frontiers | Frontiers in Sustainable Food Systems

TYPE Review
PUBLISHED 29 September 2023
DOI 10.3389/fsufs.2023.1243466

OPEN ACCESS

EDITED BY
Carola Strassner,
Münster University of Applied Sciences, Germany

REVIEWED BY
Cesare Zanasi,
University of Bologna, Italy
Juan Pablo Sciurano,
University of Parma, Italy

*CORRESPONDENCE
Charles Spillane
✉ charles.spillane@universityofgalway.ie

RECEIVED 20 June 2023
ACCEPTED 06 September 2023
PUBLISHED 29 September 2023

CITATION
Karan R, Mowlds S, McKeown PC, Lundy M and Spillane C (2023) Data for decision-making for sustainable food systems transformation in the Eastern Cape of South Africa: what is needed? *Front. Sustain. Food Syst.* 7:1243466. doi: 10.3389/fsufs.2023.1243466

Data for decision-making for sustainable food systems transformation in the Eastern Cape of South Africa: what is needed?

Romyne Karan[1], Sinead Mowlds[1], Peter C. McKeown[1], Mark Lundy[2] and Charles Spillane[1]*

[1]Agriculture and Bioeconomy Research Centre, Ryan Institute, University of Galway, Galway, Ireland, [2]Alliance of Bioversity International-CIAT, Cali, Colombia

Transforming global food systems to promote food and nutritional security can help alleviate both poverty and ill-health, and support sustainable development. Such transformations need to be tailored and sensitive to the vulnerabilities and needs of marginalized communities yet are hindered by knowledge gaps. In particular, the food and nutrition security needs of the most vulnerable are often poorly understood, as are the policy frameworks and resource requirements associated with meeting their needs. To aid the development of frameworks to address these gaps, we review the current state of indicators relating to food systems for the improvement of food and nutrition security at the national and sub-national levels in South Africa. We identify gaps in the decision-making data in South Africa, including absence of food and nutrition security indicators. Integration of the South African Multidimensional Poverty Index and Food System Dashboard indicators could help address this, especially if applied at a sub-national level. Participatory food system mapping could also link data collection with system-level interactions and feedback loops to inform sub-national stakeholders in achieving food and nutritional security.

KEYWORDS

food systems, transformation, nutrition, indicators, decision-support, marginalization, food flows

Introduction

Food systems comprise multiple interacting drivers that link production and consumption through value chains (Leeuwis et al., 2021). The High Level Panel of Experts on Food Security and Nutrition of the Committee on FAO et al. (2017, 2020) define a sustainable food system as one that 'provides food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised'(HLPE, 2020). While vital for human nutrition and health, and critical components of cultures and economies, maladapted food systems drive environmental degradation and threaten the achievement of sustainable development goals (Crippa et al., 2021). Notably, food systems are not currently providing adequate, healthy nutrition to communities worldwide, contributing to the 'double burden' of malnutrition (Fanzo et al., 2022;

Agostoni et al., 2023) while also failing to support viable, equitable rural economies (Leach et al., 2020; FAO, 2022b).

Food systems are also major contributors to greenhouse gas emissions, land use change and biodiversity loss, the emergence of zoonotic diseases, and negative impacts on soil, water and other natural resources (Willett et al., 2019; WWF, 2022; Anderson et al., 2023). At the same time, food systems are themselves under threat from the impacts of climate change, degradation of resources, and demographic shifts which impact the availability, access, utilization, stability, agency, and sustainability of food: i.e., the six dimensions of food security proposed by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (Mbow et al., 2019; HLPE, 2020; BFAP, 2021; Clapp et al., 2022). The goal of ending hunger and malnutrition by transforming current food system trajectories has gained political momentum, potentially allowing actionable development toward the UN's 2030 Agenda for Sustainable Development (Fanzo et al., 2020a).

The nature, management and regulation of transformed food systems remains complex and contentious due to the many interacting requirements, power dynamics and interests. However, any beneficial transformation will require accurate data at relevant spatial and temporal scales, made accessible to agents of change and relevant stakeholders alike (Fanzo et al., 2021; Béné, 2022). Such transformed systems will need to allow people – as individuals and communities – to meet their nutritional needs, promote adequate living conditions via the food value chain, enhance resilience, and respect planetary boundaries (Rockström et al., 2009; Leach et al., 2013). Indeed, it has been argued that food system transformation should go beyond reducing pressures on land and the environment to restoring or enhancing these, although with many discussions around the implications for land management and the associated financial supports (Mapfumo et al., 2015; Springmann et al., 2016; Khan et al., 2021). To ensure these transformations work for the most vulnerable, deep understanding of the needs of poorer or disempowered groups and communities will be needed, despite the difficulties in accessing data pertaining to the needs of such groups. Finally, any plan for transformation will need to be affordable, accessible, and accepted by multiple stakeholders (Ruben et al., 2021; Körner et al., 2022).

Achieving food systems transformation is particularly pressing in Africa where striking demographic changes are underway and where the risk of climate vulnerability is particularly acute. Compared to 2019, the African continent saw the largest increase in hunger (both in relative and absolute terms); approximately 278 million people are currently affected by hunger on the continent (FAO, 2022a). Climate change impacts on agriculture are expected to affect many African countries severely due to the higher vulnerabilities of many communities and households (Serdeczny et al., 2016; Zougmoré et al., 2021). To contribute toward sustainable and nutritious food systems and drive a significant change in hunger rates in Africa, a greater focus on the transformation of food systems in service of the marginalized is necessary. At the forefront of the 2030 Agenda for Sustainable Development is the recognition of inequality in all forms. The aim of the UN member states and goal of the Agenda is to "leave no one behind" and in doing so, "reach the furthest behind first" so that the most marginalized benefit from development and progress (United Nations, 2017). Marginalized people and communities are those with little or no access to social, economic, political, and/or educational access in society. Some examples of marginalized people include those who face exclusion due to wealth, class or social status; their gender, ethnicity, physical characteristics, immigration status and language; and membership of indigenous peoples and/or religious or sexual minorities, among many other factors (Lerner and Eakin, 2011; Sevelius et al., 2020). Furthermore, the COVID-19 pandemic left marginalized communities with further reduced access to social structures, creating additional concerns for food security (Sevelius et al., 2020). Due to growing impacts of climate variability on food systems in African countries, marginalized people and communities are most vulnerable. The number of vulnerable people in African countries is inherently linked to their risk of undernourishment, which is affected by economic activity and the ability to reduce hunger and poverty (Hosu et al., 2016). As food insecurity continues to hinder livelihoods and as many areas become increasingly urbanized, food systems need to adjust to meet the growing demands for food availability. More sustainable and nutritious approaches to food production need to be developed (Kuusaana and Eledi, 2015).

To inform the required food systems transformation, a comprehensive evidence-base is required. Despite a proliferation of digital tools and platforms to support evidence-informed decision-making for sustainable food systems, decision-makers are still often left 'in the dark' and lack key data to support effective policies and strategies to end hunger and reach the furthest behind (Fanzo et al., 2021; Herforth et al., 2022). Where data does exist within food systems and value chains, it may often be proprietary, having been derived from market research within commercial contexts.

Here, we seek to address the issue of knowledge gaps for more effective decision-making in the context of South Africa's food system by drawing on two existing frameworks: the aforementioned HLPE (2020) six dimensions of food and nutrition security and the John Hopkins-GAIN Alliance Food Systems Framework (Fanzo et al., 2020b), further described below. After summarizing current sources of information pertaining to South African food systems as a whole, we consider specifically how data can be derived at sub-national levels, using one vulnerable region (the Eastern Cape province) as an example. We consider the gaps in the Eastern Cape province data framework for food systems decision-making purposes, focussing on sustainable and nutritious diets. Finally, we consider the possible role and potential of food mapping approaches to enable more dynamic evidence-informed decision-making for food systems transformation.

South Africa's food system

As with most modern food systems, the national food system of South Africa involves the production, processing, sale and consumption of diverse foods, and their associated waste streams, based on national crop production, horticulture, and livestock farming at commercial and subsistence levels, and import of many globally traded commodities such as foodstuffs and production inputs (BFAP, 2021). Figure 1 is an outline of a basic South African food value chain illustrating some of South Africa's major agricultural links in the food value chain.

At the production level, South African agriculture faces risks from climate change and extreme weather events (e.g., drought), degradation of natural resources, inequalities in terms of access to inputs, financial instruments, a decline in commercial farm employment, and issues at the policy, infrastructure and distribution

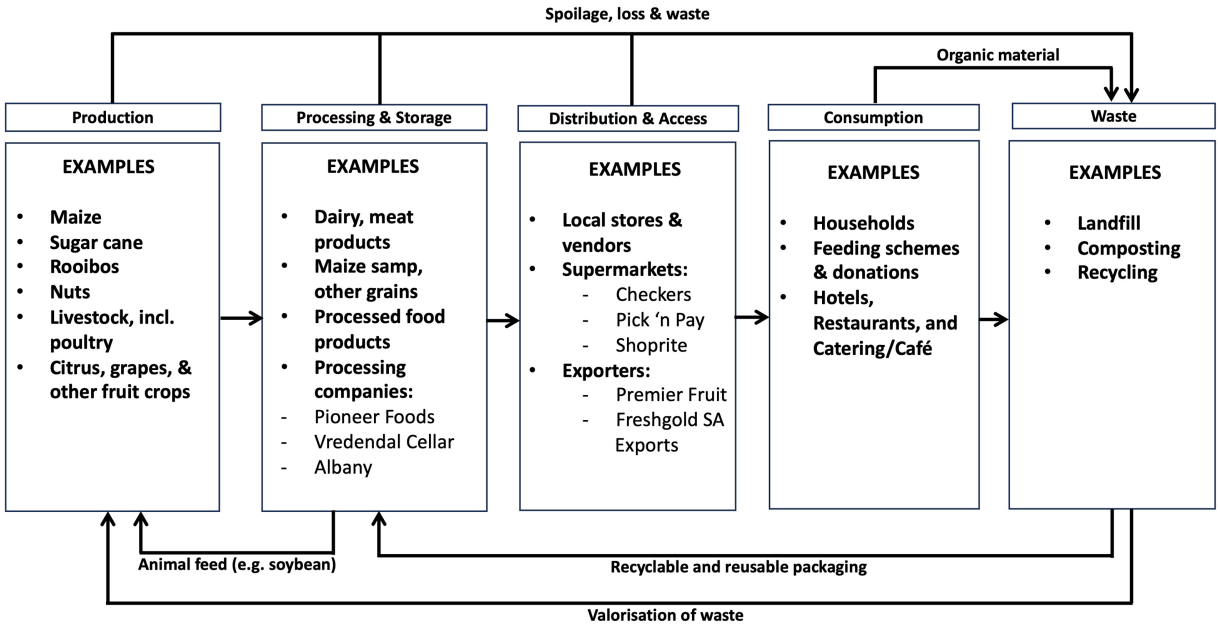

FIGURE 1
Schematic overview of South Africa's food system (adapted from the National Agricultural Marketing Council, 2022, Statistics SA, 2019, CSIR Waste Research Development and Innovation Roadmap Research Report, 2021).

level (FAO, 2022a). Social, cultural and economic factors also influence drivers affecting South Africa's agriculture (Gbetibouo and Ringler, 2009), for example, racial disparities affect farmers' equitable access to water, or disparities in access to skills and capital to access new technologies (FAO, 2022a). The share of agriculture's contribution to South Africa's Gross Domestic Product in the year 2020 was 2.3% (valued at R332 953 million) (Statistics and Economic Analysis, 2020). Although less significant than in some other countries in the southern African region, agriculture plays a vital role in South Africa's economy, and it is also an essential part of life in rural South Africa for food security and as a means of sustaining livelihoods. For example, as of 2017, 2.5 million South Africans relied on subsistence farming (Stats SA, 2019).

Land in South Africa is limited for agricultural purposes due to the impacts of climate change and land under-utilization. The availability of water resources for food production is a concern mainly due to infrastructure challenges, and ecological degradation of rivers, wetlands and soils (BFAP, 2021). Further, South Africa is projected to become hotter and drier, with reduced precipitation which will be accompanied by droughts and flooding (Blignaut et al., 2009; Gbetibouo and Ringler, 2009; Hosu et al., 2016).

In recent years, South Africa's reliance on imports of food has increased. For example, rice imports have increased whilst maize and wheat production in South Africa have decreased (Hendriks, 2014; BFAP, 2021). At the same time, input costs have increased for farmers as exemplified by the case of maize farmers; with a contributing factor being the cost of fertilizer. As a staple of the South African food basket, the increasing costs of maize creates concerns around the affordability of basic food items for low-income households (Bosiu et al., 2017). Hence, households face many limitations to food production and access, both economic and non-economic, which may in turn lead to food insecurity risks (Oldewage-Theron and Kruger, 2011). Some also argue that a contributing factor to the growing vulnerabilities of South African communities is the poor management of institutional interventions for food security and the drivers behind food security (Hosu et al., 2016). According to Musemwa (2013) and Ningi et al. (2021), these include gender roles where female household heads are associated with a household being less food secure, lack of ownership of arable land, household size where larger households result in a higher incidence of food insecurity, households that have access to credit also have high interest rates (inflation across the board is a contributing factor). Lastly, many women in rural areas often lack access to education which may decrease their purchasing power. Due to cultural and socio-economic reasons, women are often not allowed to take on certain roles which in turn affects food security. These are powerful limitations to food security (Ningi et al., 2021), making access to food challenging, whether produced through subsistence farming or through local stores and supermarkets (Oldewage-Theron and Kruger, 2011).

South Africa is experiencing increasing urbanization and food security concerns due to climate variability, which is exacerbated by marginalization in many parts of the country. The Bureau of Food and Agricultural Policy (BFAP) estimated that approximately 50% of the South African population are unable to afford the "thrifty healthy food basket" of 2021 (BFAP, 2021), and the cost of this food basket is expected to increase through 2022 [This is the South African context food basket consisting of 26 food items from all food groups for a family of four, which was projected to increase to R3 036 in 2022 from R2 921 in 2021 and from R2 778 in 2020 (BFAP, 2021)].

Urbanization in South Africa, as in many countries commonly considered developed or emerging economies, can be associated with both positive and negative nutritional impacts (Fanzo and Davis, 2019; Fanzo et al., 2022; FAO, 2022a). Food stores of different sizes, specialisms and ownership models have become critical sources of

food throughout South Africa (Pereira et al., 2014), both for staples such as cereals and other foods, including exotic and more processed produced (Shisana et al., 2013; Battersby and Haysom, 2019). Even though food may be highly accessible within communities, Ningi et al. (2021) highlight that access to food is still inadequate due to socio-economic limitations. Further, households with land ownership are more food secure than households without land ownership (Musemwa, 2013; Ningi et al., 2021); therefore, home gardens or household food production can assist in access to food (Temple et al., 2011), even in a context of urbanization and store-bought produce.

Enabling decision making for food system transformations in South Africa

Decision-making for food systems modifications is complicated by trade-offs, co-benefits and powerful feedback/forward loops relating to decisions made at any node in the food system, which also implies the existence of multiple opportunities and levers that could be used to effect change. Food systems dashboards (FSD) are considered to be useful tools for ordering data so as to assist decision-makers to prioritize actions addressing food systems challenges (Fanzo et al., 2020b; Zhou et al., 2022). For the purposes of this paper, a food systems dashboard is considered to encompass any digital, openly accessible tool that provides decision-makers (including investors, policymakers, civil society, academia, etc.) with a range of information and data to support effective decision-making processes (examples are provided below). The tools are described as being useful for improved collective action, targeting efforts by comparing across regions or countries, or for prioritization of pathways by identifying national needs and gaps in food systems, for example to signal at risk areas (e.g., for market access or food consumption), identifying the drivers of hunger (Fanzo et al., 2020b; Zhou et al., 2022; WFP, 2023).

FSDs may either attempt to incapsulate all relevant data pertaining to a defined area (e.g., a country), or target particular aspects of transformation. For example, the former category includes the Food System Dashboard which was developed by John Hopkins University and GAIN (Zhou et al., 2022), while the latter category includes the Hunger Map Live Dashboard which was created by the World Food Programme (WFP, 2023). The John Hopkins University and GAIN FSD makes use of approximately 150 indicators from more than 30 sources to describe, identify, assess, and enable action for the betterment of food systems (Fanzo et al., 2020a,b). To facilitate use of the John Hopkins University and GAIN dashboard by decision-makers, the John Hopkins University and GAIN food systems framework relates the different yet connected components surrounding food systems. The components include food supply chains, food environments, individual factors, and consumer behavior, which are further broken down to sub-components. Furthermore, relevant indicators for some of the outcomes of food systems including diets, nutrition and health, social, economic and environmental outcomes are included (Fanzo et al., 2020b). In principle, the Dashboard is intended to provide information for policymakers to utilize in decision making through the provision of national data and the capacity to compare across similar countries (Fanzo et al., 2020b). The data provided on the FSD country profiles relies on multiple sources and represents the latest available indicator data. For instance, the John Hopkins University and GAIN FSD country profile for South Africa contains a range of national level indicators (Supplementary Table S1).

However, existing FSDs also face data gaps, or struggle to model how different food system processes may influence each other, including trade-offs between these processes and the outcomes of any such trade-offs. Some have suggested the need for tools to explicitly analyse statistical data to predict future trends for the use of policy-makers and other food system actors (Fanzo et al., 2020b). Different dashboards may also take different approaches to data collection, e.g., for household dynamics, food processing and distribution, advertising and consumer preference (Marshall et al., 2021). Data gaps in the FSD at the national level for South Africa include the relative absence of data on retail and marketing, consumer behaviour and adolescent diet patterns, all of which could provide useful information to decision-makers. Further, according to Marshall et al. (2021), a key gap is the lack of sub-national data. In general, the structure and dynamics of food systems diverge at the sub-national level. At this level there are numerous influencers of the food system such as geography, food suppliers and distributors, agricultural land, and many other local context-specific drivers. In principle, sub-national data could enable both national and sub-national decision-makers to develop better strategies or policies specific to a city or province; comparisons between cities or provinces could be established. The national-level data in existing FSDs could be used to guide the identification of relevant and actionable sub-national level indicators for the food systems of sub-regional areas. Given the need to use indicators that are organized around existing and commonly accepted frameworks, in this study we consider using both the John Hopkins University and GAIN FSD framework and the HLPE's conceptualization of food security to identify useful indicators for sub-national decision-makers (Devereux et al., 2020; HLPE, 2020). A panel of indicators that can meet the needs of the dimensions of food security at the sub-national level could enable decision making that promotes transitions to more sustainable and equitable food systems for sub-national levels of South Africa. In the following section, we apply this approach to South Africa's Eastern Cape.

The John Hopkins and GAIN FSD frameworks are drawn upon for this analysis partially as they aligns with FAO's role in enabling food and nutrition security; indeed, their indicators are organized around the UN HLPE Report's conceptualisation of a food system. This provides a basis to assess the Eastern Cape's data availability based on the HLPE (2020) report's additional two dimensions of food and nutrition security: sustainability and agency. The Hopkins and GAIN FSD was selected based on its explicit goal to support more evidence-based decision-making for food systems transformation, including 'assessing food systems, supporting the prioritization of actions, and describing the state of a country's food systems and effects on nutrition and health' (Fanzo et al., 2020b).

The Eastern Cape has been selected as a study region because the province is known to experience the most pronounced levels of poverty within South Africa (Ningi et al., 2021). Apart from the socio-economic challenges faced by the Eastern Cape, the climate and geography also play a vital role in food security as the province is prone to long summer droughts and heavy rainfall during winter. This is due to the influence of midlatitude and tropical systems (Mahlalela et al., 2020). Inland areas of the Eastern Cape experience limited agricultural opportunities due to the climate and geography, and some

of the region's soils are not conducive to agriculture (Mahlalela et al., 2020; Ningi et al., 2021). Efforts toward ending poverty and hunger in South Africa will depend on effective policy decisions targeting areas of high need, such as the Eastern Cape.

Multidimensional monitoring of poverty and marginalization in the Eastern Cape

Nine groups of food are included in the Food Based-Dietary Guidelines for South Africa. These are (1) cereals, roots and tubers; (2) meat, poultry fish; (3) dairy; (4) eggs; (5) fruit and vegetables rich in vitamin A; (6) legumes; (7) other fruit; (8) vegetables (except legumes); and (9) fats and oils (Vorster et al., 2013). The Food-Based Dietary Guidelines for South Africa is used as a basis to measure dietary diversity in the country, where a Dietary Diversity Score (DDS) of less than 4 is considered to be poor in diet diversity. Findings indicate that 59.6% of the Eastern Cape have a DDS of less than four, which suggests food insecurity amongst more than half of the population (Vorster et al., 2013). Megbowon and Mushunje (2018) indicate that the main foods consumed in Eastern Cape are starches (mainly cereals), followed by oil, fat, butter, sugar, and meat and eggs. The foods consumed in smaller amounts in the Eastern Cape include vegetables such as spinach and pulses such as beans and nuts.

Unsurprisingly, poverty plays a major role in food security in the Eastern Cape with strong links to poor dietary diversity (Megbowon and Mushunje, 2018). Low intake of vegetables and pulses increases the risk of disease such as diabetes (Shisana et al., 2013), especially in female-headed households (Oldewage-Theron and Kruger, 2011). This points to the need for data relating to the food environments experienced by individuals, households and communities, to better understand characteristics of the food system such as vendor properties, availability, and affordability of a diverse and nutritious diet (Fanzo et al., 2020b).

Vulnerability to food insecurity affects people at the household level where the priority is acquiring food for the short term, making it harder for households and individuals to deal with unpredictable adverse events or shocks. It is therefore essential to understand and investigate the vulnerabilities faced by the marginalized people of the province. Poverty and marginalization vary between the nine provinces of South Africa with unemployment, health, demographics and living conditions ranking lowest in the Eastern Cape region, which is still largely rural (WorldBank, 2022; FAO, 2022a). Indicators of poverty are used to measure socio-economic development. However, measures of poverty may not always directly relate to household welfare and gaps remain for many countries in their methodology of poverty measurement (Alderman et al., 2002). Until recently, South Africa predominantly used monetary approaches to measure poverty (Mushongera et al., 2015). Many surveys (census, income and expenditure surveys, community surveys, national income dynamics study and general household surveys) have been undertaken to determine household expenditure in order to measure poverty (Fransman and Yu, 2018). More recently a shift toward a multidimensional approach to measure poverty has occurred, similar to many other countries. A multidimensional approach takes into consideration different areas of living circumstances (Mushongera et al., 2015). The Multidimensional Poverty Index (MPI), proposed by Alkire and Foster (2011) and UNDP (2021) uses a set of indicators to measure poverty. In line with this MPI approach, the South African government use 11 indicators categorised into four dimensions of poverty which include health, education, living standards and economic activity. Together this makes up the South African Multidimensional Poverty Index (SAMPI) where data is collected through surveys (Ntsalaze and Ikhide, 2016). However, gaps remain within this South African MPI approach – including an absence of direct food security and nutrition indicators as identified by Fransman and Yu (2018).

To better understand food insecurity in the Eastern Cape, household poverty and its relation to food insecurity needs to be considered (Ngumbela et al., 2020). Data sources important for the SAMPI include the census and the community surveys, the latest of which are from the years 2011 and 2016, respectively (Alderman et al., 2002; Fransman and Yu, 2018). The provincial profile of Eastern Cape's multidimensional poverty indicators and its determinants (2016) are shown in Table 1, which displays the SAMPI dimensions and the indicators for the Eastern Cape as an illustration of multidimensional poverty in the nine municipalities of the province. The indicators relating to food systems in South Africa are currently not thoroughly considered in the SAMPI even though surveys assessing consumption and nutrition exist through the South African Demographics and Health Survey 2016. However, if such data could be consolidated with the SAMPI (or as its own national food security indicator system), the linkages between poverty and nutrition outcomes (i.e., the outcomes relating to a sustainable food system) would be more apparent to support more effective decision-making for food system transitions. For example, diets are affected by an individual's food environments, i.e., accessibility and affordability of food, type of vendor outlets available and food messaging/marketing. The use of both sets of indicators could help address the gaps from both the FSD and the SAMPI, thus supporting the potential for more effective and accountable decision-making processes in the Eastern Cape's food systems.

South Africa conducts a number of surveys to assess demographics, health, nutrition and other areas of life in the country. However, these surveys do not indicate a direct relation to nutrition. For example, the Community Survey and Census has not to date included malnutrition and hunger, even though the global MPI includes nutrition into its poverty measurement (Fransman and Yu, 2018). Food security measurements can be assessed through determinants such as economic factors which result in food insecurity such as malnutrition (Jones and Ejeta, 2016). Further, another important indicator for nutrition outcomes relates to dietary diversity, required to ensure sufficient nutrient intake through the consumption of diverse foods (Oldewage-Theron and Kruger, 2011; Verger et al., 2021). Current problems relating to food systems and poverty continue to hamper development in the Eastern Cape and in other low-income areas of South Africa. For example, common health problems relating to food insecurity in children include wasting, stunting, underweight, and vitamin and iron deficiencies. Common health problems relating to food insecurity in adults are anaemia, underweight, overweight, non-communicable diseases, malnutrition, and vitamin and mineral deficiencies (Shisana et al., 2013; Pereira, 2014; FAO et al., 2021).

Sub-national food systems indicators for improved food security and human nutrition in the Eastern Cape food system

Given the challenges noted above, the question arises of how indicators relating to food security and nutrition can be better used to strengthen food systems planning, and how these relate to existing or

TABLE 1 District by district profile of the Eastern Cape province's multidimensional poverty indicators and its determinants.

Dimension	Indicator	Determinant	HLPE Dimension	Sarah Baartman	Amathole	Chris Hani	Joe Gqabi	O.R. Tambo	Alfred Nzo	Buffalo City	Nelson Mandela Bay
Education	Age 5–24 years attending educational institution		Agency	70.7%	76.6%	77.4%	79.2	77.7%	79.5%	78.5%	76.4%
	20 years and older with no schooling education*			5.2%	8.2%	10.8%	7.7%	11.9	8.3%	3.7%	2.6
Economic activity	Unemployment		Access. stability.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Standard of living	Household type	Formal	Agency	87.1%	55.9%	56.3%	69.6%	43.6%	42.6%	70.2%	92.5%
		Traditional		2.4%	38.4%	38.9%	25.6%	54.2%	53.4%	4.2%	0.2%
		Informal		9.4%	5.3%	2.9%	4.3%	1.3%	2.3%	24.9%	6.9%
		Other		1.1%	0.4%	1.8%	0.4%	0.9%	1.7%	0.8%	0.3%
	Number of people with access to water	Safe drinking water	Access. utilization	85.1%	74.9%	76.0%	72.7%	42.9%	47.6%	91.6%	90.5%
		No safe drinking water		14.9%	25.1%	24.0%	27.3%	57.1%	52.4%	8.4%	9.5%
	Location of toilet	In the dwelling	Utilization	54.2%	15.7%	29.1%	26.4%	7.5%	5.2%	51.8%	70.8%
		In the yard		41.1%	82.3%	67.2%	70.8%	91.0%	93.8%	32.2%	27.9%
		Outside yard		4.7%	2.0%	3.7%	2.8%	1.6%	1.0%	16.0%	1.3%
	Electric energy	Access to electric energy	Access. Utilization	92.5%	85.6%	93.4%	84.2%	87.2%	72.1%	87.7%	97%
		No access to electric energy		7.5%	14.4%	6.6%	15.8%	12.8%	27.9%	12.3%	3.0%
	Energy for cooking and lighting	Access to cooking energy source	Access. Utilization	99.6%	99.4%	99.8%	99.0%	99.5%	99.6%	99.4%	99.8%
		No access to cooking energy source		0.4%	0.6%	0.2%	1.0%	0.5%	0.4%	0.6%	0.2%
		Access to energy for lighting		99.5%	99.8%	99.8%	99.4%	99.7%	99.9%	99.6%	99.9%
		No access to energy for lighting		0.5%	0.2%	0.2%	0.6%	0.3%	0.1%	0.4%	0.1%

Source: Authors' compilation using Census 2011, and Community Survey, 2016. Data on the indicators which measure poverty for the Eastern Cape province were retrieved from the 2011 Census report and the 2016 Community Survey which is broken down into the six main district municipalities and two major cities. Information on economic activity and child mortality for every municipality council was not a part of the census and community survey, leaving a gap in information at the municipal level.
*Remaining population fall into different categories of education which is not included into the SAMPI.

10.3389/fsufs.2023.1243466

proposed multi-dimensional indicators of poverty (Ngumbela et al., 2020). To complement the mapping of FSD data availability in South Africa against the country's national data framework (SAMPI), we mapped the SAMPI indicators for data available on the Eastern Cape region against the HLPE six dimensions[1] of achieving food and nutrition security (Table 1). The Table also highlights the South African classification of indicators by 'determinants'. The use of determinants is commonplace in South African surveys; therefore, each potential indicator makes use of a determinant. For example, the health dimension of the SAMPI is restricted to child mortality with the determining factor being the number of deaths below the age of 5. Nutrition-related indicators form a crucial part of food system indicators as nutrition is a determining factor of health, related to survival and development of children in their future outcomes as they lean toward adulthood. The state of nutrition also affects educational outcomes and employment opportunities (Duffy et al., 2017). For developing areas like the Eastern Cape, where diets are high in starchy foods (Pereira, 2014), dietary diversity is of particular importance as a variety of food items are required in an individual's diet to ensure adequate uptake of essential nutrients (Drimie, S. et al., 2015).

The SAMPI framework places a strong emphasis on economic access and WASH conditions which will favor some aspects of food and nutrition security. However, as Table 1 indicates, there is an absence of indicators relating to dimensions such as availability and sustainability. In line with the FSD framework, availability can be seen as part of the broader food environment, which can influence how people access food and their agency in the food system (HLPE, 2020; Fanzo et al., 2020b). For example, indicators on consumer behavior are currently not directly addressed, without which there is a lack of knowledge on food acquisition, preparation and storage. These are directly aligned with how consumers would access their food, where or how it is available and if the source of food is sustainable (in terms of market availability and access to a retailer), how food is utilized by an individual or household, and who is in charge of household decisions around food leading to agency. More consequentially for this analysis, there were no disaggregated data available on child mortality at the district level in the Eastern Cape Region. This is reflected in the absence of district-level health indicators, a key dimension of food and nutrition security, which also renders decision-making relating to child and maternal health less informed or evidence based.

As a driver of food systems, the repercussions of climate change and its effects on the environment are absorbed by different systems (Serdeczny et al., 2016). However, climate related events which could cause food supply shocks are not explicitly considered in current FSDs: this could be at least partially addressed by including a Climate Risk Index Score as an indicator. Water resources are an essential component of a food system and changing precipitation will affect the production of food. Regions particularly susceptible to climate vulnerabilities such as droughts and flooding are at increased risk of experiencing food supply shocks (Mbow et al., 2019). The indicators - Average annual precipitation (mm/year) and Climate Risk Index score (low score = higher vulnerability) – to measure annual precipitation and monitor yearly weather patterns for extremities and vulnerabilities allows for planning and risk management. These climate-related events affect access to food, resulting in changes to value chains and diets. The indicator Trade (exports/imports) as a percentage of GDP can track and measure food accessibility for imports and exports.

The production system and inputs within the production system are complex and monitoring the production system through indicators is important for more efficient and resilient food value chains (Amjath-Babu et al., 2020). The addition of two indicators to monitor some environmental aspects of agricultural production systems (such as impact of fertilizer use on soil or true cost of inputs including water) could include Fertilizer consumption (KG/per hectare of arable land) and Area equipped for irrigation total per 1,000 ha. The inclusion of measuring *Per capita* food supply variability is important because variability relating to value chains are monitored (especially for food availability purposes), such as any instabilities, and results from the food system chain over a 5-year period (INDDEX Project, 2018). Gaps in the South African FSD profile remain for the socio-economic dimension which relate to all HLPE dimensions; therefore, we propose that these gaps can be bridged with the inclusion of the following indicators: motorization rate (vehicles per 1,000 inhabitants), Public transport rate (bus, taxi, train per 1,000 inhabitants), Age 5–24 years attending educational institution (%), 20 years and older with no schooling education (%), Ethnic diversity (% of each ethnic group within a province), Employment rate by gender (%), and Age structure of population (%). Food preparation and food storage are important determinants of the food system as they control what food is purchased, how food is cooked, the hygiene of food, and quality of purchased food in a specific time frame. Indicators to measure household abilities to utilize food in a stable and sustainable way include Availability of energy (availability per 1,000 households), Availability of safe water source (availability per 1,000 households), and Availability of cold storage (availability per 1,000 households).

To transition toward a food system with adequate nutritional supplies, the proposed sub-national food system indicator panel can be used to identify populations that are most marginalized within food systems. However, we recognize that what we are proposing does not consider who will routinely collect such data, and who will pay for the routine data collection at the scale and frequency necessary to support for decision-making. With this caveat in mind, we have indicated in Supplementary Table S2 our proposed panel of sub-national food systems indicators for the Eastern Cape. The panel of indicators is not only an extension of the SAMPI but a consolidation of indicators from the SAMPI and the FSD, including options for which entities could routinely collect the data for each indicator at scale.

Can food flow mapping augment indicator-based decision-making regarding food systems?

In addition to the need for integrated sets of food systems indicators, robust food systems transformation will also require dynamic

1 Agency relates to the ability of individuals/households/communities to influence their own choices around food security decisions related to type of food production, what is consumed, distribution decisions and policy decisions; Access refers to the physical and economic ability to source food that is sufficient in quality, quantity and diversity. Stability refers to the constant supply of food which is influenced by factors such as income and economic resources; Utilization indicates the nutritional and safety components of food, such as how food is prepared.

monitoring of short-term changes (Sweeney et al., 2015; Alarcon et al., 2021; Fanzo et al., 2021), including at even more granular levels than the province. Food mapping has been proposed as a way of enhancing indicator data by mapping food systems within an area of interest and providing more dynamic insights (including consideration for food systems interactions) than static overviews provided by the diagnostic approaches found in dashboards (Marte, 2007; Wight and Killham, 2014; Alarcon et al., 2017). Food mapping combines spatial analysis, census information and other forms of data to create maps on a regional or city level (Wight and Killham, 2014; Kiambi et al., 2018). Food mapping is amenable to participatory approaches, which helps ensure food systems transformation occurs in a progressive manner with suitable emphasis on agency and social sustainability within the food systems paradigm (Sweeney et al., 2015; Alarcon et al., 2017). Food systems mapping is also useful in providing insights into local food supplies, infrastructure conditions, trade, and individual and external factors (Alarcon et al., 2017; Kiambi et al., 2018; Alarcon et al., 2021). Hence, food mapping could potentially provide a useful complement to Dashboards, which may be more comprehensive but equally may be relatively static given the nature of their underlying datasets.

In the context of the Eastern Cape, food mapping could indicate the geography of food systems which is especially important in areas with few or no food retail outlets, or where evidence regarding nutrition or other aspects of food flows is lacking. Mapping can also improve pathways for data collection through the identification of data gaps, e.g., in areas where infrastructure or finances make data collection challenging. There is no routine method for food mapping as it can require a number of different approaches to depict or visualize distinct features of a food system (Wight and Killham, 2014). For example, aspects might include agricultural activity, home gardens, food waste and food distribution can be used to map features such as location of where food is sold. Research on food mapping makes use of spatial and/or temporal analysis through GIS software (Appeaning Addo, 2010; Tsuchiya et al., 2015; Karg et al., 2016; Rich et al., 2016; Jensen and Orfila, 2021), participatory participation (Tsuchiya et al., 2015; Rich et al., 2016), and quantitative studies (Karg et al., 2016).

Food flow mapping can be conducted in a participatory manner, including the use of citizen science approaches. This can be of particular relevance given the importance of social sustainability and agency within the food systems approach. In the past, geographical systems and research were not as easily accessible to people and consumers; however, this has changed due to citizen science approaches to co-creation of knowledge (Trojan et al., 2019). Citizen-science approaches have been widely interfaced with geospatial analyses – examples of this include OpenStreetMap, Esri ArcGIS, and Geoserver. Participatory methods for mapping can enable the creation of knowledge which could be utilized in the identification of key actors, interactions and solutions for a food system (Jacobi et al., 2019). In principle, the role of participatory approaches for food flow mapping can better allow actors such as researchers, policymakers, and other stakeholders to link their knowledge of food systems to decide on where and how to collect necessary data and to map data. Data can be utilized through the resulting food flow maps for decision-making around improving food systems (Jacobi et al., 2019). Food flow maps can provide information on the drivers, challenges, and interactions of the food system – the geography, farming techniques, policies, food types, nutrition of food, distribution, feedback loops, and other related information. For example, a spatial mapping analysis of agricultural infrastructure conducted by Charles and Battersby (2019) in the Mhlontlo municipality of the Eastern Cape revealed the potential for production of high-value crop and fruit (by mapping the vital agricultural zones) if agricultural land were better utilized and infrastructure not constrained. Some of the infrastructure required for improved productivity included infrastructure development for irrigation, processing and storage facilities, access to road networks, and technology. Through mapping, an opportunity that emerged included infrastructure development for water availability which involved the development of irrigation schemes and water reservoirs to maintain production. Furthermore, the development of agricultural information centres could be utilized for the communication of key agricultural information and communication relating to the food system (Charles and Battersby, 2019).

Through participatory approaches to food flow mapping, more effective and socially inclusive value chains can be realized to enhance food and nutrition security, economic growth and poverty reduction. The use of food system mapping, supplemented by the food system indicators could enable gaps between food systems and stakeholders to be bridged. Both sub-national dashboards and food flow mapping can better enable decision-making toward food systems to create more positive feedbacks (Nhemachena and Chakwizira, 2013; Tsuchiya et al., 2015) and create opportunities for South Africa to utilize participatory approaches to mapping which is suitable for its sub-national food and nutrition security needs.

Conclusion

Transformative changes are needed throughout our global food systems to achieve food and nutrition security while minimizing negative impacts on other dimensions of sustainable development and promoting positive feedback effects and co-benefits wherever possible. Yet, such transformations are hindered by a lack of data, especially at sub-national levels and among the most vulnerable. Here, we have considered the prospects for applying a food system lens at a sub-national context for tackling food and nutrition insecurity in South Africa. We have identified possible gaps in the current food systems decision-making data landscape in South Africa and specially in the Eastern Cape. We have identified indicators from other frameworks which could synergise with SAMPI and FSD datasets collected nationally, to more clearly track progress toward achieving the six HLPE dimensions of food security in the municipalities of the Eastern Cape. We also consider options to bolster food systems decision-making through using participatory approaches and citizen science to develop food flow maps. The approach of consolidating and integrating indicators from global, national, and sub-national level data is one that could be applied in other regions and countries, but will require participation and investment from state and private sector actors within diverse fields, and continued development of enabling environments for policy makers and other stakeholder groups.

Author contributions

CS, PM, and ML conceptualized the review under the guidance of CS, PM, and ML. SM and RK made drafts of the review, which were subsequently revised, prior to finalization of the manuscript (which was reviewed by all authors prior to submission). All authors contributed to the article and approved the submitted version.

Acknowledgments

The authors acknowledge funding support from European Union International Partnerships and the International Fund for Agricultural Development (IFAD) to CS and ML for the EU-IFAD funded EcoFoodSystems project (www.ecofoods.org), led by the University of Galway, Ireland.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1243466/full#supplementary-material

References

Agostoni, C., Baglioni, M., La Vecchia, A., Molari, G., and Berti, C. (2023). Interlinkages between climate change and food systems: the impact on child malnutrition-narrative review. *Nutrients* 15:416. doi: 10.3390/nu15020416

Alarcon, P., Dominguez-Salas, P., Fèvre, E. M., and Rushton, J. (2021). The importance of a food systems approach to low and middle income countries and emerging economies: a review of theories and its relevance for disease control and malnutrition. *Front. Sust. Food Sys.* 5:642635. doi: 10.3389/fsufs.2021.642635

Alarcon, P., Fèvre, E. M., Murungi, M. K., Muinde, P., Akoko, J., Dominguez-Salas, P., et al. (2017). Mapping of beef, sheep and goat food systems in Nairobi - a framework for policy making and the identification of structural vulnerabilities and deficiencies. *Agric. Syst.* 152, 1–17. doi: 10.1016/j.agsy.2016.12.005

Alderman, H., Babita, M., Demombynes, G., Makhatha, N., and Ozler, B. (2002). How low can you go? Combining census and survey data for mapping poverty in SA. *J. Afr. Econ.* 11, 169–200. doi: 10.1093/jae/11.2.169

Alkire, S., and Foster, J. (2011). Counting and multidimensional poverty measurement. *J. Public Econ.* 95, 476–487. doi: 10.1016/j.jpubeco.2010.11.006

Amjath-Babu, T. S., Krupnik, T. J., Thilsted, S. H., and Mcdonald, A. J. (2020). Key indicators for monitoring food system disruptions caused by the COVID-19 pandemic: insights from Bangladesh towards effective response. *Food Sec.* 12, 761–768. doi: 10.1007/s12571-020-01083-2

Anderson, M., Clapp, J., Guttal, S., Paskal, A., and Monsalve Suárez, S. (2023). IPBES-Food. Brussels, Belgium: Association International Sans But Lucratif' – AISBL. Available at: https://www.ipes-food.org/pages/tippingthescales

Appeaning Addo, K. (2010). Urban and Peri-urban agriculture in developing countries studied using remote sensing and in situ methods. *Remote Sens.* 2, 497–513. doi: 10.3390/rs2020497

Battersby, J., and Haysom, G. (2019). *How food secure are south African cities? African Centre for Cities*, University of Cape Town. Cape Town.

Béné, C. (2022). Why the great food transformation may not happen – a deep-dive into our food systems' political economy, controversies and politics of evidence. *World Dev.* 154:105881. doi: 10.1016/j.worlddev.2022.105881

BFAP (2021). "*Agricultural outlook: 2021–2030*". Pretoria: BFAP: Bureau for Food and Agricultural Policy.

Blignaut, J., Ueckermann, L., and Aronson, J. (2009). Agriculture production's sensitivity to changes in climate in South Africa. *S. Afr. J. Sci.* 105, 61–68.

Bosiu, T., Nair, R. D., and Paelo, A. (2017). The global food value chain and competition law and policy in BRICS countries: insights from selected value chains in South Africa. *CCRED Working Paper* 21, 1–97. doi: 10.2139/ssrn.3103599

Charles, A., and Battersby, J. (2019). City of Cape Town Food Systems Scenario Analysis Final Report, IDRC Grant/ Subvention du CRDI: 108458-001-Urban food systems governance for NCD prevention in Africa. Ottowa, Canada: IDRC.

Clapp, J., Moseley, W. G., Burlingame, B., and Termine, P. (2022). The case for a six-dimensional food security framework. *Food Policy* 106:102164. doi: 10.1016/j.foodpol.2021.102164

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F. N., and Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food* 2, 198–209. doi: 10.1038/s43016-021-00225-9

Devereux, S., Béné, C., and Hoddinott, J. (2020). Conceptualising COVID-19's impacts on household food security. *Food Sec.* 12, 769–772. doi: 10.1007/s12571-020-01085-0

Duffy, C., Murray, U., Nowak, A., Girvetz, E., Corner-Dolloff, C., Twyman, J., et al., (2017). National level indicators for gender, poverty, food security, nutrition and health in Climate Smart Agriculture (CSA) activities. CCAFS Working Paper no. 195". [Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)].

Fanzo, J., Covic, N., Dobermann, A., Henson, S., Herrero, M., Pingali, P., et al. (2020a). A research vision for food systems in the 2020s: defying the status quo. *Glob. Food Sec.* 26:100397. doi: 10.1016/j.gfs.2020.100397

Fanzo, J., and Davis, C. (2019). Can diets be healthy, sustainable, and equitable? *Curr. Obes. Rep.* 8, 495–503. doi: 10.1007/s13679-019-00362-0

Fanzo, J., Haddad, L., Mclaren, R., Marshall, Q., Davis, C., Herforth, A., et al. (2020b). The food systems dashboard is a new tool to inform better food policy. *Nature Food* 1, 243–246. doi: 10.1038/s43016-020-0077-y

Fanzo, J., Haddad, L., Schneider, K. R., Bene, C., Covic, N. M., Guarin, A., et al. (2021). Viewpoint: rigorous monitoring is necessary to guide food system transformation in the countdown to the 2030 global goals*. *Food Policy* 104:102163. doi: 10.1016/j.foodpol.2021.102163

Fanzo, J., Rudie, C., Sigman, I., Grinspoon, S., Benton, T. G., Brown, M. E., et al. (2022). Sustainable food systems and nutrition in the 21st century: a report from the 22nd annual Harvard nutrition obesity symposium. *Am. J. Clin. Nutr.* 115, 18–33. doi: 10.1093/ajcn/nqab315

FAO (2021). *Africa – Regional overview of food security and nutrition 2021: statistics and trends.* Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO (2022a). *Food systems profile – South Africa. Catalysing the sustainable and inclusive transformation of food systems*. (Rome, Italy: Food and Agriculture Organization of the United Nations).

FAO (2022b). *The state of food security and nutrition in the world 2022. Repurposing food and agricultural policies to make healthy diets more affordable*. Rome, Italy: Food and Agriculture Organization of the United Nations.

FAO, IFAD, UNICEF, WFP and WHO. (2017). *The State of Food Security and Nutrition in the World 2017. Building resilience for peace and food security*. Rome, Italy: FAO.

FAO, IFAD, UNICEF, WFP and WHO. (2020). *The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets*. Rome, Italy: FAO.

Fransman, T., and Yu, D. (2018). Multidimensional poverty in South Africa in 2001–16. *Dev. South. Afr.* 36, 50–79. doi: 10.1080/0376835X.2018.1469971

Gbetibouo, G. A., and Ringler, C. (2009). *Mapping south African farming sector vulnerability to climate change and variability: a subnational assessment*. IFPRI discussion paper 885. Washington DC, USA: International Food Policy Research Institute (IFPRI).

Hendriks, S. (2014). Food security in South Africa: status quo and policy imperatives. *Agrekon* 53, 1–24. doi: 10.1080/03031853.2014.915468

Herforth, A., Bellows, A. L., Marshall, Q., McLaren, R., Beal, T., Nordhagen, S., et al. (2022). Diagnosing the performance of food systems to increase accountability toward healthy diets and environmental sustainability. *PloS one*, 17:e0270712.

HLPE (2020). "*Food security and nutrition: building a global narrative towards 2030. A report by the high level panel of experts on food security and nutrition of the committee on world food security*". (Rome, Italy: Committee on World Food Security, Food and Agriculture Organization of the United Nations).

Hosu, S. Y., Cishe, E. N., and Luswazi, P. N. (2016). Vulnerability to climate change in the Eastern Cape Province of South Africa: what does the future holds for smallholder crop farmers? *Agrekon* 55, 133–167. doi: 10.1080/03031853.2016.1157025

INDDEX Project (2018). *Data4Diets: building blocks for diet-related food security analysis*. Tufts University, Boston, MA.

Jacobi, J., Wambugu, G., Ngutu, M., Augstburger, H., Mwangi, V., Zonta, A., et al. (2019). Mapping food systems: a participatory research tool tested in Kenya and Bolivia. *Mt. Res. Dev.* 39, R1–R11. doi: 10.1659/MRD-JOURNAL-D-18-00024.1

Jensen, P. D., and Orfila, C. (2021). Mapping the production-consumption gap of an urban food system: an empirical case study of food security and resilience. *Food Sec.* 13, 551–570. doi: 10.1007/s12571-021-01142-2

Jones, A. D., and Ejeta, G. (2016). A new global agenda for nutrition and health: the importance of agriculture and food systems. *Bull. World Health Organ.* 94:228.

Karg, H., Drechsel, P., Akoto-Danso, E., Glaser, R., Nyarko, G., and Buerkert, A. (2016). Foodsheds and City region food systems in two west African cities. *Sustainability* 8:1175. doi: 10.3390/su8121175

Khan, N., Ray, R. L., Kassem, H. S., Hussain, S., Zhang, S., Khayyam, M., et al. (2021). Potential role of technology innovation in transformation of sustainable food systems: a review. *Agriculture* 11:984. doi: 10.3390/agriculture11100984

Kiambi, S., Alarcon, P., Rushton, J., Murungi, M. K., Muinde, P., Akoko, J., et al. (2018). Mapping Nairobi's dairy food system: an essential analysis for policy, industry and research. *Agric. Syst.* 167, 47–60. doi: 10.1016/j.agsy.2018.08.007

Körner, J., Thornton, P., and Klerkx, L. (2022). How to swarm? Organizing for sustainable and equitable food systems transformation in a time of crisis. Global. *Food Sec.* 33:100629. doi: 10.1016/j.gfs.2022.100629

Kuusaana, E. D., and Eledi, J. A. (2015). As the city grows, where do the farmers go? Understanding Peri-urbanization and food systems in Ghana - evidence from the tamale Metropolis. *Urban Forum* 26, 443–465. doi: 10.1007/s12132-015-9260-x

Leach, M., Nisbett, N., Cabral, L., Harris, J., Hossain, N., and Thompson, J. (2020). Food politics and development. *World Dev.* 134:105024. doi: 10.1016/j.worlddev.2020.105024

Leach, M., Raworth, K., and Rockström, J. (2013). *Between social and planetary boundaries: navigating pathways in the safe and just space for humanity*. Paris, France: World Social Science Report, OECD.

Leeuwis, C., Boogaard, B. K., and Atta-Krah, K. (2021). How food systems change (or not): governance implications for system transformation processes. *Food Sec.* 13, 761–780. doi: 10.1007/s12571-021-01178-4

Lerner, A. M., and Eakin, H. (2011). An obsolete dichotomy? Rethinking the rural-urban interface in terms of food security and production in the global south. *Geogr. J.* 177, 311–320. doi: 10.1111/j.1475-4959.2010.00394.x

Mahlalela, P. T., Blamey, R. C., Hart, N. C. G., and Reason, C. J. C. (2020). Drought in the Eastern Cape region of South Africa and trends in rainfall characteristics. *Clim. Dyn.* 55, 2743–2759. doi: 10.1007/s00382-020-05413-0

Mapfumo, P., Onyango, M., Honkponou, S. K., El Mzouri, E. H., Githeko, A., Rabeharisoa, L., et al. (2015). Pathways to transformational change in the face of climate impacts: an analytical framework. *Clim. Dev.* 9, 439–451. doi: 10.1080/17565529.2015.1040365

Marshall, Q., Bellows, A. L., Mclaren, R., Jones, A. D., and Fanzo, J. (2021). You say you want a data revolution? Taking on food systems accountability. *Agriculture* 11:422. doi: 10.3390/agriculture11050422

Marte, L. (2007). Foodmaps: tracing boundaries of 'home' through food relations. *Food Foodways* 15, 261–289. doi: 10.1080/07409710701620243

Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., et al. (2019). "Food security" in *Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. eds. P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, et al. (UK and New York, NY, USA: Cambridge University Press, Cambridge), 896.

Megbowon, E. T., and Mushunje, A. (2018). Assessment of food security among households in Eastern Cape Province, South Africa. *Int. J. Soc. Econ.* 45, 2–17. doi: 10.1108/IJSE-07-2016-0187

Musemwa, L. (2013). Factors affecting household access to enough food in the Eastern Cape Province of South Africa. *J. Dev. Agric. Econ.* 5, 84–91. doi: 10.5897/JDAE12.039

Mushongera, D., Zikhali, P., and Ngwenya, P. (2015). A multidimensional poverty index for Gauteng Province, South Africa: evidence from quality of life survey data. *Soc. Indic. Res.* 130, 277–303. doi: 10.1007/s11205-015-1176-2

Ngumbela, X. G., Khalema, E. N., and Nzimakwe, T. I. (2020). Local worlds: vulnerability and food insecurity in the eastern cape province of South Africa. *Jamba* 12:830. doi: 10.4102/jamba.v12i1.830

Nhemachena, C., and Chakwizira, J. (2013). "Spatial mapping and analysis of integrated agricultural land use and infrastructure" in *Mhlontlo local municipality* (South Africa: Eastern Cape), 505–521.

Ningi, T., Taruvinga, A., Zhou, L., and Ngarava, S. (2021). Factors that influence household food security in Hamburg and Melani, Eastern cape, South Africa. African journal of science, technology. *Afr. J. Sci. Technol. Innov. Dev.* 14, 1050–1056. doi: 10.1080/20421338.2021.1927467

Ntsalaze, L., and Ikhide, S. (2016). Rethinking dimensions: the south African multidimensional poverty index. *Soc. Indic. Res.* 135, 195–213. doi: 10.1007/s11205-016-1473-4

Oldewage-Theron, W., and Kruger, R. (2011). Dietary diversity and adequacy of women caregivers in a peri-urban informal settlement in South Africa. *Nutrition* 27, 420–427. doi: 10.1016/j.nut.2010.05.013

Pereira, L. M. (2014). *The future of South Africa's food system: what is the research telling us?* SA Food Lab, South Africa.

Pereira, L. M., Cuneo, C. N., and Twine, W. C. (2014). Food and cash: understanding the role of the retail sector in rural food security in South Africa. *Food Sec.* 6, 339–357. doi: 10.1007/s12571-014-0349-1

Rich, K. M., Rich, M., Dizyee, K., and Phil, M. (2016). Participatory systems approaches for urban and peri urban agriculture planning: the role of system dynamics and spatial group model building. *Agric. Syst.* 160, 110–123. doi: 10.1016/j.agsy.2016.09.022

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., et al. (2009). A safe operating space for humanity. *Nature* 461, 472–475. doi: 10.1038/461472a

Ruben, R., Cavatassi, R., Lipper, L., Smaling, E., and Winters, P. (2021). Towards food systems transformation-five paradigm shifts for healthy, inclusive and sustainable food systems. *Food Sec.* 13, 1423–1430. doi: 10.1007/s12571-021-01221-4

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., et al. (2016). Climate change impacts in sub-Saharan Africa: from physical changes to their social repercussions. *Reg. Environ. Chang.* 17, 1585–1600. doi: 10.1007/s10113-015-0910-2

Sevelius, J. M., Gutierrez-Mock, L., Zamudio-Haas, S., Mccree, B., Ngo, A., Jackson, A., et al. (2020). Research with marginalized communities: challenges to continuity during the COVID-19 pandemic. *AIDS Behav.* 24, 2009–2012. doi: 10.1007/s10461-020-02920-3

Shisana, O., Labadarios, D., Rehle, T., Simbayi, L., Zuma, K., Dhansay, A., et al., (2013). *South African National Health and nutrition examination survey (SANHANES-1)*. Cape Town: HSRC Press.

Springmann, M., Godfray, H. C., Rayner, M., and Scarborough, P. (2016). Analysis and valuation of the health and climate change cobenefits of dietary change. *Proc. Natl. Acad. Sci. U. S. A.* 113, 4146–4151. doi: 10.1073/pnas.1523119113

Statistics and Economic Analysis (2020). "Economic review of the south African agriculture" in *Department of Agriculture, land reform and rural development* (Pretoria, South Africa: Department of Agriculture, Land Reform and Rural Development, Government of the Republic of South Africa).

Stats SA (2019). "*Towards measuring the extent of food security in South Africa: an examination of hunger and food adequacy*". (Statistics SA, Pretoria: Statistics South Africa).

Sweeney, G., Hand, M., Kaiser, M., Clark, J. K., Rogers, C., and Spees, C. (2015). The state of food mapping: academic literature since 2008 and review of online GIS-based food mapping resources. *J. Plan. Lit.* 31, 123–219. doi: 10.1177/0885412215599425

Temple, N. J., Steyn, N. P., Fourie, J., and De Villiers, A. (2011). Price and availability of healthy food: a study in rural South Africa. *Nutrition* 27, 55–58. doi: 10.1016/j.nut.2009.12.004

Trojan, J., Schade, S., Lemmens, R., and Frantál, B. (2019). Citizen science as a new approach in geography and beyond: review and reflections. *Mor. Geo. Rep.* 27, 254–264. doi: 10.2478/mgr-2019-0020

Tsuchiya, K., Hara, Y., and Thaitakoo, D. (2015). Linking food and land systems for sustainable peri-urban agriculture in Bangkok metropolitan region. *Landsc. Urban Plan.* 143, 192–204. doi: 10.1016/j.landurbplan.2015.07.008

Undp, O. (2021). *Global multidimensional poverty index: unmasking disparities by ethnicity, cast and gender*. New York, USA: United Nations Development Programme and Oxford Poverty and Human Development Initiative.

United Nations (2017). "Leaving no one behind: equality and non-discrimination at the heart of sustainable development" in *The United Nations system shared framework for action*. (United Nations, New York, USA).

Verger, E. O., Le Port, A., Borderon, A., Bourbon, G., Moursi, M., Savy, M., et al. (2021). Dietary diversity indicators and their associations with dietary adequacy and health outcomes: a systematic scoping review. *Adv. Nutr.* 12, 1659–1672. doi: 10.1093/advances/nmab009

Vorster, H. H., Badham, J. B., and Venter, C. S. (2013). An introduction to the revised food-based dietary guidelines for South Africa. *S. Afr. J. Clin. Nutr.* 26, S1–S164.

WFP (2023). *World Hunger Map*. (Accessed June 12, 2023).

Wight, R. A., and Killham, J. (2014). Food mapping: a psychogeographical method for raising food consciousness. *J. Geogr. High. Educ.* 38, 314–321. doi: 10.1080/03098265.2014.881936

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., et al. (2019). Food in the Anthropocene: the EAT–lancet commission on healthy diets from sustainable food systems. *Lancet* 393, 447–492. doi: 10.1016/S0140-6736(18)31788-4

WorldBank (2022). *South Africa country climate and development report*. (Washington, D.C.: World Bank Group).

WWF (2022) in *Living planet report 2022 – building a naturepositive society*. eds. R. E. A. Almond, M. Grooten, J. Bignoli and T. E. D. Petersen (Gland, Switzerland: WWF)

Zhou, B., Liang, S., Monahan, K. M., Singh, G. M., Simpson, R. B., Reedy, J., et al. (2022). Food and nutrition systems dashboards: a systematic review. *Adv. Nutr.* 13, 748–757. doi: 10.1093/advances/nmac022

Zougmoré, R. B., Läderach, P., and Campbell, B. M. (2021). Transforming food Systems in Africa under climate change pressure: role of climate-smart agriculture. *Sustainability* 13:4305. doi: 10.3390/su13084305