Part 4

TOWARD MORE RESILIENT FOOD SYSTEMS

Climate change, locusts, global price volatility, and COVID-19 have placed the Kenyan food system under strain in recent years. These external drivers disrupt the capacity of the food system to operate productively and supply healthy foods at all times. A resilient food system can withstand and recover from these shocks and adapt to changing conditions. As shocks become more prevalent with the changing climate and a rapidly evolving global environment, building food system resilience has become increasingly important. Part 4 addresses food system resilience in general and presents several financial solutions to boosting the resilience of smallholder farmers in particular.

The Kenyan food system has gradually become more resilient over the past 20 years. Chapter 10 presents the results of input–output modeling to measure food system resilience. Food system resilience is linked to its sophistication and diversification. As such, production sectors with more downstream linkages (that is, to processors, manufacturers, or retailers) and more diversified systems help build food system resilience. From the policy standpoint, developing market linkages (that is, value chain development) and promoting diversification can be promising avenues to build food system resilience. However, this brings to the forefront the challenge of simultaneously diversifying and intensifying agricultural production. Small producers, who are often the most vulnerable to shocks, may need other measures, such as insurance, to de-risk their production.

Insurance can help build resilience for small producers and protect them against risks that on-farm practices, technologies, and diversification cannot (for example, severe drought). However, as Chapter 11 indicates, traditional indemnity-based insurance can be expensive to scale because in-person visits are needed to assess damage. Digital solutions can enable alternatives, such as index- or picture-based insurance. However, insurance products cannot be one-size-fits-all and must address the varying needs of farmers, herders, women, the poor, and the non-poor. Insurance should also be bundled with other interventions, as it is not a silver bullet.

One example of bundling insurance, discussed in Chapter 12, is risk-contingent credit (RCC). RCC is insurance bundled with credit, whereby loan repayments are essentially insured for farmers facing climate risk. Such a solution overcomes the problem of risk rationing in credit markets and solves liquidity constraints to adopting insurance (as discussed in Chapter 11). Chapter 12 shows that RCC can increase credit uptake and has potential to scale up but is hindered by a lack of reliable yield data. The public sector can play a supporting role by promoting large-scale data collection so that researchers can better estimate yields nationwide.

In sum, Part 4 discusses several issues related to food system resilience in Kenya. Creating more diverse production systems and promoting more value chain linkages can help build climate resilience for the food system. At the farm level, innovative financial products can help de-risk production while also supporting more intensified production. However, these solutions cannot be pursued in isolation, and must also work in unison with enhancing productivity through on-farm technology adoption (Part 3) and ensuring production meets the demand for healthy diets (Part 2).

Chapter 10

ASSESSING THE RESILIENCE OF KENYA'S FOOD SYSTEM: A PRODUCTION APPROACH

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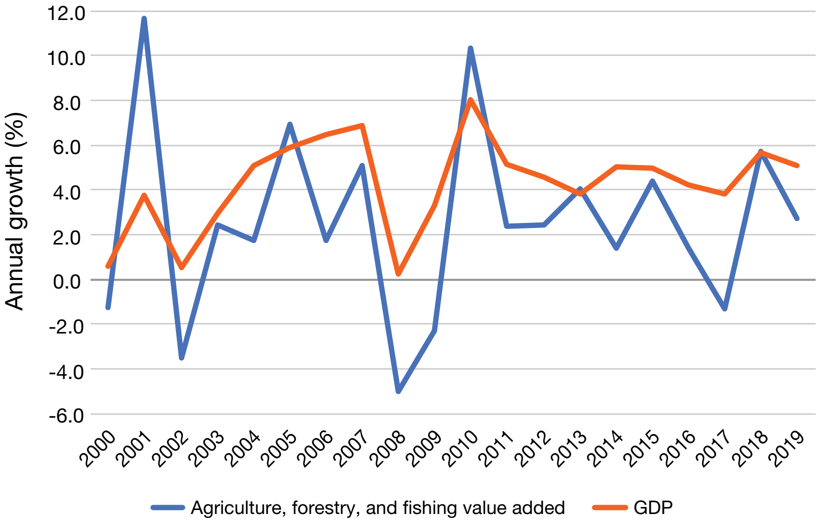
A food system includes all elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation, and consumption of food, and the outputs of these activities, including socioeconomic and environmental outcomes (HLPE 2017). Thus, a food system links society and nature (Blesh and Wittman 2015). Resilience is "the ability of people, households, communities, countries and systems to mitigate, adapt to, and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth" (USAID 2018). Applied to food systems, resilience is defined by the Alliance for a Green Revolution in Africa (AGRA) as the ability to withstand major shocks and stressors emanating from climate/weather, conflict, disease, external economic shocks, and other sources, which, if not prevented or mitigated, would delay, or limit economic progress, transformation, prosperity, and self-reliance (AGRA 2021). In this sense, resilience of a food system may be considered a system property that plays a critical role in its sustainability (Jacobi et al. 2018), thus ensuring sustained food security. This chapter adopts this definition with the objective of assessing the resilience of Kenya's food system and its components using systemwide metrics. Specifically, we use a production approach based on input–output linkages.

A consensus emerging across the globe is that building resilient and sustainable food systems is crucial to ensuring sustainable economies and achieving the Sustainable Development Goals (SDGs) and the Africa Agenda 2063 goals (AGRA 2021). However, ongoing and recent shocks to food systems emanating from climate change crises such as droughts, famines, floods, and locust invasions, as well as civil conflicts and the COVID-19 pandemic, are delaying the progress made in achieving these targets. For this reason, building the resilience of food systems to endure such constant shocks becomes even more important. It also requires coordination and partnership at every level of the system, to ensure the system's efficient functioning.

Over the years, Kenya has taken big strides in building the foundations needed to transform its food system and boost household food resilience. Article 43 of the Constitution of Kenya recognizes the basic human right to freedom from hunger. To achieve its food and nutrition security aspirations, Kenya seeks to transform the agriculture sector in line with its commitments to the Comprehensive Africa Agriculture Development Program (CAADP), the SDGs, the Big Four Agenda, and, by extension, Medium-Term Plan III of Vision 2030. Vision 2030 identifies agriculture as a key sector to transform the economy, given its significant contribution to GDP (Figure 10.1). This important contribution further confirms the need to strengthen synergies between agriculture and Kenya's economy. When agriculture grows, its extensive linkages with the off-farm stages of the food system and nonfarm sectors expand employment and livelihoods in the rest of the economy (AGRA 2021).

The policy framework for the implementation of agricultural transformation includes the Agricultural Sector Transformation and Growth Strategy (ASTGS) 2019–2029 as well as a short-term National Agriculture Investment

FIGURE 10.1 Kenya's annual GDP and agricultural value-added growth trend, 2000–2019



Source: Authors using World Bank's World Development Indicators.

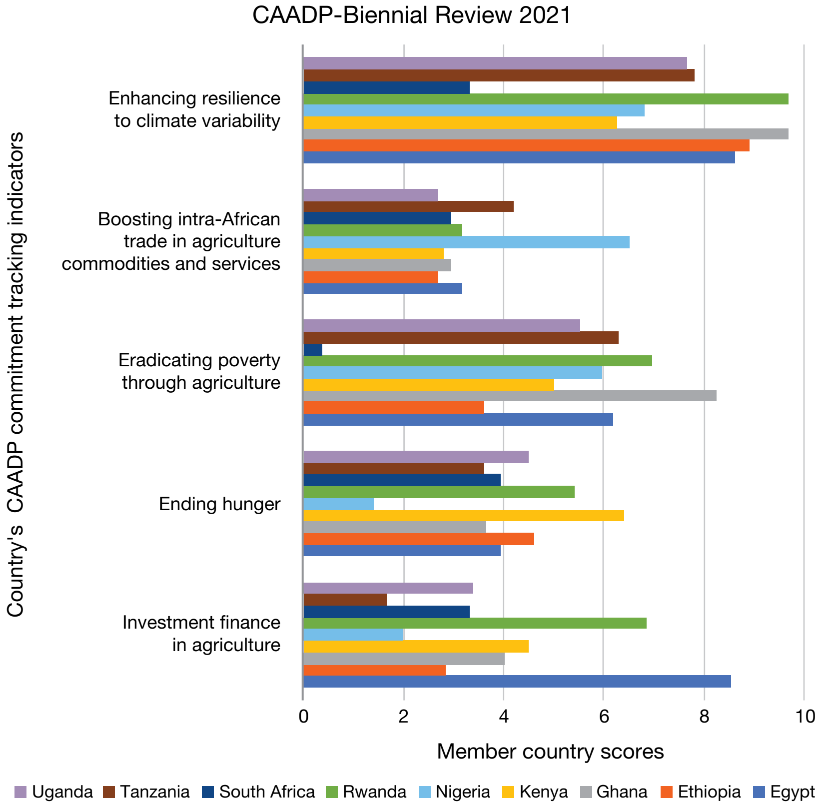
Plan (NAIP) for the period 2019–2024. The ASTGS and the NAIP are premised on a transformed, vibrant, commercial, modern, and equitable agriculture sector to achieve complete food and nutrition security by 2030, and to sustainably support economic growth. The framework has identified three overarching targets, closely aligned with global (SDGs), regional (CAADP, Agenda 2063), and national (Big Four Agenda) aspirations. The first target is to increase small-scale farmer, pastoralist, and fisherfolk incomes in line with SDG target 2.3. The second is to increase agricultural output and value added, directly derived from CAADP's target of annual agricultural GDP growth of 6 percent. The third, increased household food resilience, aligns with the Big Four Agenda commitments of 100 percent food and nutrition security.

CAADP is a policy framework for stimulating production and bringing about food security among the populations of Africa. It was launched in 2003 under the Maputo Declaration on Agriculture and Food Security. In 2014, African heads of state and government adopted the Malabo Declaration on Accelerated African Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods, in which they recommitted to the principles and values of CAADP and set ambitious targets in five broad areas (enhancing agricultural investment, ending hunger, reducing poverty, boosting intra-African agricultural trade, and enhancing resilience of livelihoods and production systems). The member states track and monitor their progress on commitments through Biennial Review reports. Kenya signed to the CAADP Compact in July 2010, thereby forming the basis for its NAIPs and sector transformation strategies.

The current 10-year CAADP tracks seven key commitment areas: recommitment to the CAADP process; investment finance in agriculture; ending hunger; eradicating poverty through agriculture by 2025; boosting intra-African trade in agricultural commodities and services; enhancing resilience to climate variability; and enhancing mutual accountability for actions and results. Figure 10.2 shows Kenya's progress relative to its peers on five of these commitment areas, drawing on the 2021 Biennial Review report (AU 2022).

Notably, Kenya lags on most of the commitment areas. However, the country shows five key areas of strong performance: 75 percent of youth engaged in new job opportunities in agricultural value chains; a 63.2 percent reduction in postharvest losses for national agricultural commodities; a 100 percent budget allocation of the total (CAADP 2015–2025) requirement for social protection for vulnerable social groups from the government budget; a 109.8 percent increase in agricultural value added per agricultural worker; and a 126.7 percent increase in agricultural value added per hectare of arable land.

FIGURE 10.2 The current 10-year tracking of CAADP commitment areas in selected member countries

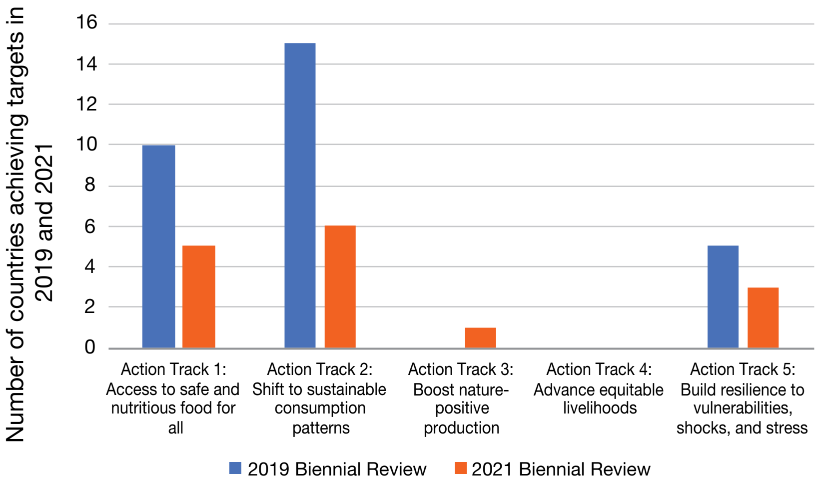


Source: AU (2022).

The 2021 CAADP Biennial Review report maps its indicators to the five Action Tracks of the 2021 United Nations Food Systems Summit. Figure 10.3 presents the change in the performance indicators between the Biennial Reviews of 2019 and 2021 (AU 2020, 2022).

Figure 10.3 shows that, with respect to the indicators under Action Track 1 of the UN Food Systems Summit, 10 countries were on track in 2019 compared with only 5 in 2021. On Action Track 2, the numbers had fallen from 15 to only 6. On Action Track 3 only one country was on track in 2021, up from zero in 2019. Numbers remained at zero for both years on Action Track 4. With respect to indicators under Action Track 5, five countries were on track in 2019 compared with only three in 2021.

FIGURE 10.3 CAADP implementation by UN Food Systems Summit action tracks



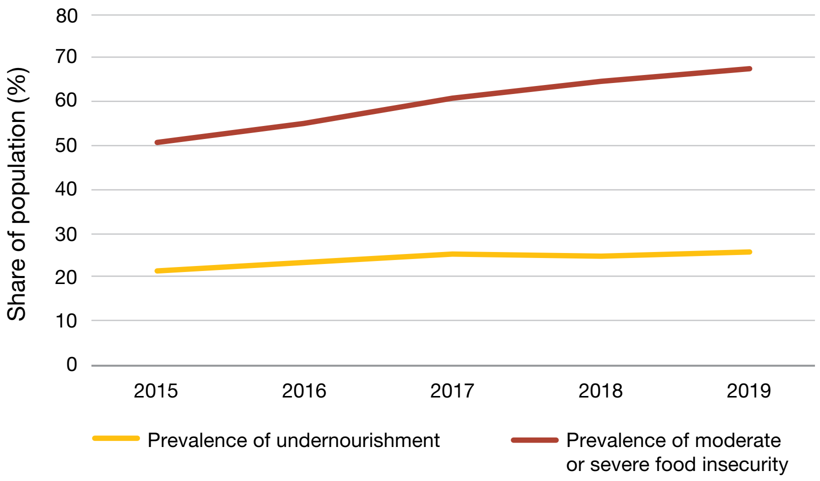
Source: AU (2022).

The results suggest that Kenya, like most African countries, has not made significant progress in transforming its food system to ensure wealth creation, food and nutrition security, poverty alleviation and prosperity, and resilience and sustainability. The momentum created by the UN Food Systems Summit is therefore an opportunity to substantially improve on implementation of the CAADP agenda.

Despite progress made in transforming the food system in Kenya, it remains fragile and vulnerable to climate shocks such as drought and changes in rain patterns, as most of its production is rainfed. In recent years, agricultural production has faced a desert locust invasion in the northern, eastern, and central zones; drought; delayed short and long rains; and the adverse impacts of the COVID-19 pandemic, which has caused disruptions in every component of the food system. Indicators suggest that, even before the pandemic, undernourishment and food insecurity were on the rise (Figure 10.4).

The UN Food Systems Summit 2021, through its Action Tracks, underscored the need to have food systems that can maintain functionality, recover from the adverse effects of shocks and stresses, and build back better, and thus that are more resilient to future shocks (UNFSS 2021). Resilience is thus critical at all stages (both upstream and downstream) of the food system.

FIGURE 10.4 Undernourishment and food insecurity trends in Kenya, 2015–2019



Source: Authors using World Bank's World Development Indicators.

Modeling food system resilience

Resilience is notoriously difficult to measure yet the concept is gaining steam among development partners and policymakers because it captures not just the ability to "bounce back" so much as to "bounce forward" after a shock alters a system. The need to build such resilience drives many development interventions, drawing on a breadth of disciplines, including ecology, medicine, and psychology (Holling 1973; Walker et al. 2004, 2009; Fleming and Ledogar 2008; Béné 2012).

A multitude of practical approaches to measuring resilience, using different types of data, have thus been developed in the past decade. One of the most prominent is the Resilience Index Measurement and Analysis II (RIMA-II) methodology developed by the Food and Agriculture Organization of the United Nations (FAO), which, along with its predecessor RIMA, has been implemented in some 15 African countries to estimate households' ability to maintain well-being in the face of shocks (FAO 2016). The RIMA/RIMA-II approach has gained considerable momentum and has been incorporated into the monitoring and evaluation of resilience-building efforts under the CAADP agenda.

RIMA-II estimates a resilience capacity index at the household and location/community level that can be used to rank households and identify the least resilient. First, factor analysis is used to construct four pillars (interventions) that are expected to contribute to overall resilience, based on a larger set of underlying variables. Second, structural equation modeling is used to estimate resilience capacity as a latent variable, based on the pillar values and on outcome variables, usually reflecting food security. The resilience capacity score generated for each household is standardized so that values fall between 0 and 1, with higher scores indicating greater resilience capacity.

Not all current resilience metrics measure system resilience, which requires accounting for the interdependence of food system components. In other words, a metric for food system resilience cannot be implemented unless the food system is defined as a network of connected components working together to achieve the desired outcome.

This chapter focuses on assessing the resilience of the food system in Kenya. We use the production approach of Leontief, whereby an economy is described through a set of specialized production units. Each of these units relies on the flow of inputs from its suppliers to produce its own output, which in turn is routed toward other downstream units forming a production network (Carvalho and Voigtländer 2014). Hence, a shock affecting only a particular node along the chain can propagate throughout the economy and shape the network outcomes. Such shock propagation will ultimately affect the main outcome of the food system, which is food and nutrition security.

Following Barzel and Barabási (2013) and Barzel, Liu, and Barabási (2015), we model the food system as a network of N sectors whose activities are interconnected. Given the interdependence of sectors, the network effective state can be characterized using the average nearest-neighbor activity, as follows (Barzel, Liu, and Barabási, 2015):

$$x_{\text{eff}} = \frac{\langle s^{out}x\rangle}{\langle s\rangle} \tag{1}$$

where $s^{out} = (s_1^{out}, \dots, s_N^{out})^T$ is the vector of outgoing weighted degrees, $s^{in} = (s_1^{in}, \dots, s_N^{in})^T$ is the vector of incoming weighted degrees, and $\langle s^{out}x\rangle = (1/N)\sum_i^N={}_1 s_i^{out}x_i$, $\langle s\rangle$ is the average weighted degree.

The slope of the network effective state, which determines the system resilience, is given by:

$$\beta_{\text{eff}} = \frac{\langle s^{out}s^{in}\rangle}{\langle s\rangle} \tag{2}$$

Equation 2 can be rewritten as:

$$\beta_{\text{eff}} = \langle s \rangle + S\mathcal{H} \qquad 3$$

where $\langle s \rangle$, S, and $\mathcal{H}$ represent three characteristics (density, symmetry, and heterogeneity) of the system adjacency matrix A_{ij}. It follows that the resilience index (β_{eff}) dependence on the network density $\langle s \rangle$ indicates that a denser network has a large β_{eff}. The system heterogeneity in the s^{in} and s^{out} is captured by $\mathcal{H} = \sigma_{in}\,\sigma_{out}/\langle s \rangle$, where σ_{in}^2 and σ_{out}^2 are the variance of the marginal probability density functions $P(s^{in})$ and $P(s^{out})$ of in and out weighted degrees, respectively. Finally, the symmetry between s^{in} and s^{out} is given by $S = (\langle s^{in}\,s^{out} \rangle)/(\sigma_{in}\,\sigma_{out})$, which is the in–out weighted degree correlation coefficient.

To help understand how food systems can be more resilient, Piters and colleagues (2021) subdivide resilience capacities according to five phases of a shock/stressor scenario that we group in three: (1) anticipation and prevention, which relate to the phase prior to the occurrence of any shocks, (2) absorption, which plays the largest role during the occurrence of a shock, and (3) adaptation and transformation, which are most relevant in the aftermath of the shock and influence the recovery toward post-shock food and nutrition security. They then define four properties of system resilience building:

- Agency—the means and capacities of people to mitigate risks and to respond to shocks;
- Buffering—resources to fall back on in the face of shocks and stressors;
- Connectivity—the interconnection of and communication between actors and market segments; and
- Diversity at different scales and in different places, from production to consumption and from farm level to regional diversity.

The metrics derived from Equation 3 fall under "connectivity" and "diversity". Connectivity refers to the nature and strength of the interactions between the various components of a given food system. It follows that maintaining and building connectivity helps build resilience and guard against negative outcomes (Love et al. 2020). As Piters and colleagues point out, improved connectivity in agricultural value chains improves a food system's capacity to respond to shocks and stressors and is an essential contributor to adaptation and transformation capacities. Regarding diversity, evidence suggests that resilient systems are diverse systems, as the loss of one resource may be compensated by another (Levia et al. 2020; Benton et al. 2021). For example, Piters and colleagues report that more diverse farming systems have greater capacity to absorb the effects of shocks and stressors, and this capacity stabilizes food supplies throughout value chains to consumer markets.

Data

We use Kenya's input–output tables (IOTs) compiled by IFPRI for 2003, 2013, and 2019 (IFPRI 2021). IOTs describe transaction flows within an economy for a given period; they involve sales and purchases between producers and consumers and reconcile the supply and use of goods and services. Each IOT illustrates flows between final and intermediate sales and purchases of industry outputs or those of product outputs. The actual I–O analysis, also referred to as "inter-industry analysis," measures the relationships between various sectors in the economy. We extracted food systems by adding every other sector to food sectors with a non-zero interaction with food sectors. This allows us to avoid the bias of truncated food systems where the food system is analyzed outside of the overall economic system. For example, we know that fertilizer, which is in the chemicals sector, is a key ingredient in the primary production component of the food system. In another example, the transport sector is important to the food system when it facilitates the movement of raw materials and intermediate and final outputs to markets. Further, the processing sector is vital to the food system since it demands raw materials and intermediate goods and supplies final products to the food system. In the latter case, looking specifically at maize farming, maize is supplied to flour processing firms and in turn these firms sell animal feed as a byproduct from the processing activity to the food system. Hence, analyzing food system resilience without these sectors will likely lead to biased results. Table 10.1 presents key characteristics of

TABLE 10.1 Key characteristics of Kenya's food system, 2003, 2013, and 2019

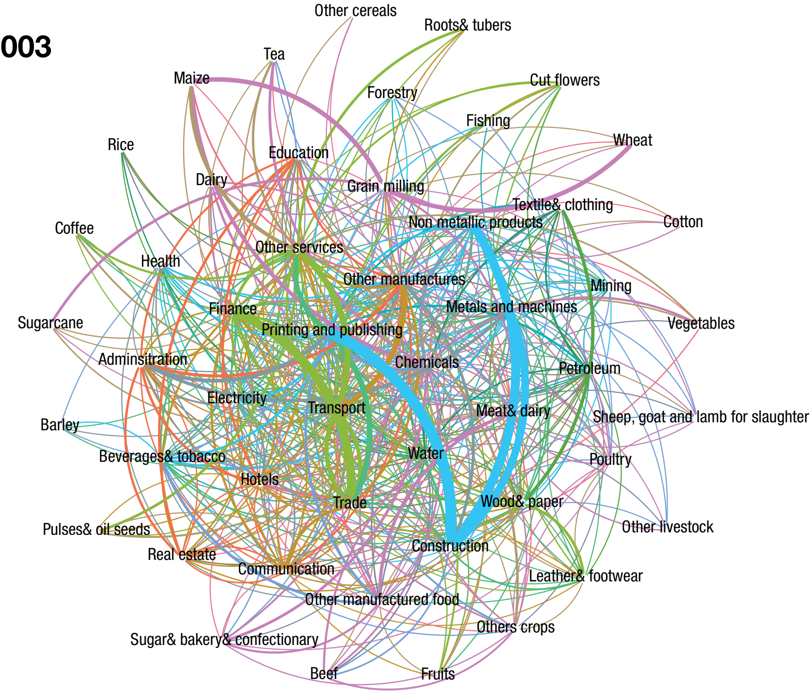
Period	Number of sectors	Number of links	Density	Average clustering coefficient
2003	45	193	0.097	0.113
2013	52	293	0.099	0.187
2019	42	192	0.111	0.266

Source: Authors' calculations using OITs compiled by IFPRI (2021).

Note: Density describes the portion of the potential connections in a network that are actual connections. A "potential connection" is a connection that could potentially exist between two "sectors"—regardless of whether it actually exists. It is estimated as the ratio of actual connections over potential connections, which is equal to nx(n−1)/2 for a network of n sectors. A sector's clustering coefficient measures how close its neighborhood is to a complete network in terms of the relative density of links in its neighborhood.

FIGURE 10.5 Visual representations of Kenyan food system, 2003–2019

(a) 2003



(b) 2013

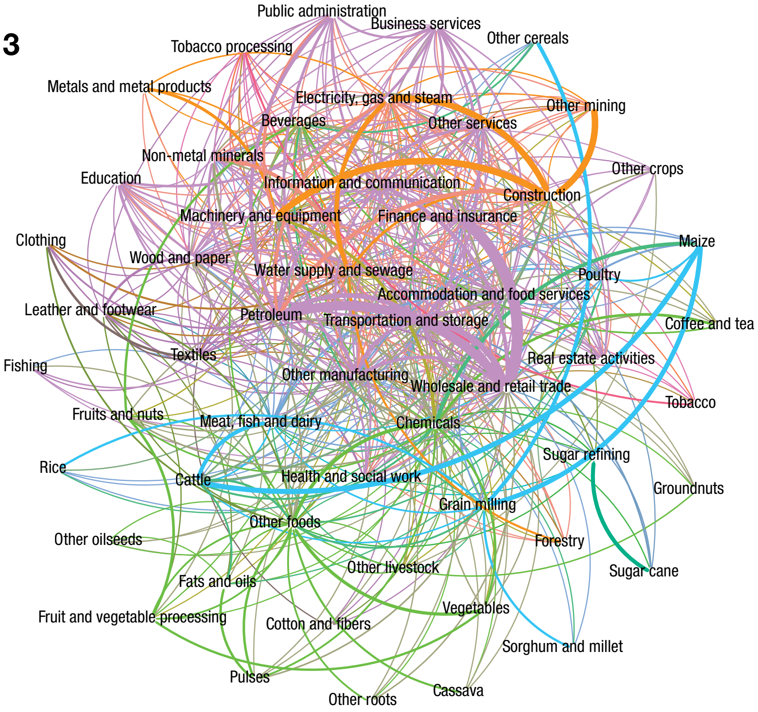
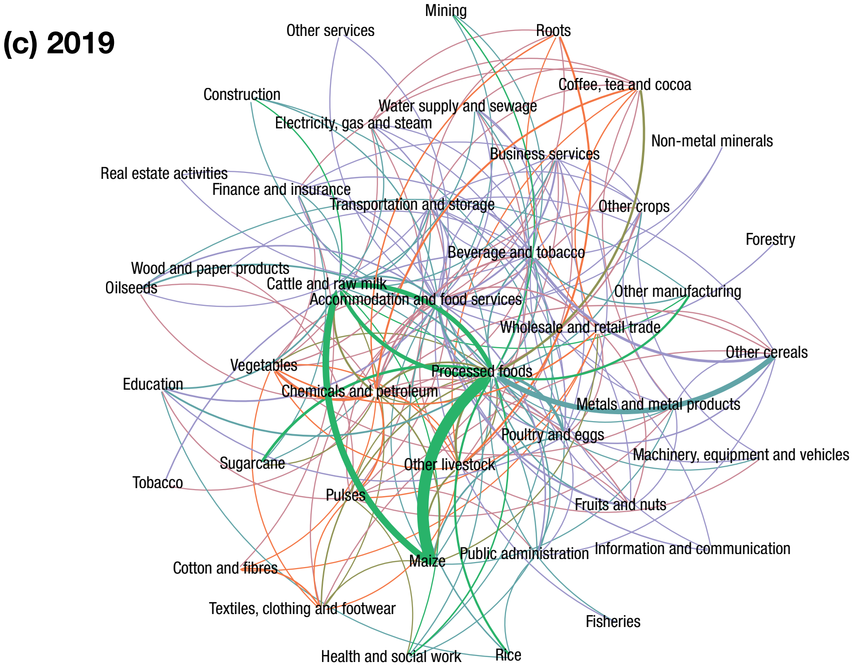


FIGURE 10.5 **Visual representations of Kenyan food system, 2003–2019** *continued*



(c) 2019

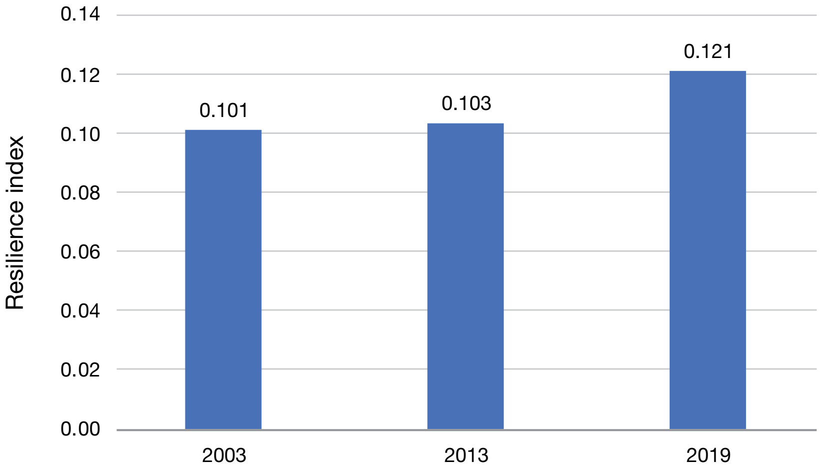
Source: Authors using https://gephi.org/.

Note: Colors represent different network modularity classes; nodes/edges with the same color belong to the same class. Modularity measures the strength of division of a network into clusters or communities (see Newman 2006 for a brief presentation). The size of the arrow represents the value of the interactions between sectors; for example, in 2003, the highest transaction occurred between "Maize" and "Grain milling."

Kenya's food system for periods for which we have IOTs. Figure 10.5 provides visual representations of the system in different years.

The increased number of sectors could be explained partly by the new government that came into place in 2002 and the subsequent bold structural and economic reforms as elaborated in the Economic Recovery Strategy (ERS) covering the 2003–2007 period that paved way toward the adoption of Kenya's Vision 2030 in 2008. The ERS was anchored in three key pillars—namely, restoration of economic growth, rehabilitation, and expansion of infrastructure; equity and poverty reduction; and improving governance. Examples of the reforms include—but are not limited to—the introduction of free primary education; reforming the public transport sector, especially by tightening rules and regulations for minibus operators and by reconstructing roads; and improving efficiency and productivity in the coffee, pyrethrum, sugar, and cooperative subsectors.

FIGURE 10.6 Kenya's food system resilience, 2003–2019



Source: Authors' calculations.

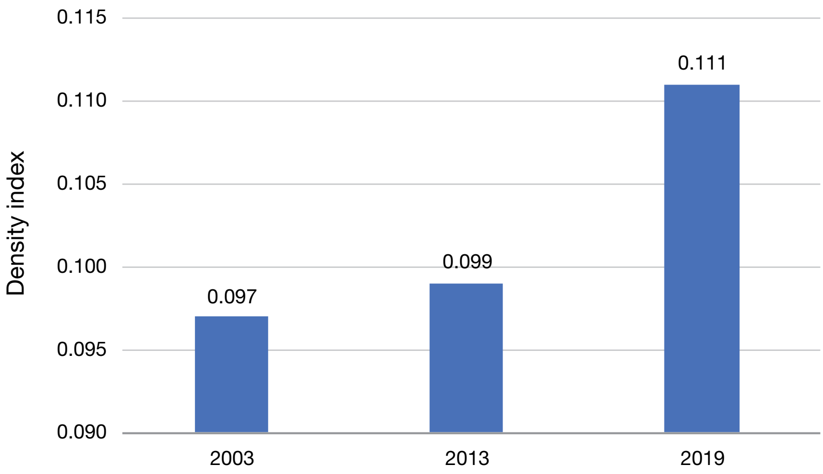
The government also took several measures to improve the business environment and stimulate production, including enhancing the tax incentives first introduced in 2003/04, which included duty waivers on capital goods, industrial plant, and equipment. The incentives largely attracted firms to export promoting zone firms (OECD 2007).

Overall, the ERS entailed the adoption of a growth strategy based in the sectors that would generate employment most rapidly and that would provide more income-generating opportunities for the poor. The sectors identified included agriculture, tourism, trade and industry, ICT, forestry, and mining (Kenya, Republic of Kenya 2007).

Results and discussions

Our findings suggest a slow but gradual increase of Kenya's food system resilience from 2003 to 2019 (Figure 10.6). Despite this, the system remains fragile and vulnerable to shocks, which are tending to occur more often, reversing gains from the increase in resilience. Examples of shocks include climate shocks, crop diseases, the COVID-19 pandemic, the global oil crisis, and the recent Russia-Ukraine conflict. Of the three drivers of system resilience derived above—namely, density, heterogeneity, and symmetry—it appears

FIGURE 10.7 Kenya's food system density, 2003–2019



Source: Authors' calculations.

that heterogeneity may explain the substantial increase in resilience in 2019 compared with 2003 and 2013.

A dense food system can be understood as a web with integrated strings, which makes it more resilient compared with a sparse food system (see Figure 10.7). In the economic literature, network density also reflects economic diversification. As Usman and Landry (2021) point out, there are several ways of measuring economic diversification, including variety-, quality-, and output-based approaches. This chapter uses the variety-based approach (number of connected nodes), which measures the diversity of economic activities regardless of their quality.

There is evidence of a significant relationship between density in particular industries and the ability to withstand shock (Brown and Greenbaum 2017). Exploring the extent to which a less concentrated meat processing sector in the United States would be less vulnerable to the risks of temporary plant shutdowns, Ma and Lusk (2021) find that, when each plant in the industry faces a chance of shutdown equal to 10–30 percent, a more concentrated packing sector performs better than a diffuse or sparse packing sector in ensuring a relatively high level of output. Using fixed effects models, Brown and Greenbaum (2017) examined the influence of industrial diversity and concentration on unemployment rate stability in Ohio counties between 1977 and 2011. Their results indicate that counties with more diverse industry structures fare better during times of national or local employment shock.

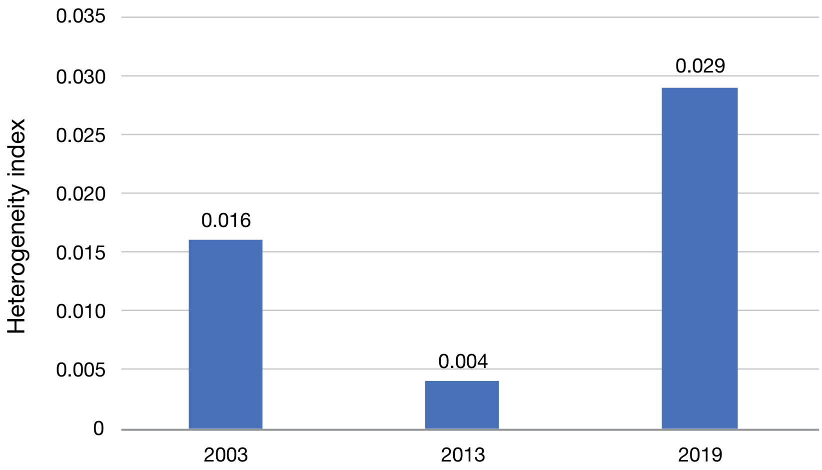
In the case of Kenya, the economy lacks diversification in terms of exports, imports, markets, and value addition to its products, and hence relies on exporting primary commodities and importing high-value goods. Specifically in terms of product diversification, coffee, tea, spices, and cut flowers still dominate Kenya's exports, at 29 percent. This implies that the country is still far from diversifying its exports, even with Vision 2030, which seeks to make the country globally competitive and prosperous through massive investments in critical international trade infrastructure and improvements in the quality of exportable commodities (that is, tea, horticulture, coffee, apparel and clothing, and vegetable oils).

Our findings suggest that the country experienced an increase in diversity from 2003 to 2019 (see Figure 10.7), but Kenya still needs to address its limited economic diversification. As pointed out by former Managing Director of the International Monetary Fund Christine Lagarde, "We know that economic diversification is good for growth. Diversification is also tremendously important for resilience" (Usman and Landry 2021, 1).

In addition to containing interconnected nodes (sectors), heterogeneous systems are characterized by links of different types. Heterogeneity of a system also reflects the sophistication of its sectors; for example, a food system that manages to produce oil, alcohol, animal feeds, and biofuel is more sophisticated and resilient than a system that produces only maize. Economic sophistication is defined as the ability to produce complex products that require specific skills and tacit knowledge embedded in labor (Arif 2021). A key component of a country's growth process and ultimately its resilience is an increase in this "sophistication" of the country's production, which may evolve either through an increase in the quality of previously produced goods or through a move into new, more complex products (Anand, Mishra, and Spatafora 2012). Rodrik (2007) notes that countries that can produce and export more sophisticated goods grow faster. According to Hausmann and colleagues (2021), economic growth is driven by diversification into new products that are incrementally more complex and less ubiquitous.

Figure 10.8 presents food system heterogeneity in Kenya from 2003 to 2019. Kenya's economic sophistication has been low, given that the largest share of the economy's output is from primary agriculture, which does not require special skills or advanced technology. The heterogeneity index is the highest in 2019, after a significant decrease between 2003 and 2013. If the 2019 trend is sustained, this will show that Kenya's food system has become more complex.

FIGURE 10.8 Kenya's food system heterogeneity, 2003–2019

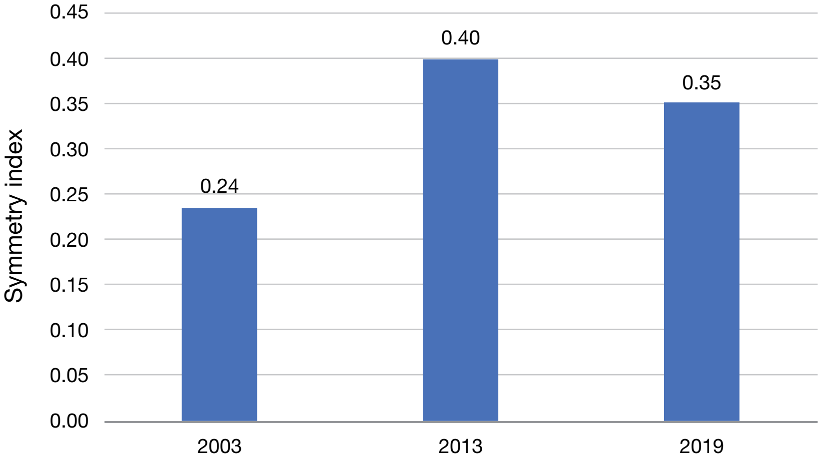


Source: Authors' calculations.

However, the increase in the heterogeneity index in 2019 may be explained partly by the adoption of technology in the country, especially in the implementation of Vision 2030, whose main objective is to transform Kenya into a newly industrializing, middle-income country with a key role for science, technology, and innovation (Kenya, Republic of Kenya 2007).

While sectors and their interactions are the building blocks of a food system, the types of relationships that the interactions represent play a significant role in the system dynamics. Indeed, understanding the nature of the interaction between two sectors is important to capture system resilience. In particular, symmetry is a crucial attribute that determines the resilience of a food system. This has practical implications that have not yet been fully explored, nor systematically exploited by network practitioners (Sánchez-García 2020). Acemoglu and colleagues (2012) have shown that aggregate volatility is observed from sectoral idiosyncratic shocks only if significant asymmetry exists in the interactions between sectors. Crowcroft (2015) points out that a symmetric network, with sectors offering as well as demanding resources, maximizes diversity. Similarly, symmetric interactions amplify network heterogeneity. One example would be the interaction between maize and energy sectors, where the first supplies maize to the second to produce biofuel, which is then used by the first sector to power equipment used in its production process. In the case of Kenya's

FIGURE 10.9 Kenya's food system symmetry, 2003–2019



Source: Authors' calculations.

food system, the symmetry index in 2003 was 0.236 (see Figure 10.9); it reached 0.399 in 2013, but decreased by 12 percent in 2019.

The food system resilience index and its components discussed above are all systemwide metrics that highlight how input–output linkages play a crucial role in transmitting shocks between economic actors (Carvalho et al. 2020). However, the "central" sectors are the ones responsible for the amplification of idiosyncratic shocks (Contreras and Fagiolo 2014). There are various measures of system centrality, depending on how connected a given sector is (degree centrality) or how far on average it is from any other sectors in the system (closeness centrality), or how crucial a given sector is in connecting other sectors (betweenness centrality). This chapter uses the eigenvector centrality developed by Bonacich (1987) to identify central sectors. This is also called the "influence measure" of centrality, whereby sectors are relatively more central in the system if their neighbors are themselves well-connected sectors (Carvalho 2014).

Table 10.2 presents the top 10 central sectors with their respective centrality measure. Because of constant changes in the IOT nomenclature, it is impossible to follow the dynamics of each top central sector from 2003 to 2019. However, using 2003 as a reference period, some relevant trends can be observed. For example, meat and dairy, along with poultry, have consistently been among the top 5 while beverages and tobacco have gone from the top spot in 2003 to

TABLE 10.2 Top 10 central sectors in Kenya, 2003, 2013, and 2019

2003		2013		2019	
Sector	Eigen centrality	Sector	Eigen centrality	Sector	Eigen centrality
Beverages and tobacco	1	Accommodation and food services	1	Accommodation and food services	1
Meat and dairy	0.685685	Meat, fish, and dairy	0.77386	Processed foods	0.667106
Poultry	0.504577	Beverages	0.72147	Beverage and tobacco	0.418471
Other manufactured food	0.491296	Other foods	0.58553	Poultry and eggs	0.390752
Sugar, bakery, and confectionary	0.441409	Poultry	0.36538	Cattle and raw milk	0.366997
Dairy	0.422082	Fruit and vegetable processing	0.33508	Other livestock	0.328605
Grain milling	0.403196	Cattle	0.33025	Vegetables	0.295296
Beef	0.276732	Fats and oils	0.32399	Coffee, tea, and cocoa	0.22337
Sheep, goats, and lambs for slaughter	0.276732	Other livestock	0.28725	Pulses	0.204533
Others crops	0.25363	Grain milling	0.26838	Fruits and nuts	0.187565

Source: Authors' calculations.

number three in 2019. It is worth noting the appearance of accommodation and food services in first place in both 2013 and 2019. This sector includes hotels, restaurants, and fast food. Given their role, the top 5 or 10 central sectors should be the targets of policies aimed at building a resilient food system in Kenya.

As part of measures to contain the spread of COVID-19, the Kenyan government, in addition to setting a daily curfew from 8 pm to 4 am, prohibited all public gatherings and in-person meetings, and bars and restaurants remained closed (only allowing takeaway) (GAIN 2021). Therefore, we implemented an extreme scenario assuming that these COVID-19-related restrictions took out the entire accommodation and food services sector. More specifically, the simulated shock corresponds to the removal of the sector from the 2019 food system. As Table 10.3 shows, the impact is felt in all types of interactions across the food system—those incoming (in degree) as well as those outgoing (out degree). The values of these interactions are also affected. It goes without saying that, if no mitigation measure is implemented, such an impact will ultimately reduce system production and eventually food and nutrition outcomes. With respect to incoming transactions, the most affected are construction, finance and insurance, information and communication, wholesale and retail

TABLE 10.3 Simulated effect of the removal of accommodation and food services as a result of the COVID–19 shock

	In degree	Out degree	Weighted in degree	Weighted out degree
Beverage and tobacco	0.0	–14.3	0.0	–83.3
Business services	–50.0	–12.5	–83.3	–61.2
Cattle and raw milk	0.0	–16.7	0.0	–12.2
Chemicals and petroleum	0.0	–5.6	0.0	–1.8
Coffee, tea, and cocoa	0.0	–50.0	0.0	–7.5
Construction	–100.0	–33.3	–100.0	–50.0
Cotton and fibers	0.0	0.0	0.0	0.0
Education	–16.7	0.0	–28.6	0.0
Electricity, gas, and steam	0.0	–12.5	0.0	–43.3
Finance and insurance	–100.0	–12.5	–100.0	–26.9
Fisheries	0.0	–50.0	0.0	–70.0
Forestry	0.0	0.0	0.0	0.0
Fruits and nuts	0.0	–33.3	0.0	–68.6
Health and social work	–16.7	0.0	–15.2	0.0
Information and communication	–100.0	–50.0	–100.0	–92.9
Machine, equipment, and vehicles	0.0	–25.0	0.0	–28.6
Maize	0.0	–20.0	0.0	–0.2
Metals and metal products	0.0	0.0	0.0	0.0
Mining	0.0	–33.3	0.0	–13.3
Non–metal minerals	0.0	–50.0	0.0	–33.3
Oilseeds	0.0	–25.0	0.0	–38.2
Other cereals	0.0	0.0	0.0	0.0
Other crops	0.0	–33.3	0.0	–9.8
Other livestock	0.0	–16.7	0.0	–4.2
Other manufacturing	0.0	0.0	0.0	0.0
Other services	0.0	0.0	0.0	0.0
Poultry and eggs	0.0	–20.0	0.0	–32.0
Processed foods	0.0	–11.1	0.0	–12.1
Public administration	–14.3	0.0	–41.8	0.0
Pulses	0.0	–20.0	0.0	–40.0
Real estate activities	0.0	–100.0	0.0	–100.0
Rice	0.0	–25.0	0.0	–22.5
Roots	0.0	–50.0	0.0	–6.9
Sugarcane	0.0	0.0	0.0	0.0
Textiles, clothing, and footwear	0.0	–16.7	0.0	–8.3
Tobacco	0.0	0.0	0.0	0.0
Transportation and storage	–50.0	–7.1	0.0	–11.9
Vegetables	0.0	–33.3	0.0	–41.7
Water supply and sewage	0.0	–14.3	0.0	–23.7
Wholesale and retail trade	–100.0	0.0	–100.0	0.0
Wood and paper products	0.0	0.0	0.0	0.0

Source: Authors' calculations.

trade, and transportation and storage. With respect to outgoing transactions, real estate; coffee, tea, and cocoa; fisheries; information and communication; non-metal minerals; and roots experience the most negative effect.

Concluding remarks and policy implications

Defined as the ability to maintain an acceptable level of the desired outcome despite stressors or shocks, resilience is inherently a dynamic concept—which makes it difficult to measure. Still, the concept is gaining interest among development partners and policymakers because it also captures the ability to bounce forward after a shock alters the system. To make matters more complicated, the resilience of a system is not a mere sum of the resilience of its components. As Cerqueti, Ferraro, and Iovanella (2019) point out, system disruption depends on the magnitude of the shock and its propagation across the system because of the interconnectivity of its components.

This chapter, drawing on the ecological and engineering literature, has used systemwide metrics to measure food system resilience and its components. We used a production approach based on input–output linkages. Our results suggest that the resilience of a food system is driven by its density, heterogeneity, and symmetry. In economic terms, this means that economic diversification (more food sectors) and sophistication (high-value food sectors) are the main drivers of a resilient food system.

There was a sharp decline in Kenya's food system resilience between 2001 and 2003, followed by a slow but gradual increase from 2003 to 2019. These resilience dynamics were driven mostly by loss of density and symmetry. Overall, though, the country's food system density increased from 2003 to 2019. The symmetry index reached 0.351 in 2019, up from 0.236 in 2003. As Carvalho (2014) points out, central production sectors—those with more direct or indirect downstream interactions—are relatively more important in determining aggregate system volatility. We identified and ranked these central sectors for each period. Frequent changes in the IOT nomenclature mean we could not properly analyze the dynamics of each top central sector from 2003 to 2019. Nonetheless, given their role, the top 5 or 10 central sectors should be the targets of policies aimed at building a resilient food system in Kenya.

Waha and colleagues (2018) have demonstrated that diversification plays an essential role in ensuring food security and stabilizing food production in Africa. Other research (such as Jones, Shrinivas, and Bezner-Kerr 2014) shows clear relations between farming diversity and food security, and a linkage to nutritional diversity, but conclusions on how market orientation influences the relationship vary (Sibhatu, Krishna, and Qaim 2015). This suggests the need for incentives to promote diversification while intensifying production systems. Households may still be limited in their ability to diversify because of soil, labor, input, or land constraints or because of their remote location without access to extension services that provide support for new crops or crop management techniques (Waha et al. 2018).

Given the critical role of livestock in supplying food of animal origin, Vision 2030, which is Kenya's development blueprint, identifies this as one of the eight priority sectors within its economic pillar, with various programs for the period 2018–2022. These include the Livestock Production Program, the Smallholder Productivity and Agroprocessing Program, and the Pastoral Resilience Building Program (Kenya, Republic of Kenya 2018).

Overall, to reinforce, maintain, and improve sectors' interconnectivity for increased system resilience, a systemic policy approach is needed to prevent the build-up of vulnerabilities and reduce exposure to shocks. Such a policy should cover relevant institutions, infrastructures, regulations, and markets.

As many have suggested before, what is required to build a resilient food system in a country such as Kenya is a fundamentally different model of agriculture based on diversifying farms and farming landscapes, optimizing biodiversity, and stimulating interactions between different sectors for a sustainable healthy diet for all. Together, a varied and balanced diet, a wide range of crops and foodstuffs, and a diverse system of production and distribution make for a more resilient, stable, and healthy food system (EC 2020).

Finally, the concept of a food system is very appealing because it emphasizes connectivity and interdependence of activities, actors, and institutions to achieve a sustainable healthy diet for all. This calls for coordination and partnership at every level to ensure the whole system functions efficiently and yields the expected outcomes. In this, the development of food system modeling frameworks is critical in integrating the complex interactions between food, ecology, economy, and society, to provide evidence on trade-offs when diversifying food systems to improve their resilience (Hertel et al. 2021). This will require substantial investments in building statistical systems that capture the main participants in a food system along with related operations and connections.

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