedding at least 10% of natural vegetation (%)		Publicly available longitudinal data; important to inform decision-making and policy	Data may be less available/disaggregated in certain regions (i.e., low- and middle-income countries)	(Jones et al., 2021)

Conclusions

The metrics identified during this scoping exercise cover a broad range of methods to measure food systems drivers, inputs, components, and outcomes. Decisions regarding which metrics to focus on, or which to use will depend on the specific purpose of the decision-makers' agenda. Thus, to provide a comprehensive view, we do not provide a strict prioritization by area. Instead, we present the information necessary for individual entities to make their own decisions about which metrics should be used in certain situations. We provide an operational typology which highlights not only gaps in available metrics but also the newest, most innovative ways of measuring important aspects of food systems in each domain to support intervention and transformation strategies for efficient and sustainable food systems. Using the table of metrics and its accompanying narrative, we hope that institutions will be able to identify areas for continued research and development, in addition to choosing the metrics best suited to evaluate their current projects.

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