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Viewpoint

Viewpoint: Rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals☆

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ABSTRACT

Food systems that support healthy diets in sustainable, resilient, just, and equitable ways can engender progress in eradicating poverty and malnutrition; protecting human rights; and restoring natural resources. Food system activities have contributed to great gains for humanity but have also led to significant challenges, including hunger, poor diet quality, inequity, and threats to nature. While it is recognized that food systems are central to multiple global commitments and goals, including the Sustainable Development Goals, current trajectories are not aligned to meet these objectives. As mounting crises further stress food systems, the consequences of inaction are clear. The goal of food system transformation is to generate a future where all people have access to healthy diets, which are produced in sustainable and resilient ways that restore nature and deliver just, equitable livelihoods.

A rigorous, science-based monitoring framework can support evidence-based policymaking and the work of those who hold key actors accountable in this transformation process. Monitoring can illustrate current performance, facilitate comparisons across geographies and over time, and track progress. We propose a framework centered around five thematic areas related to (1) diets, nutrition, and health; (2) environment and climate; and (3) livelihoods, poverty, and equity; (4) governance; and (5) resilience and sustainability. We hope to call attention to the need to monitor food systems globally to inform decisions and support accountability for better governance of food systems as part of the transformation process. Transformation is possible in the next decade, but rigorous evidence is needed in the countdown to the 2030 SDG global goals.

1. Introduction

Food systems are essential to achieving most of the 17 Sustainable Development Goals (SDGs), particularly "zero hunger" and "zero poverty," (United Nations General Assembly, Seventieth Session, 2015; Independent Group of Scientists appointed by the Secretary-General, 2019) and for staying within "planetary boundaries," the Earth System processes that define a safe space for humanity and all species (Rockström et al., 2009, 2020; Springmann et al., 2018). With less than a decade remaining to achieve the SDGs (the "2030 Agenda") and amidst mounting social, political, health, and ecological crises, the global community faces a critical juncture to transform food systems so that they support healthy diets in sustainable, resilient, just, and equitable ways (Blesh et al., 2019; Cowan, 2020; Regilme, 2020; Sachs et al., 2021; Salas et al., 2020; Stevano et al., 2021; Watson et al., 2020). Food systems are central to meeting the SDGs and the targets and commitments established in the three Rio Conventions on climate change (UNFCCC), the Convention on Biological Diversity (UNCBD), and the UN Convention to Combat Desertification (UNCCD). In addition to global goals and commitments, achieving equity in food system outcomes and the livelihoods of those whose welfare is tied to food systems require more just food systems in which greater power is vested in the hands of consumers and workers (Anderson, 2008; Fanzo and Davis, 2019; Giron-Nava et al., 2021; Klassen & Murphy, 2020; Rockström et al., 2021; Walls et al., 2020; Whitfield et al., 2021).

Food systems have contributed to great gains for humanity throughout history (Barrett et al., 2020; Conway, 2012; Fanzo and Davis, 2019; Global Panel on Agriculture and Food Systems for Nutrition, 2020; UNICEF, WHO, & World Bank, 2020). However, these meaningful contributions conceal significant challenges. Billions of people lack access to affordable, healthy diets, are at risk of poor health, and are increasingly suffering from diet-related diseases (Afshin et al., 2019; Bennett et al., 2020; FAO, IFAD, UNICEF, WFP and WHO, 2020, FAO, IFAD, UNICEF, WFP and WHO, 2021; Mulik and Haynes-Maslow, 2017; Penne and Goedemé, 2021; Pinard et al., 2016). Food production and waste are responsible for 21–37% of global greenhouse gas (GHG) emissions and contribute to many other types of environmental degradation threatening the Earth's systems, but at the same time are one of the largest levers for positive change (Béné et al., 2020d,a; Cattaneo et al., 2021; Fanzo et al., 2020; Gerten et al., 2020; Henriksson et al., 2021; Kremen & Merenlender, 2018; Kummu et al., 2012; Mbow et al., 2019; Molden, 2007; Poore & Nemecek, 2018; Reyers & Selig, 2020; Rockström et al., 2020; Rosenzweig et al., 2020; Springmann et al., 2018; Yates et al., 2021).

People who earn their livelihoods in food systems are among the most marginalized, vulnerable, and exploited (Anderson, 2008; Borras et al., 2008; Christiaensen et al., 2021; Fleischer et al., 2013; Holt Giménez & Shattuck, 2011; Hunt, 2016; Parks et al., 2020; International Labour Organization and Organisation for Economic Co-operation and Development, 2019; One Fair Wage et al., 2020). Most food systems are currently unable to sufficiently anticipate, absorb, and adapt to shocks and stresses or to meet the long-term needs of current and future populations – concerns becoming even more important with the anticipated increase in frequency and severity of these shocks in coming decades (Barrett, 2020; FAO, IFAD, UNICEF, WFP and WHO, 2020; FSIN & GNFC, 2021; Herrero et al., 2020b; Béné et al., 2021a; FAO IFAD UNICEF WFP and WHO, 2018; Loboguerrero et al., 2019; Nordhagen et al., 2021; Puma et al., 2015; Rockström et al., 2020; Tendall et al., 2015; Webb et al., 2021). Finally, longstanding power asymmetries, including those related to gender, ethnicity, and wealth, and the enduring legacies of colonization and slavery have led to structural inequities around the control and organization of food systems (Anderson, 2008; Blesh et al., 2019; Harris et al., 2021; Klassen & Murphy, 2020; Leach et al., 2020; Palumbo & Sciurba, 2018; Passidomo, 2013; Walls et al., 2020). Unless designed and governed differently, the structure of food systems may reinforce and deepen existing inequities (Klassen & Murphy, 2020; Passidomo, 2013).

These challenges necessitate urgent transformation (Barrett et al., 2020; Webb et al., 2020). The global community increasingly agrees that

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addressing the longstanding, inherent synergies and trade-offs in food systems must be done through a systems lens, rather than isolated entry points (Barrett et al., 2020; Blesh et al., 2019; Fanzo et al., 2020; Global Panel on Agriculture and Food Systems for Nutrition, 2020; HLPE, 2017; Ingram, 2011; IPES-Food & ETC Group, 2021). In addition to the need to consider the complexity and directionality of the relationships within food systems, for many critical indicators the desirable direction of change ("transformation") depends on the starting point and structure of the food system. Some common goals exist across systems, including equitable access to and use of resources (e.g., financial and natural resources, health services, nutrition security, and information), infrastructure, and respect for human rights, while respect for cultural traditions, food preferences, and fulfilling livelihoods are individual and context specific.

Transformation further requires redressing the long-standing vested interests that contribute to current outcomes. The food industry faces enormous incentives to continue producing highly profitable ultra-processed food and drink. The agriculture sector faces incentives to continue focusing on scale and productivity above all else (Barrett et al., 2020; Herrero et al., 2020a). The concentration and market power of a small number of multinational firms in all sub-sectors of food systems exert enormous control over the product landscape and research agendas, and strongly influence government actions (Canfield et al., 2021; Clapp, 2021). Human rights violations, social welfare loss, and environmental degradation carry low (or zero) costs, leaving these impacts as externalities of the food system for which no one is held accountable and no one pays a price (L. Baker et al., 2020; Gemmill-Herren et al., 2021; Hendriks et al., 2021; A. Kennedy & Liljeblad, 2016; Kennedy et al., 2021; Rockefeller Foundation, 2021).

The urgent need for transformation is undeniable, yet there is currently no coordinated effort to monitor all aspects of food systems and their interactions. Doing so in a scientifically rigorous, multi-disciplinary, inclusive manner is necessary to track change, urge action, and hold decision-makers at all scales accountable. Quantitative efforts to develop and measure indicators of food system impacts can also provide inputs into realizing true cost accounting for food systems, with the goal of internalizing the costs of the current externalities food systems create (L. Baker et al., 2020; Gemmill-Herren et al., 2021; Hendriks et al., 2021; Kennedy et al., 2021; Rockefeller Foundation, 2021). In addition to addressing the full spectrum of economic, social, and environmental activity surrounding food, a systems perspective can help identify the entry points to connect knowledge with actions capable of spurring change and stimulating monitoring-based learning practices. Monitoring systems offer an important mechanism to track change, identify tradeoffs, and develop policy options to address challenges (Belesova et al., 2020; GEOGLAM Crop Monitor, 2021; IPCC, 2019a; Sacks et al., 2021; Swinburn et al., 2013; The Lancet Diabetes Endocrinology, 2015). Building on the 2021 UN Food Systems Summit (UNFSS) and the window of opportunity with food systems on the international political agenda, and in recognition of the need for monitoring and accountability, the authors have come together to propose an overarching framework to monitor food systems, commit ourselves to attempt to implement such monitoring, and invite others to collaborate and be similarly inspired by this call to action.

1.1. *The potential to monitor food systems globally*

A comprehensive, independent, science-based mechanism to globally measure and monitor (i.e., "track") the performance of food system activities could help achieve meaningful progress by aligning food system actors, recognizing priorities, setting clear targets for actions, and identifying trade-offs. Such a mechanism can offer food system actors and other stakeholders (e.g., civil society, governments, and international organizations) actionable evidence to hold governments, consumers (specifically, those with the privilege to choose), and the private sector accountable for food system transformation. The authors in this paper propose a monitoring framework for food systems populated with a clear set of relevant, high quality, interpretable, and useful indicators to support evidence-based policymaking. Regularly comparing and analyzing these indicators can help illustrate the current performance of food systems, draw comparisons and lessons across countries, and track changes over time. Assessing performance relative to established targets and goals can track progress and incentivize action. Using a systems perspective—including analyzing interactions, feedback loops, and distal impacts—would provide insight into the state of food systems and their transformation. This type of analysis would complement other global and regional monitoring and tracking initiatives focused on related outcomes, such as sustainable agriculture, nutrition, and health (Micha et al., 2020; Victora et al., 2016; Watts et al., 2021; Our World In Data, 2021; Tubiello et al., 2021b).

1.1.1. *A proposed architecture*

To build the architecture of this monitoring framework, we suggest adapting the High-Level Panel of Experts of the Committee on World Food Security food system framework (HLPE, 2017), which was informed by many previous frameworks (Ericksen, 2008; Gustafson et al., 2016; Ingram, 2011; National Research Council, 2015). Fig. 1 presents our adaptation, illustrating the confluence and interrelationships between actions across food system components that together manifest in many outcomes. We recognize that a static framework is useful to depict the components of a system, but food systems are dynamic in nature. Drivers can influence the directionality and dynamism of interactions between actors and components, which can help or hinder transformation (Béné et al., 2020a; HLPE, 2017). Food systems also influence these drivers in a series of feedback loops (Ericksen, 2008). Governance and policy actions can both influence and be influenced by food system drivers, components, actors, and outcomes (OECD, 2021). Risks, shocks, and vulnerabilities threaten food system outcomes and their resilience and sustainability (Gaupp et al., 2019; Klassen & Murphy, 2020; Tendall et al., 2015). Food systems also play a role in limiting opportunities and reinforcing socio-ecological and poverty traps; analyzing food systems from a systems perspective can be useful in developing holistic interventions that address the inherent coupled dynamics and feedback loops (Barrett, 2008; Galli et al., 2018; Golden et al., 2021; Rufino et al., 2013).

We propose five thematic areas for which we have identified initial indicator domains that can be mapped to the framework and demonstrate the important relationships necessary to monitor. Three thematic areas focus on the outcomes of food systems: (1) Diets, nutrition, and health; (2) Environment and climate; and (3) Livelihoods, poverty, and equity. Cross-cutting areas focus on (4) Governance and (5) Resilience and sustainability. These thematic areas arise from systemic analysis of food systems, the entry points for change, established targets and goals, and the necessary processes and capacities to bring about change. We organized ourselves into working groups around these areas and each working group developed the initial indicator domains proposed in Table 1. These indicator domains are the result of more than two dozen meetings over a four-month period involving all the authors, as well as an internal peer review across our working groups.

The next section of this paper describes the rationale for these thematic areas and indicator domains, and their role in a monitoring system. These domains are an initial proposal and will be subject to external consultation in the next stage of our endeavors together with an open consultation process to identify candidate indicators. A description of the consultation and selection process follows the thematic areas.

2. Thematic areas and indicator domains

2.1. *Diets, nutrition, and health*

Healthy diets are essential for nutrition and health (Micha et al., 2020; HLPE, 2017; WHO, 2018). Sub-optimal diets are a direct cause of

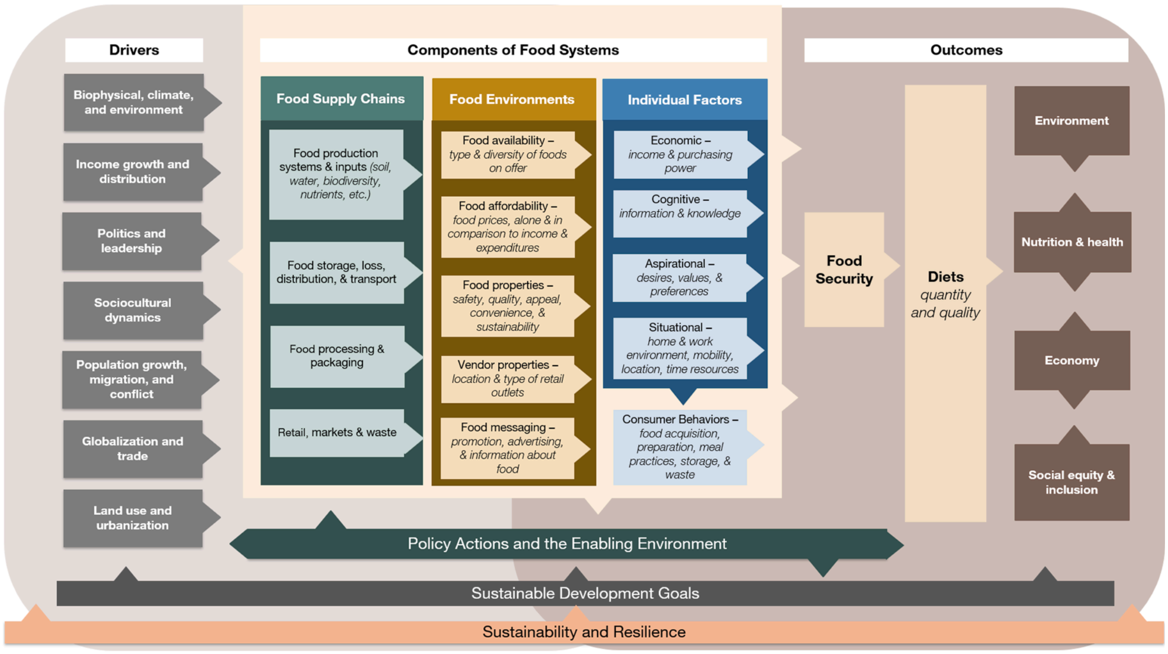

Fig. 1. Food system components, drivers, and outcomes. Legend: This figure depicts the drivers, components, and outcomes of food systems; though static in representation, we emphasize that the drivers are processes, and the components have feedback loops with each other and with the drivers and outcomes. Though not explicit within this figure, power dynamics shape interactions and outcomes throughout food systems—such as by shaping whose voice is heard in politics and leadership, and whom is benefited or harmed by globalization and trade (Anderson, 2008; Gereffi et al., 2005; Klassen & Murphy, 2020; Leach et al., 2020; Walls et al., 2020). Similarly implied is that this schematic reflects a single food system, but food systems exist at multiple scales and interact with one another.

Table 1
Thematic areas and indicator domains.

Diets, nutrition, and health
• Diet quality
• Food security
• Food environments
• Policies affecting food environments
Environment and climate
• Land use
• Greenhouse gas emissions
• Water use
• Pollution
• Biosphere integrity
Livelihoods, poverty, and equity
• Poverty and income
• Employment
• Social protection
• Rights
Governance
• Shared vision
• Strategic planning and policies
• Effective implementation
• Accountability
Resilience and sustainability
• Exposure to shocks
• Resilience capacities
• Agrobiodiversity
• Food security stability
• Food system sustainability index

malnutrition in all its forms, including undernutrition and diet-related noncommunicable diseases (DR-NCDs; e.g., diabetes mellitus, cardiovascular disease, hypertension, stroke) (Afshin et al., 2019; FAO, IFAD, UNICEF, WFP and WHO, 2020, FAO, IFAD, UNICEF, WFP and WHO, 2021; Global Panel on Agriculture and Food Systems for Nutrition, 2016; Hawkes et al., 2020; Swinburn et al., 2019). An estimated 3 billion people cannot afford healthy diets globally, including the majority of people in sub-Saharan Africa and South Asia (FAO, IFAD, UNICEF, WFP and WHO, 2021; Herforth et al., 2020a). This number reflects many aspects of food systems. It speaks to food insecurity, revealing widespread lack of access to healthy diets. It exposes problems in food environments, where healthy diets are too expensive and/or foods available are not necessarily proportional to needs (FAO, IFAD, UNICEF, WFP and WHO, 2020; Herforth et al., 2020a). Food policies are often not aligned with the provision of healthy diets for all (Sacks et al., 2021). Each of these aspects suggests entry points for food system transformation toward healthy, sustainable diets for everyone.

Improving food systems for healthy diets involve monitoring in four essential domains: diet quality, food security (which, by definition, includes access to adequate nutritious food), food environments, and policies affecting food environments (Fig. 1). This thematic area concentrates on diets and their determinants, rather than health and nutrition indicators, which are influenced by more than dietary intake alone and are tracked in other reports (Bennett et al., 2020; Micha et al., 2020; UNICEF, 1990; UNICEF et al., 2020). Specifically, it covers food security and the role that food and food systems play in good nutrition, but would not include the care practices, sanitation, or hygiene required for nutrition security (UNICEF, 1990).

2.1.1. Indicator domains

Diet quality: A healthy diet is "health-promoting and disease-preventing. It provides adequacy without excess of nutrients and health-promoting substances from nutritious foods, and avoids the consumption of health-harming substances" (Neufeld et al., 2021). Diet quality is measured at the individual level to characterize individual dietary consumption. Understanding the connection between food systems and nutrition requires understanding diet quality and how diets are changing (Herforth et al., 2020b). Efforts are underway to expand and strengthen the global evidence base on diet quality. For example, the Gallup World Poll is collecting nationally representative diet data for all individuals aged 15 and older, and the Demographic and Health Surveys is doing so for women aged 15–49. Both will yield data for the Minimum Dietary Diversity for Women indicator and indicators about consumption of unhealthy foods and beverages. The Gallup World Poll additionally yields gender-disaggregated data and indicators reflecting diets that protect against DR-NCDs, including food groups that protect health and food groups to limit or avoid (such as ultraprocessed foods and beverages) (Herforth et al., 2020b). These new data will complement the dietary diversity scores already collected across countries for infants and young children aged 6–23 months (Micha et al., 2020). Other efforts are also underway to increase the collection of, or public access to, quantitative dietary intake data (i.e., specific amounts of foods consumed by individuals), which offer greater depth of information but lower frequency and coverage than monitoring data (Intake – Center for Dietary Assessment, 2020, Intake – Center for Dietary Assessment, 2021; Imamura, 2015; Khatibzadeh et al., 2016; Leclercq et al., 2019; Miller et al., 2021).

Food security: A prerequisite for consuming healthy diets is having access to them; when food security is lacking, so is diet quality (FAO, IFAD, UNICEF, WFP and WHO, 2020). Food security exists when “all people at all times have physical, economic, and social access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, IFAD, UNICEF, WFP and WHO, 2020). Three indicators of food security are broadly used in global reports, and the latest assessment is that (1) 9.9% of the global population (768 million people) lack access to sufficient calories to meet their needs; (2) about 2.37 billion people report experiencing moderate or severe food insecurity; and (3) 3 billion people cannot afford healthy diets (FAO, IFAD, UNICEF, WFP and WHO, 2021). Food systems need to support availability of and access to sufficient healthy food, resilience, and sustainability, as well as agency of people to shape these systems—all of which constitute food security (HLPE, 2020).

Food environments: Food environments encompass availability, affordability, and properties of food (including safety, quality, convenience, and sustainability), as well as food messaging and vendor properties (Fig. 1) (Downs et al., 2020; Herforth & Ahmed, 2015; HLPE, 2017; Turner et al., 2018). People’s interactions with these environments shape healthy and unhealthy food acquisition and consumption (Downs et al., 2020; Drewnowski et al., 2020; HLPE, 2017). While healthy food environments promote equitable access to healthy foods, unhealthy food environments can lead to unhealthy diets and associated disease (Drewnowski et al., 2020; Hawkes et al., 2020; Herforth & Ahmed, 2015; Laar et al., 2020; Sacks et al., 2021). Food availability and affordability have sufficient data for monitoring across countries (FAO, IFAD, UNICEF, WFP and WHO, 2020), but for other aspects, such as marketing and product properties (e.g., food safety), the best monitoring angle may be through policies, including regulations (Laar et al., 2020; Nieto et al., 2019; Sacks et al., 2021; Swinburn et al., 2013).

Policies affecting food environments: Policies can contribute positively or negatively toward food availability, food access, product properties, and/or food messaging—and ultimately diets and nutrition. Some of the most important policies to track are those related to marketing to children, marketing of breastmilk substitutes, fiscal measures such as soda and ultraprocessed food taxes, *trans*-fat regulation, added sugar, salt/sodium content, and food safety standards. However, implementation of many of these policies is limited (Booth et al., 2021; Laar et al., 2020; Sacks et al., 2021; Swinburn et al., 2019; Vandevijvere et al., 2019). Monitoring in this domain has been advanced by the International Network for Food and Obesity/NCDs Research, Monitoring and Action Support, which offers ten protocols to evaluate various components of the food environment and create national benchmarks that can be compared between countries, such as the Healthy Food Environment Policy Index (Food-EPI) (Laar et al., 2020; Nieto et al., 2019; Sacks et al., 2021; Swinburn et al., 2013; Vandevijvere et al., 2019). The Food and Agriculture Organization of the United Nations (FAO) legislative and policy database, FAOLEX, and the World Health Organization (WHO) NCD Progress Monitor report, which includes data from all WHO member states, offer other indicators. Data and indicators from these sources or others are needed to track progress toward regulation of marketing practices, product formulation, and other policies to ensure access to healthy diets.

2.2. Environment and climate

Food systems affect and are affected by the earth’s systems. The main environmental systems and processes interacting with food systems are land use, climate, water use, biosphere integrity, and pollution (e.g., biogeochemical flows/novel entities) (Fig. 2). These represent the critical components and processes that regulate the behavior and maintain the stability of the Earth system itself (Crutzen, 1970; Ripple et al., 2017; Steffen et al., 2015; Vitousek et al., 1997). Humans have currently exceeded safe environmental limits on climate, biodiversity, and water pollution globally, and on freshwater use locally (IPCC, 2019a; Rockström et al., 2009). Reversing and improving upon these impacts is required to guarantee basic environmental services for humanity and ecosystems to thrive. These impacts are so significant that many are already supported by international commitments, such as the UNFCCC, UNCBD, UNCCD, and the 2030 Agenda. These commitments also inform many national and regional food production initiatives, as well as industry and other stakeholder commitments and goals. Monitoring and reporting indicators to demonstrate progress toward these commitments and goals forms the basic accountability principle in all these processes. Doing so specifically for food systems can help to better quantify the role of food systems in achieving necessary change.

These environmental domains are closely interconnected (Lade et al., 2020a). For example, land clearing (land domain) leads to carbon emissions (climate domain). Surface climate warming (climate domain) impacts land, freshwater, and ocean biosphere integrity (biosphere domain) (Mantyka-Pringle et al., 2015). Clearing of land for agriculture (land) is usually followed by application of fertilizers and fresh water (water), which impacts biodiversity habitat (biosphere) and GHG (climate) (Lade et al., 2020a). Land acquisitions also have negative social impacts and often violate human rights while increasing deforestation and the associated GHG emissions (Chu et al., 2015; Liao et al., 2021; Nolte, 2014; Nolte & Voget-Kleschin, 2014). Nutrient inputs and freshwater extraction can lead to eutrophication in freshwater and ocean systems (pollution). Most interactions are amplifying, meaning that impacts on one domain lead to increased impacts on other domains (Lade et al., 2020a). These interactions add complexity to the governance of food systems because they often occur across different scales (local, ecosystem, global) and thereby involve multiple levels of decision-making, but these interactions also offer substantial scope for synergies: if positive impacts in one domain are obtained, gains in other domains can be easier to achieve (Griggs, 2015).

2.2.1. Indicator domains

Land use: Agriculture dominates global land use with approximately 1.5 billion hectares of cropland, of which 30–40% is used to produce feed, and 3.5 billion hectares of grazing land (Mbow et al., 2019). Together, these lands cover approximately 40% of the world’s ice-free land (Ramankutty et al., 2018). Monitoring land use change is essential, as it is at the center of many environmental processes. Halting deforestation and land conversion will reduce GHG emissions, improve water cycles, and protect biodiversity; together with restoration, this action has the potential to store 200–330 gigatons of carbon (IPCC, 2019a; Leclère et al., 2020). Methodologies to measure forest loss and land use change are constantly improving, as remote sensing data are available at greater resolution and integrated with local statistics, and FAO also reports land use statistics (MohanRajan et al., 2020; Showstack, 2014; Woodcock et al., 2020). The concept analogous to land use for aquatic systems is the spatial expanse of inland waters and oceans used for aquatic capture food production. It is difficult to quantify due to data and technological limitations, and the challenge of defining

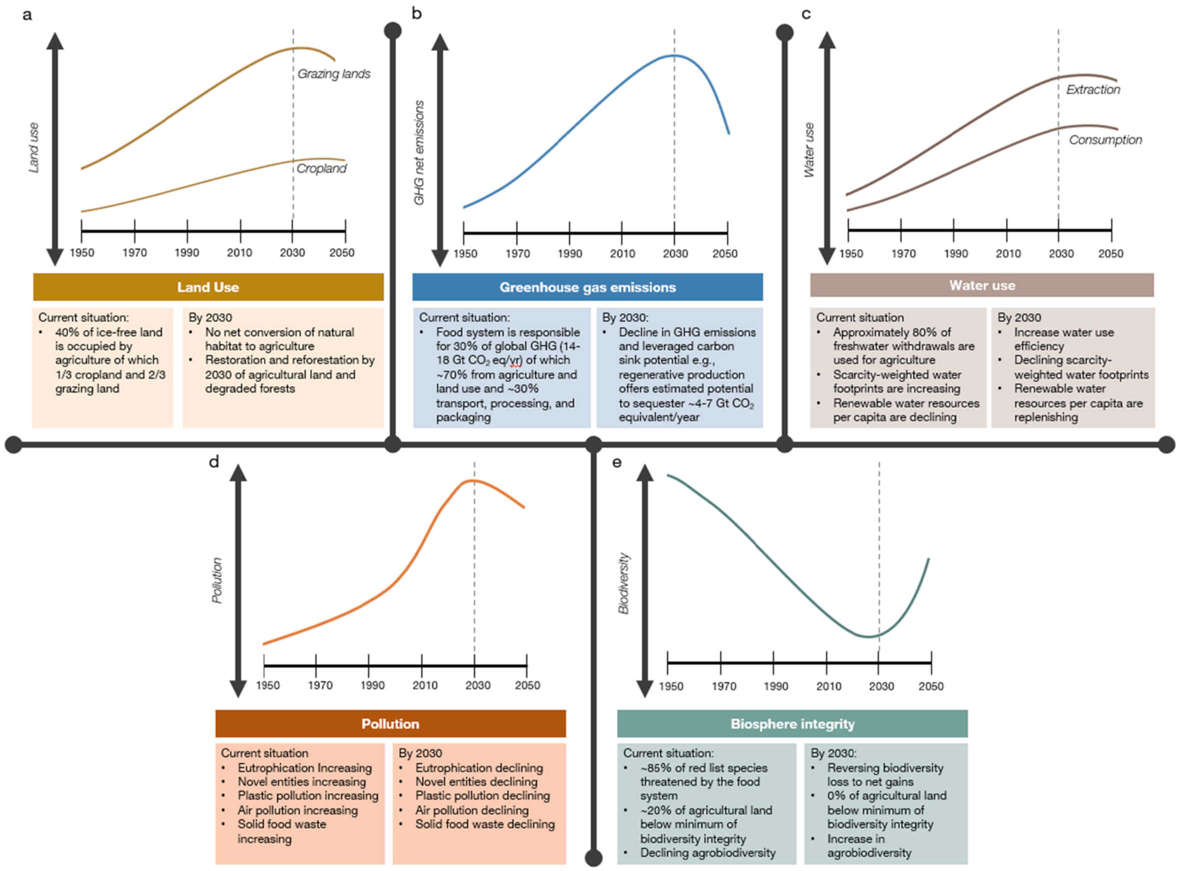

Fig. 2. Environmental domains impacting and impacted by food systems, and needed global change. Legend: This figure depicts existing evidence, international agreements, and expert input over time that provide insights on historical changes needed to achieve proposed futures reflecting desired changes. They help justify which indicators need to be tracked, as the trend for these indicators is critically important for an effective transformation toward more environmentally sustainable food systems. Sources: (Brondizio et al., 2019; Convention on Biological Diversity, 2021; Crippa et al., 2021; FAO, 2021; Geyer et al., 2017; IPBES, 2019; IPCC, 2019a; Leclère et al., 2020; NYDF Assessment Partners, 2019; The Bonn Challenge, 2020, The Water Convention and the Protocol on Water and Health, 2016, United Nations General Assembly, 2015).

fisheries' spatial boundaries. Satellite data are being used to start to close this data gap (Kroodsma et al., 2018), though work on methodologies and specific indicators in this area is incipient.

Greenhouse gas emissions: In order to keep global temperature rise below 1.5 °C, curbing food system GHG emissions, especially achieving net-zero agriculture emissions, is essential (Rockström et al., 2017; Smith et al., 2015). Food systems account for 21–37% of total GHG emissions, two-thirds of which come from crop and livestock production, land use, and land use change, and the remainder from processing, transport, and packaging (Clark et al., 2020; Crippa et al., 2021; Mbow et al., 2019; Poore and Nemecek, 2018; Rosenzweig et al., 2020; Tubiello et al., 2021a; IPCC, 2019a). Specific emissions of concern relevant to food systems are methane from enteric fermentation (in ruminant animals) and rice paddies; carbon dioxide from land use change, transport, and processing; and nitrous oxide from fertilizer application and manures. Data are available for many countries through regular emissions reporting (by sector) to UNFCCC, though data from low-income countries are largely missing. FAO publishes global datasets of emissions from land use and agriculture.

Water use: Water scarcity constrains food systems and human well-being; an estimated 1.2 billion people experience physical water scarcity and another 1.6 billion have insufficiently-developed water resources (Molden, 2007). Food production is responsible for 70–80% of global freshwater "consumptive use"—surface and groundwater removed from the local water cycle—which can drive water scarcity if not locally replenished (D'Odorico et al., 2020; FAO, 2021). Key indicators relevant to food systems include consumptive use by agriculture, livestock, and aquaculture relative to water scarcity and the quantities of freshwater remaining in ecosystems (i.e., environmental flows) to support inland fisheries (Ridoutt & Pfister, 2010). The degree to which waterways globally are dammed or diverted for food and energy production is a complementary available measure (Grill et al., 2019). Data for most of these indicators are available through AQUASTAT, though the necessary spatial and temporal resolution will be carefully considered in the selection of specific indicators and data sources. Water availability, for instance, varies by location at quite a granular level, and new research in this area (Gleeson et al., 2020) can provide the data necessary to make subnational estimations of water scarcity.

Pollution: Environmental pollution from food systems can be classified into four major categories: (1) nutrient loss and run-off (e.g., nitrogen, phosphorus) from food production into water bodies, land, and/or air, and soil degradation (Häder et al., 2020); (2) novel entities, notably biocides (e.g., pesticides, antibiotics) used in agricultural production systems (European Union, 2021); (3) particulate air pollution from food systems (e.g., burning residues or land clearing, air pollution caused, to a large degree, from manure and nitrogen fertilizer application) (Lelieveld et al., 2015); and (4) solid waste across food value chains (e.g., non-degradable plastics, other non-degradable unrecycled materials, excess animal waste not used as fertilizer, food waste of which 95% is estimated to be sent to landfills) (FAO, 2019; Geyer et al., 2017; Melikoglu et al., 2013; Yates et al., 2021). Pollution causes environmental harm, negatively impacts human health, and limits land and water available for food cultivation. Further, there are clear links between food system waste and negative environmental and livelihood outcomes. The higher content of food waste in total landfill mass changes the known chemical processes that occur in landfills and increases methane emissions (Adhikari et al., 2006; Zhan et al., 2017). The impacts of increasingly used bioplastics in food packaging are just beginning to be understood (Huset et al., 2011; Kakadellis & Harris, 2020). Finally, the proliferation of solid waste reinforces the market for waste picking, an extremely dangerous livelihood strategy and which employs many child laborers (Amegah & Jaakkola, 2016; Ferronato & Torretta, 2019; ILO and UNICEF, 2021). Yet there remain critical research and data gaps in this domain, especially at the national level.

Biosphere integrity: Biosphere integrity is a measure of the quantity and quality of natural systems and resources required to maintain nature's contributions to people and halt species extinction (Gerten et al., 2020). Within food production systems, it is nature's capacity to support food production. Indicators of the quantity and distribution of seminatural habitat embedded in agriculture track the capacity of biodiversity to support food production, notably through crop pollination, pest and disease regulation, and the maintenance of diverse rangeland ecosystems (Mokany et al., 2020). Indicators of soil health, notably soil organic matter, measure the production capacity of agricultural soils. Indicators relevant to wild capture fisheries reflect the range of ecosystem services which support them, including clean water, sufficient freshwater flows, intact nursery habitats, and sustainable management of target and nontarget populations (Barbier, 2017). Biosphere integrity is encapsulated in several UNCBD goals (Díaz et al., 2020). Its measures are derived from currently available remotely sensed vegetation and land-use data with anticipated improvements in measurement quality and capacity to include soil and aquatic ecosystems (DeClerck et al., 2021).

2.3. Livelihoods, poverty, and equity

Food systems support the livelihoods of hundreds of millions of people, as well as countless others whose food security depends on them (FAO, IFAD, UNICEF, WFP and WHO, 2020; FAO, 2017). Ensuring food systems are inclusive requires assessing and monitoring the livelihoods of those involved in food supplies and environments. Doing so enhances the ability of policymakers to address the needs of poor and vulnerable groups, and of others who stand to lose in the transformation process. To identify boundaries around the aspects of livelihoods related to food system transformation, we define the scope of this thematic area as the livelihoods of those working in any part of food systems. Most people who work in food systems are among the poorest and most vulnerable in the world, and that poverty occurs in rural and urban areas, though in terms of absolutely global numbers it is disproportionately rural (Kruseman et al., 2020; P. Pingali et al., 2019; World Bank, 2020; World Bank Group, 2016). The conceptualization of those livelihoods draws on frameworks that consider peoples' assets, capabilities, strategies, and vulnerabilities, as well as multidimensional issues of labor, social protection, and human rights (Giron-Nava et al., 2021; Leach et al., 2020; UNDP, 2020).

Dismantling barriers to just and equitable livelihoods, such as lack of access to productive resources or decent jobs, requires institutional changes, policy support, and investments to empower those whose livelihoods are tied to food systems (IFAD, 2016; OECD, 2019). Invisibility in statistics and exclusion from public programs are major challenges to documenting and supporting food system-based livelihoods. For example, the informal food economy is typically excluded from policy and planning, despite its critical contribution to the food security of low-income citizens (Resnick, 2017). Another example is that fisheries subsidies are disproportionately given to large-scale fishing fleets, leaving out many smaller-scale women and youth who work in the fisheries sector and low-income countries (Schuhbauer et al., 2017). What is not visible is neither valued nor viewed as a viable part of food system transformation. To advance monitoring in this area, we emphasize the critical importance of data disaggregation to understanding the unique livelihood challenges that face women, youth, and minoritized groups working in food systems.

2.3.1. Indicator domains

Poverty and income: Despite their importance, the livelihoods earned in food systems are often insecure and insufficient to support quality standards of living. Agriculture employs a disproportionate share of the world's poorest people (Castañeda et al., 2018; World Bank, 2007), and poverty affects workers throughout food systems (Global Panel on Agriculture and Food Systems for Nutrition, 2020), across the rural–urban divide, and at all country income levels (Klassen & Murphy, 2020). Wages in food systems are commonly below minimums established for other sectors (Giron-Nava et al., 2021; Renkin et al., 2020), particularly for migrants, women, and other minoritized groups (Béné & Friend, 2011; Freeman, 2010; Palumbo & Sciurba, 2018). Measuring the incomes, poverty levels, and welfare of workers in food systems is necessary to monitor progress in its transformation, but the data available to do so are sparse, scarce, and uneven (Dang et al., 2019). Income-based and multidimensional measures of poverty are measured in most countries (Alkire & Kanagaratnam, 2020; World Bank, 2017), but income derived from food systems and clear identification of food system-tied livelihoods are not.

Employment: Monitoring employment quantity and quality is essential to improving equity and livelihoods in food systems. Existing data can capture the scale of primary employment in agriculture, food manufacturing, and food and food-related hospitality services (Thurlow, 2021). Coverage is uneven in other food-based jobs, such as trade and transportation, or where it is difficult to capture the contributions of family labor, seasonal fluctuations, and secondary employment. Fig. 3 presents a range of current estimates to quantify the magnitude of livelihoods tied to food systems and illustrates the empirical challenges. We note that the quantification exercise is an essential part of understanding the welfare of this group, but that the number of livelihoods tied to food systems is not an indicator of transformation. Once identified, indicators such as labor productivity, which is closely tied to income and wages, can reflect the quality of employment (Amin et al., 2019; Zimmermann, 2020).

In addition to quantity, it is important to monitor aspects of job quality. This refers to various aspects of working conditions, including slavery, exploitation, harassment, worker safety, and labor rights (ILO, 2018). Women and informal, migrant, undocumented, and "gig" workers in food systems are especially vulnerable to exploitation in poor quality jobs (Davies, 2019; Goldstein, 2016; Hunt, 2016; Palumbo & Sciurba, 2018). Data on these issues are, however, generally limited or lacking.

Social protection: Universal social protection, i.e., guaranteed minimum access to healthcare, pensions, income or food by vulnerable or low-income citizens regardless of their employment status, is particularly important to support the livelihoods of many food system workers due to the widespread vulnerability and poverty described above (Devereux, 2016; Gentilini & Omamo, 2011). Further, many social protection programs are tied to food, and therefore may play multiple roles in food system transformation. Current indicators of social protection capture spending, while others assess performance, including coverage and impacts on poverty and inequality. Measuring the coverage of food systems workers by national universal social protection programs will be particularly important for our framework. Moreover, existing indicators do not account for informal forms of support, such as remittances, which have important impacts on livelihoods, especially in low-income countries (Housen et al., 2013; Stavropoulou et al., 2017).

Rights: Ensuring the human rights of all is key to transforming food systems from their current state to one that is equitable (Anderson, 2008). The most basic right in food systems is the right to food, codified in the Universal Declaration of Human Rights; the International Covenant on Economic, Social and Cultural Rights; and the UN Declaration on the Rights of Peasants and Other People Working in Rural Areas

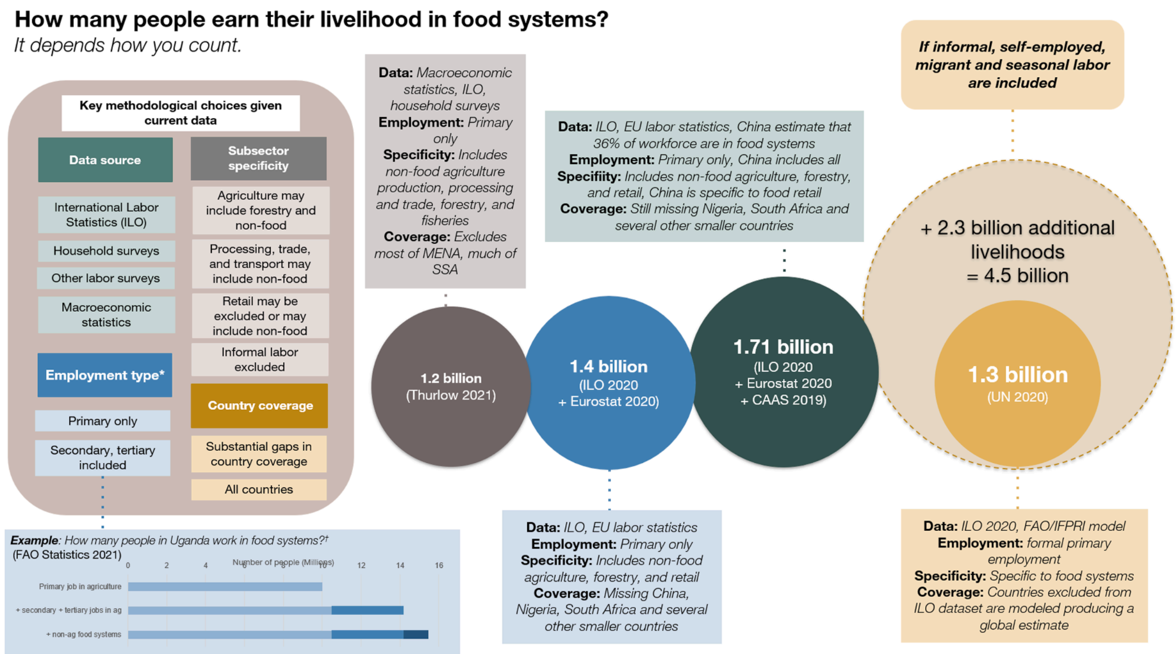

Fig. 3. Challenges in identifying livelihoods tied to food systems. Legend: * Official labor statistics (i.e., International Labour Organization [ILO] statistics) count a person as employed if they worked for at least one hour in the reference period for pay or profit (ILO, 2021). Multi-topic household surveys typically ask about the activities in which a person spent the most time within a reference period (prior seven days, one month, and/or 12 months, depending on the country), defining primary and secondary activities based on reported time allocation. ** Circles drawn to scale.† Uganda estimate computed by FAO Statistics using the Uganda National Panel Survey (2013–14) and FAO Rural Livelihoods Information System (RuLIS). May undercount work in food retail and services. Sources: (Chinese Academy of Agricultural Sciences, 2019; Eurostat, 2020; ILOSTAT, 2020; United Nations, 2020).

(United Nations General Assembly, 1948, 1966, 2018). The rights to water and participation in public affairs have also been codified by the UN (Office of the United Nations High Commissioner for Human Rights, 2018; United Nations General Assembly, 2010). Specific rights that affect the livelihoods of food system workers include land and property rights, especially for women; rights to unionization and collective action; and rights to public space, which are crucial for informal workers (Anderson, 2008; Freeman, 2010; Giron-Nava et al., 2021; Meinzen-Dick et al., 2019).

Monitoring rights is essential to address the reality that current power imbalances favor large corporations, often serving their vested interests at the expense of smallholders', workers', and consumers' rights (Bisoffi et al., 2021; Canfield et al., 2021; Stuckler & Nestle, 2012). Large-scale land acquisitions offer just one example of how current power structures that drive existing food systems manifest in undesirable outcomes; they underscore how larger actors have overwhelming influence and smaller actors comparatively little resulting in adverse residual impacts beyond localized effects (i.e., harm extends beyond local communities and smallholders) (Liao et al., 2021; Nolte, 2014; Nolte & Voget-Kleschin, 2014). Even where there are policies in place to avert social welfare losses, such as Zambia's law requiring compensation of internally-displaced persons, efforts to protect the well-being of the vulnerable have had limited success (Chu et al., 2015). While existing indicators (such as FAO's Gender and Land Database, indicators to monitor SDG 5, or the Social Institutions and Gender Index) capture some of these areas, the data are not available across the globe and the most vulnerable remain invisible in current frameworks and databases.

2.4. Governance

Although governance is critical to achieve positive food system transformation, there are multiple challenges to conceptualizing and measuring it. First, "governance" depends on what is being governed—food-producing natural resources, food products, food environments, or private industry, among others—and who has the authority to govern in a particular domain (van Bers et al., 2019). Second, governance spans multiple geographic scales and administrative levels, requiring different priorities to be addressed and different coordination mechanisms to be present at various levels (Gereffi et al., 2005; Hospes & Brons, 2016; Tefft & Jonasova, 2020; Termeer et al., 2018). Third, different disciplines operationalize governance in quite distinct ways. The major foci include institutional structures and policy interventions; citizen rights to food, human rights violations, and exploitation perpetrated by food system actors; asymmetrical power between consumer and industry groups; market power and corporate concentration and their influence on prices, products, policies, research, and innovation; and political incentives by leaders to reform practices detrimental to healthy, sustainable, resilient, just, and equitable food systems (Clapp, 2018; Clapp & Purugganan, 2020; Davies, 2019; Delaney et al., 2018; Digal & Ahmadi-Esfahani, 2002; Gereffi et al., 2005; Gillespie & Nisbett, 2019; Hospes & Brons, 2016; Ruggie, 2018; van Bers et al., 2019).

Recognizing these challenges, our initial conceptualization of food system governance takes an expansive definition inclusive of the different perspectives above, while also emphasizing policy processes that would be relevant across different food system domains and scales. We propose a working definition of governance for positive food system transformation as the mode of interaction among the public sector, private sector, civil society, and consumers to identify, implement, resource, and monitor solutions for achieving healthy, sustainable, resilient, just, and equitable food systems without leaving anyone behind. Collectively, attention to these domains can foster alignment and coherence across different food system actors, their activities, and progress toward results. Even more so than for other thematic areas in this monitoring framework, there are substantial data gaps specific to food system transformation that will need to be addressed by developing new indicators and collecting new data.

2.4.1. Indicator domains

Shared vision: Shared vision refers to inclusive, participatory processes to identify priorities and provide guidance on desired outcomes across all the thematic areas of food system transformation. It can be measured by, for example, whether governments establish multi-stakeholder platforms incorporating relevant stakeholders at regular intervals. Where they have been used (Kusters et al., 2018), such platforms uncover hidden power dynamics and informal relationships that constrain progress (Barzola Iza et al., 2020). Country and independent summit dialogues as part of the UNFSS process have also catalyzed the development of shared visions for food systems in many places (Synthesis of Member State Dialogues Report 1, 2021; Synthesis of Member State Dialogues Report 2, 2021). Further proxies for the participatory environment include indices on freedom of association and civil society organization (te Lintelo & Pittore, 2020), including those captured in the Rural Sector Assessments by the International Fund for Agriculture Development or the civil society index by Varieties of Democracy (V-Dem). Critical consideration is warranted regarding who are considered relevant stakeholders in such processes (Leach et al., 2020) and requires in-country expert assessment as is already done for the Comprehensive Africa Agriculture Development Program (CAADP) process led by the African Union (Department of Rural Economy and Agriculture and Union, 2020).

Achieving shared vision also requires redressing power imbalances, which include market competition and asymmetries in influence that different actors hold in negotiations. A growing body of literature measures the level of concentration and market power in global food value chains, highlighting how such concentration of power in the hands of a few corporations has a wide range of negative consequences for food systems (Bui et al., 2019; Fuglie, 2016; Fuglie et al., 2011; Howard, 2016; IPES-Food, 2017; Swinburn et al., 2019). The greater the market power held by a firm, the more potential it holds to shape markets and features of food environments (e.g., product mix, placement, prices), influence policies and governance through lobbying and other means, and steer research and development agendas (Clapp, 2018, 2021; Diez et al., 2018; Fabbri et al., 2018; Meghani & Kuzma, 2011; Ruggie, 2018). To date, no agreed upon indicators or global databases exist to monitor the degree of market power held by international corporations in food systems (including agricultural input and output markets as well as the retail food product industry), but the existing literature offers a pathway forward to do so (P. Baker & Friel, 2016; Clapp, 2018; Digal & Ahmadi-Esfahani, 2002; Howard, 2016; IPES-Food, 2017; McKeon, 2014; Murphy, 2008; Nes et al., 2021; Swinburn et al., 2015).

Strategic planning and policies: Strategic planning and policies must underpin the shared vision, including relevant legal frameworks and multi-sectoral policy documents that holistically address food systems and reconcile trade-offs. Existing related indicators include the Hunger and Nutrition Commitment Index (HANCI), which tracks whether governments have established nutrition policies aligned with other sectoral agendas and whether the right to food has been incorporated in food policies, or the Food-EPI protocol to monitor food environment policies. Since horizontal coordinating bodies are viewed as essential to address the multi-sectoral nature of nutrition policies, for example, their existence for food systems also should be assessed (Gillespie & Nisbett, 2019; Haddad, 2013; Nisbett et al., 2014). More broadly, the general degree of public sector policy coordination is indicative of the potential to develop well-aligned food system policies, which is assessed regularly by the Bertelsmann Transformation Index through subjective evaluations of the extent to which “the government coordinates conflicting objectives into a coherent policy” (Hartmann, 2016). Further, a food system policy index could be developed to monitor specific policies deemed essential to achieving the goals of food system transformation articulated throughout the thematic areas we address in this paper.

Effective implementation: Effective implementation requires the alignment of strategic planning and policies with state, private sector, and civil society capacities that are supported by sufficient human and financial resources. Monitoring the level and stability of resource disbursements by governments in line with their food system policy frameworks and national and international commitments is one way to measure implementation. The HANCI, Scaling Up Nutrition, Global Nutrition Report, and Global Network against Food Crises already track budget allocations for food security and nutrition commitments, while the CAADP tracks government expenditure on agriculture. Sustaining expenditures over time requires they be funded by revenue from taxes as opposed to international donors; where new food system commitments are tracked, it is important to disaggregate by funding source. Governments must also allocate relevant human resources—including agricultural extension agents, food safety and quality regulators, cadastral agents, and health providers—to ensure policy actions can be realized. And in more decentralized countries, where autonomy and authority for functions critical to food systems have been devolved to subnational actors, multilevel coordinating bodies are necessary for effective implementation (Gillespie & Nisbett, 2019; Hodge et al., 2015). Other actions could be evaluated against the UN guidelines on effective implementation of the right to participate (Office of the United Nations High Commissioner for Human Rights, 2018). Finally, there is an increase in sustainable finance mechanisms that align corporate incentives with sustainability goals (Fatemi & Fooladi, 2013; Lehner, 2016; Quatrini, 2021). To date, the adoption and use of sustainable financing in food system sectors has lagged behind other areas of economic activity (Barrett, 2020; Koerner et al., 2020; Loboguerrero et al., 2020), but monitoring its adoption and concomitant outcomes within food systems offers another potential measure of effective implementation.

Accountability: Accountability mechanisms use monitoring and evaluation to learn what policies work or not, and reward (or sanction) public and private sector actors who deliver on commitments (or fail to). Food system transformation requires so many actors to work coherently toward the shared vision that collective action problems—when all stand to benefit from coordinating for a collective outcome but individual incentives favor acting in one’s self-interest—can emerge, making accountability particularly necessary (Resnick, 2020). Indicators of accountability, and the tools that track those indicators, could include the presence of mechanisms such as public sector performance contracts (e.g., the Government of Rwanda’s *imihigo* accountability system) (World Bank Group, 2018); community scorecards whereby citizens independently monitor and report public or private sector performance on agreed commitments (e.g., for health services in Ghana and Uganda) (Kiracho et al., 2020; Ghana community scorecard., 2021); or global/regional comparative performance metrics that rely on peer pressure to compel governments or the private sector to alter behavior (e.g., CAADP’s Agricultural Transformation Scorecards, the Access to Nutrition Index, and the World Benchmarking Alliance’s evaluation of private food sector actors). In the domain of mandatory international commitments, the UN human rights framework holds sovereign states and, increasingly, corporate actors accountable, and reports are regularly presented at the UN Council on Human Rights (FAO, 2008). In general, more transparent environments that allow for the free exchange of information and timely access to data are more likely to facilitate accountability of food systems. Several governance data initiatives can approximate such environments (e.g., V-Dem, Freedom House, Open Budget Initiative), though none are specific to food systems at the present time.

2.5. Resilience and sustainability

2.5.1. Resilience of food systems

While “resilience” has been used in various parts of the academic literature for almost a century (Lade et al., 2020b; Nara and Inamura, 2020), it only recently emerged in the field of food systems (Béné, 2020; Béné et al., 2021a; Hansen et al., 2020; Meyer, 2020; OECD, 2020; P. Pingali et al., 2005; Ponis & Koronis, 2012; Puma et al., 2015;

Schipanski et al., 2016; Seekell et al., 2017; Tendall et al., 2015). Pragmatically, very little is known about what makes a food system resilient (Béné et al., 2021b; OECD, 2020). Yet understanding and being able to measure food system resilience is critical to guide food systems toward more sustainable outcomes.

We define food system resilience as the ability of different individual and institutional food system actors to maintain, protect, or quickly recover the key functions of that system despite the impacts of disturbances (Fan et al., 2014; Harris & Spiegel, 2019; Tendall et al., 2015). For instance, weather-related extreme events, such as drought or flood, or longer-term local disturbances, such as conflict, corruption, COVID-19 lockdown measures, local insecurity, or seasonal road inaccessibility, can severely affect local and regional food supply chains and prevent them from operating efficiently (Bakalis et al., 2020; Barrett, 2020; Brück & d'Errico, 2019; Harvey et al., 2014; Hendrix & Brinkman, 2013; Laborde et al., 2021; Sabates-Wheeler et al., 2008). These disturbances generally result in physical and economic disruptions of food systems, leading to food shortages, food loss, or price volatility, with implications for the food security and nutritional status of local populations. A resilient food system would maintain or quickly recover food security following shocks and stresses (Fan et al., 2014; Harris & Spiegel, 2019; Tendall et al., 2015). Beyond maintaining or protecting people's food security, resilience is central to other key functions of food systems, including contributing to climate mitigation and adaptation (Ching et al., 2011; Ericksen, 2008); safeguarding or restoring ecosystem health (Ingram, 2011; Lade et al., 2020a); and providing income stability for the millions who earn their livelihoods in food systems (Fan et al., 2014; Béné et al., 2021a).

Finally, there is a growing consensus that food system resilience is strongly related to food system sustainability (Seekell et al., 2017). Resilience contributes to sustainability in the sense that a food system cannot be sustainable in the long run if it is not resilient to shocks and stressors in the short term. In essence, resilience is a necessary condition for sustainability.

It is generally recognized that measuring resilience is methodologically very challenging. Part of the challenge is that conceptualization of resilience is still being debated, with different approaches leading to different measurement challenges. In a recent review, Barrett et al. (2020) identify three broad conceptualizations employed for the resilience concept applied to individual or household well-being – resilience as capacity, as a normative condition, or as return to equilibrium (Barrett et al., 2020). Proponents of resilience as capacity, the most common conceptual approach, see the main challenge as being that resilience cannot be measured directly, requiring proxy indicators (e.g., resilience capacities) and measuring elements related to resilience (e.g., exposure to shocks) (Alinovi et al., 2010; Béné & Doyen, 2018). Advocates of resilience as a normative condition focus on measuring resilience as an individual's probability of achieving at least some minimal standard of living conditional on a wide range of observable characteristics, and exposure to stressors and shocks (Barrett and Constas, 2014). Resilience as "return to equilibrium" is closer to how ecology and engineering frame the resilience concept, and the focus is on measuring ex-post recovery after a shock (Ganin et al., 2016; Holling, 1996).

The approaches above are all centered around individual or household well-being. Another challenge, particularly relevant here, is whether different measures can be scaled up or aggregated beyond the level for which they were conceptualized, or if different measures are needed that consider emergent properties of a system at a more aggregate level. Resilience is scale-dependent, meaning it can be observed at several scales simultaneously, and resilience at one scale (e.g., household) does not guarantee resilience at another (e.g., district), even if an internally-consistent approach is applied across scales (Béné et al., 2011; Mock et al., 2015). This means that measuring resilience at different scales for the same system may show completely different results. Conflict, in particular, can create such conditions where increasing resilience at one level can undermine resilience at another, which is especially relevant since resilience concerns commonly arise in conflict-affected areas (Bateman et al., 2016; Brück & d'Errico, 2019; Ensor et al., 2018; Hendrix & Brinkman, 2013; Jaspars, 2021; P. Pingali et al., 2005). Recent progress on defining and measuring resilience in the humanitarian and food security literature guided the selection of indicator domains described below (Constas et al., 2014; d'Errico et al., 2016; Knippenberg et al., 2019; Puma et al., 2015; von Grebmer et al., 2013).

2.5.2. Sustainability of food systems

Although sustainable food systems are discussed extensively in the literature (Béné et al., 2019b; Eakin et al., 2017; IPCC, 2019b; Kremen, 2015; Swinburn et al., 2019; Willett et al., 2019), interpretations of "what a sustainable food system looks like" and how to measure that sustainability vary greatly, leaving the answer unclear ; Béné et al., 2019b; Johnston et al., 2014). It is broadly acknowledged that food system sustainability transcends multiple systems: health, environmental, economic, financial, social, and political (Caron et al., 2018; Dasgupta, 2021; FAO, 2018; Global Panel on Agriculture and Food Systems for Nutrition, 2016; IPES-Food, 2016; Johnston et al., 2014; Melesse et al., 2020; Rockström et al., 2020; Westhoek et al., 2016).

We use a multi-dimensional definition of sustainability that is inclusive of all food system components and outcomes: nutrition; environmental considerations; and economic, social, and equity aspirations, as well as policy coherence and accountability (Global Panel on Agriculture and Food Systems for Nutrition, 2020; OECD, 2021; Thow et al., 2018). Progress toward sustainability cannot be achieved without political commitment or the management of inherent trade-offs and conflicts of interest in food system goals (Webb et al., 2020). Overall, this means that food, nutrition, climate, and environmental security, as well as decent livelihoods and human rights are equally intransgressible goals now and for future generations (Caron et al., 2018; Mainali et al., 2018). Recognizing these core values is instrumental to a holistic understanding of food system sustainability.

Measuring food system sustainability provides a clear, normative guide for decision-making. Past food system "transformations" such as "supermarketization" (Popkin & Reardon, 2018; Reardon et al., 2005; Reardon & Timmer, 2007), agricultural intensification (Mahon et al., 2017), crop and diet homogenization (Khoury et al., 2014), or even the Green Revolution (Patel, 2013; P. L. Pingali, 2012) generated both positive and negative outcomes. It is therefore important not only to monitor and report changes in food systems but also to associate those changes with expected positive outcomes (Searchinger et al., 2019).

Measuring sustainability can also unite the issues addressed in the preceding sections into one comprehensive element as an attempt to "put all the pieces back together." Doing so embraces the holistic nature of food systems (Ericksen, 2008) and emphasizes that the sustainability of food system transformation involves more than just the sum of each outcome moving toward its own individual target.

Measuring sustainability can capture the interactions, interdependencies, and dynamics of outcomes. Accumulating empirical data suggests that not all food system outcomes can be improved simultaneously and that managing and navigating compromises may become an important part of building or restoring sustainability. Better understanding and monitoring of those interactions is thus critical, and doing so makes it possible to explore the synergies or trade-offs between different food system elements and goals (D'Alessandro et al., 2021; Gusenbauer & Franks, 2019; Kremen, 2015; Mainali et al., 2018; Phalan et al., 2011; Runting et al., 2019).

2.5.3. Indicator domains

Four domains pertain to resilience, complemented by two domains for sustainability.

Exposure to shocks: Assessing food system resilience requires first assessing and documenting the adverse events that affect those systems (Choularton et al., 2015). Some events have been mentioned previously: droughts and flooding, but also typhoons/cyclones or natural disasters

Table 2
Consultative process for indicator domain finalization and initial indicator selection.

Stage	Goals	Procedures
Vet domains and identify candidate indicators	Gather feedback to refine the indicator domains. Identify a long list of candidate indicators.	Hold virtual stakeholder workshops by region and/or theme. Survey a broad and diverse (discipline, sector, geography, role) set of external experts. Gather indicator proposals from our research group.
	Eliminate any candidate indicators that clearly fail to meet identified criteria (see below).	Evaluate proposed indicators against criteria. Eliminate any indicators that do not meet the criteria.
Refine the list of indicators	Assess the coverage of indicators across indicator domains and thematic areas.	Assess overall menu of indicators on the following dimensions: Within and across thematic areas and domains for any redundancy with multiple indicators of the same underlying concept.Any multi-purpose indicators used in more than one indicator domain. Gap analysis.
	Reduce indicators where there is any potential redundancy.	Rank indicators against criteria and propose a shortlist. Decisions regarding inclusion/exclusion of multi-purpose indicators made by a combination of relevant authors across working groups. Where 2 or more indicator options exist for the same concept, use a decision panel where working group members in favor of each indicator present a case for that indicator to a panel of external expert decision-makers.
Finalize indicators for analysis in 2022	Gather feedback from external stakeholders on proposed indicator list. Develop final list and all supporting documentation.	Survey stakeholder workshop participants and prior survey respondents, as well as any new stakeholders identified in the interim. Address any major comments. Finalize indicator list. Finalize supporting documentation of all decisions and indicator *meta*-data.

(e.g., earthquakes). Others include local or regional economic crises, political unrest, pandemics (e.g., avian influenza, COVID-19), pest outbreaks (e.g., desert locust, fall armyworm), and protracted crises (including population displacements and migrations) (UNISDR, 2015). Internationally available country-level data (e.g., International Disaster Database, Global Disaster Information System) capture the nature, frequency, and intensity of the main shocks that affect food systems, thus providing one indicator relevant for food system resilience.

Resilience capacities: Though issues of resilience measurement are still being debated, the most widespread approach, is to measure resilience capacities (Béné et al., 2020b; Constas et al., 2014). These are the features that are expected to make a system or its actors more resilient. Though evidence remains sparse, they are generally accepted to include characteristics such as redundancy (Fader et al., 2016), diversity (Dainese et al., 2019; DuVal et al., 2019; Haughey et al., 2018; Lade et al., 2020b; Renard & Tilman, 2019), flexibility, connectivity, anticipation, self-efficacy (Béné et al., 2019a), or access to insurance or formal credit (Pomeroy et al., 2020; Salignac et al., 2019). Potential indicators of resilience capacities include food system actors' adaptive capacities (e.g., connectivity, social capital), social cohesion, or measures of value chain flexibility, such as the new FAO Dietary Sourcing Flexibility Index that measures the diversity in the different pathways to source a unit of food. From a food system perspective, focusing on resilience capacities has the advantage that proxies can be envisaged at different scales, tailored to available data, and interpreted as a contribution to resilience at the relevant scale.

Agrobiodiversity: There is a large, well-established body of evidence that agrobiodiversity plays an important role in building resilience in crop, livestock, forest, fishery, and aquaculture production systems. Interactions between genetic, species, and ecosystem diversity at different spatial scales maintain stability in the face of increasing occurrence of shocks and stresses, enable adaptation, and support recovery from disturbances (Dainese et al., 2019; DuVal et al., 2019; Haughey et al., 2018; Renard & Tilman, 2019). Moreover, agrobiodiversity secures the resilience capabilities of food systems for future generations and yet-unknown shocks.

Food security stability: One of the most important aspects of food system resilience is the capacity to maintain people's food security in the face of shocks (Béné, 2020; Constas et al., 2014). Monitoring the stability (e.g., food availability, access, and utilization) of the food security indicators discussed above, over time, is an essential element of food system resilience (Béné, 2020). The emphasis in monitoring the indicators in this domain is on their variability over time rather than absolute levels at each reporting. For example, the FAO Price volatility index measures stability of food access and the per capita food supply variability index measures stability of food supply availability.

Food system sustainability index: We propose developing two complementary indices to capture the various elements and relationships of sustainable food systems. The first would aggregate all the indicators in the preceding thematic areas into an all-inclusive, unidimensional composite index. The second would incorporate a parsimonious set of emblematic indicators (still covering all thematic areas). This dual approach aims to balance and benefit from the strengths of each type of index, with comprehensiveness from the first and ease of interpretation from the second (Becker et al., 2017). Both indices can build on well-established methodologies already used in international initiatives (e.g., Human Development Index [HDI] and the more recent Planetary Pressures Adjusted-HDI, Global Hunger Index), and recent analysis of food system sustainability (Béné et al., 2019c; Chaudhary et al., 2018; The Economist Intelligence Unit, 2016), with attention to the need for decomposition to make the data useful and interpretable by policymakers over time (Barclay et al., 2019).

3. Moving forward

The authors of this *Viewpoint* represent an international, multidisciplinary research collaboration, which includes experts from 27 academic institutions, non-governmental organizations, and UN agencies from nearly all continents. As we go forward, we are committed to consultative processes, inclusiveness, and transparency. We welcome new collaborators and are actively seeking to expand our disciplinary and experiential diversity. Over the next year, we intend to submit our framework as proposed in this *Viewpoint* and the selection of indicators to external consultation through an adapted Delphi process. We will use that process to determine the initial set of indicators for which data currently exist, or can feasibly be collected, to analyze in a subsequent manuscript planned for 2022.

Beyond that, we intend to update and expand the monitoring and analyses in subsequent biennial publications. Our foci in the coming years will include deepening the complex systems science in our analytical approach through analyses of interactions and feedback loops; contributing to new indicator development and data collection where necessary and feasible to undertake ourselves; and continuing to expand collaborations with others, particularly where we can expand the interdisciplinary dialogue and review around the specific indicators, interpretation of their status and trends, and systems analyses. We hope

Table 3
Indicator criteria.

	Relevant	High-quality	Interpretable	Useful
Definition	Indicator measures something meaningful for food systems across a variety of settings and during relevant time periods.	Best practices in data collection and aggregation (including quality controls) and rigorous statistical methodologies.	Clear desirable direction of change, comparable across time and space, and easily communicated.	Scale and rate of change align to policy and decision-making and meet articulated information needs.
Required criteria	Can be mapped to the food system framework Non-redundancy (one indicator per concept) Observing change is possible within a decade Existing data have been updated in the last 10 years and will be updated at least once before 2030	Well-documented methodologies and metadata Grounded in accepted theory and practice	Quantitative indicators Change has a clear meaning Data can be compared across spatial and temporal scales	Addresses issues over which target entities have at least some ability to influence change Adds value to existing data and reporting mechanisms
Desirable criteria	Strong preference for indicators and data in the public domain (or that will be in the public domain where new indicators and data are proposed) Specific to food systems (including systems that drive or are impacted by food systems and their activities) Existing indicators are already widely accepted, new indicators fill an identified gap Direct measures (as opposed to proxies), where possible Country, region, and income-level coverage (indicators that represent best practices but are only available for a small number of countries could be included if it was technically possible to fill in all countries if resources were available) If data are not already collected widely, collection at a minimum of two time points before 2030 is feasible (technically and resourced)	Indicators of latent concepts (i.e., unobservable phenomena such as the experience of food insecurity) have been rigorously empirically validated Methodologies and validation published in a peer-reviewed journal Confidence intervals around point estimates	A directional change is positive or negative Easy to communicate with varied audiences Summary or composite indicators can be disaggregated into coherent components	Thresholds and/or targets have been developed or articulated Demand-driven (i.e., meets the expressed needs of policy/ decision makers)

to develop processes of country-level, multi-stakeholder engagement so that this collaboration—a scientific, desk-based effort—can support the accountability mechanisms and social movements necessary to bring about transformation within countries. Data and evidence can provide support to these actions, but we fully recognize that data and evidence alone are insufficient and that partnerships with groups who can use the evidence to enact (e.g., policymakers, business leaders, direct service organizations, consumers) or call for (e.g., advocates, civil society organizations) change will dramatically enhance the relevance of our work. Supporting civil society, governments, and private sector firms as they endeavor to change food systems is also a way in which we can contribute one form of knowledge—using quantitative Western science—to a dialogue with room for additional ways of knowing (e.g., Indigenous knowledge systems), broader perspectives, and localized priorities and values.

3.1. Consultative processes

In the coming months, we will use an adapted Delphi process to gather feedback on the proposed architecture laid out here, identify candidate indicators, and vet the selection of final indicators to be monitored in the first analysis. Our three-stage process is described in Table 2. Throughout the process we commit ourselves to transparently documenting all decisions and revisiting the indicator list in all subsequent publications to consider any new data or indicators developed in the intervening years.

3.2. Indicator criteria

We conducted a tailored literature review to develop criteria for the indicators to be monitored. Given the known limitations of many of the possible indicators and data sources, we divided the criteria into required and desirable characteristics. We hope the articulation of desirable characteristics can also inspire indicator development and data improvement initiatives. Table 3 summarizes the criteria, and we provide further detail in the supplementary materials.

4. Conclusion

Food systems have undeniably advanced humanity and sustained a growing number of lives, but such gains have not been evenly shared and have come at great cost to nature and the health and livelihoods of many people. In the present era, humanity faces significant challenges across food systems; many people consume poor quality diets, basic functions of the Earth's systems and many living beings are threatened, and deep inequities shape livelihoods tied to food systems and the welfare of those who labor within them. National and global governments are struggling to govern the increasingly complex crises and powerful forces in food systems, especially as the COVID-19 pandemic and climate change have shown the fragility of food systems and the lack of sustainability to continue along the present course. These crises and challenges underscore the urgency to change the trajectory for food systems but also offer great potential to do so (Barrett et al., 2020; Herrero et al., 2020a; Herrero & Thornton, 2020; Klassen & Murphy, 2020; Rosenzweig et al., 2020; Webb et al., 2020). Food systems must be part of the solution, and some existing Indigenous, local, and circular food systems can provide positive lessons for other societies and places. In this context, the good governance of food systems has never been more important, and monitoring is an essential component to support that endeavor.

Data and analyses that are accurate, timely, trusted, comprehensive, and accessible can provide a foundation to sustain accountability mechanisms. High-quality evidence is not sufficient to generate action, but it is critical to facilitate *informed* action founded in deliberate, reasoned consideration of the trade-offs inherent to shifting food systems. Quantifying the impacts of food systems also supports others to develop true cost accounting for food systems (L. Baker et al., 2020; Gemmill-Herren et al., 2021; Hendriks et al., 2021; Kennedy et al., 2021; Rockefeller Foundation, 2021). Monitoring food system transformation in this manner can aid governments in setting priorities and establishing incentives and regulations to align food systems in a transformative direction. Data and evidence also inspire action by civil society, consumers, and governments, which can hold food system actors to account for their commitments and responsibilities. High-quality evidence allows food system actors to undertake "course corrections" and demonstrates those who did, or did not, make needed changes.

We intend to pursue the effort described here, but we cannot address all the data, evidence, and analytical gaps on our own. We hope that others will also heed this call to action and contribute further evidence of successes and challenges in food system transformation and offer actionable recommendations based on that evidence. Doing so can help spur accountability toward inclusive food system transformation, a future where all people have access to healthy diets, produced in sustainable, resilient ways that restore nature and deliver just and equitable livelihoods. This transformation is achievable. Rigorous monitoring is necessary to keep progress on track.

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