How Climate Change Impacts Nutrition Security in Low- and Middle-Income Countries

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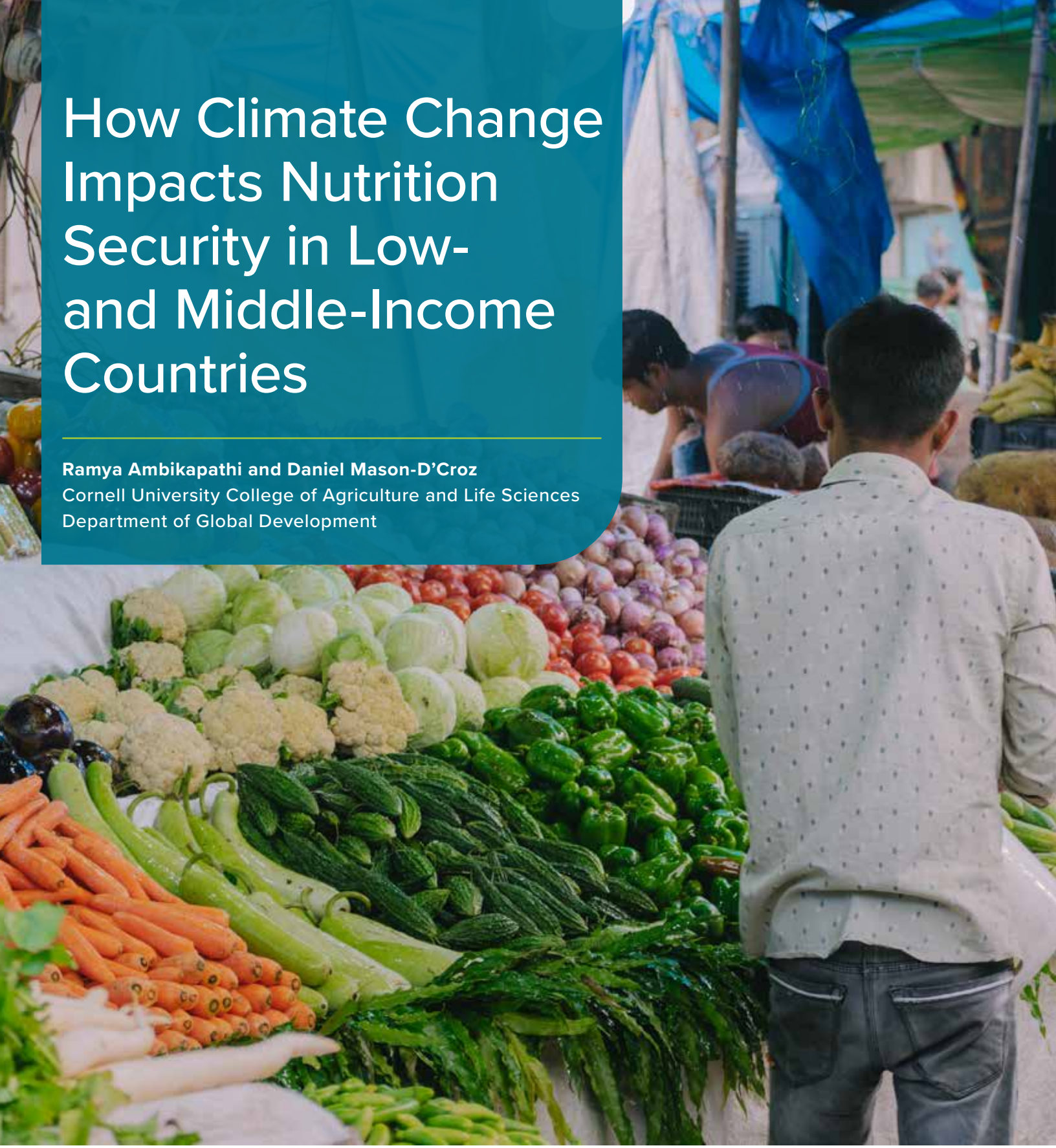

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About This Report

This report was commissioned by Farm Journal Foundation and published in May 2024.

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I. EXECUTIVE SUMMARY

A series of global challenges in the past few years – including the COVID-19 pandemic, regional conflicts, and climate change – has sent the world hurtling in the wrong direction when it comes to food and nutrition security. Today, about 10 percent of the global population experiences hunger, significantly higher than in recent years, and 3 billion people are unable to afford a well-balanced, healthy diet that includes whole grains, fruits, vegetables, and animal-sourced foods.

Climate change, in particular, has imposed significant burdens on global nutrition outcomes. The increasing frequency of extreme weather events – including droughts, floods, wildfires, heat waves, and severe storms – has a disproportionate effect on low- and middle-income countries where large proportions of the population rely on agriculture to make a living. Extreme weather can lead to crop failures, pressure from diseases and pests, lost crop and livestock productivity, and lower nutritional value of food – ultimately hurting farmers' livelihoods and leading to higher costs for consumers. Low- and middle- income countries also often have limited capacity to adapt to climate challenges, due to a lack of safety net programs for low-income households, robust infrastructure, and tools and technologies that would enable farmers to produce good crops even in the face of increasingly difficult conditions. Women are particularly vulnerable to food and nutrition insecurity, as they generally have lower incomes compared with men, and studies show that during times of financial pressure, they often reduce their food intake or skip meals so that other members of their household can eat.

High food costs and lost agricultural incomes contribute to increasing rates of malnutrition in all forms, including micronutrient deficiencies, undernutrition, and more recently, overweight and obesity. Children, adolescents, and women who are pregnant or lactating have higher nutrient needs, leaving them especially at risk. Improving nutrition outcomes and shoring up our global food system to deal with climate change will require a whole of society and government approach, to ensure that policy solutions work both for nutrition security as well as the natural environment.

Given this context, the U.S. government should consider the following policy recommendations to support global nutrition security:

- **Support greater investments in agricultural research and development.** To address challenges from both malnutrition and climate change, research funding should be focused on retaining or enhancing nutrient content where possible, food crops beyond major staple grains, tailored research to support smallholders in different geographies, solutions to improve value chains for nutritious foods (e.g. animal-sourced foods, legumes, fruits, and local vegetables), food loss and waste, and forgotten crops that may have nutrition and climate benefits.
- **Invest in programs that benefit women's nutrition and women working in agriculture and food systems.** There are multiple ways to support women in the agri-food value chain, including by investing in value-chain sectors that are dominated by women (e.g. fruit and vegetables), strengthening the collection of gender-disaggregated data in the agri-food sector, and enhancing access to girls' education within the context of climate change.
- **Incentivize governments to expand access to technical assistance and extension services.** Extension and technical assistance can facilitate the adoption or scaling of conservation agriculture practices, which can help reduce risks, manage water, improve soil, and increase productivity and incomes in the face of climate shocks.
- **Provide adequate financing for agricultural development programs, especially those that take a whole-of-society-and-government approach.** Programs such as the U.S. Feed the Future initiative support agricultural-led growth and increased incomes by helping to build more resilient food systems. Feed the Future and similar programs aimed at addressing the root causes of hunger and malnutrition within the context of climate change deserve more support.
- **Identify financing mechanisms for governments to increase access to safety net programs.** Increasing coverage of both climate-sensitive and nutrition-sensitive social protection programs such as insurance mechanisms, cash transfers, and school feeding programs, especially under shocks, can help smallholder farmers recover from shocks and improve both food security and healthy diets.
- **Invest in programs that help strengthen private- and public-sector value chains and infrastructure.** Investments in infrastructure that support agriculture, including in improved storage, transportation, and adapted inputs and seed technologies including biofortified crops, can better connect farmers to markets, improve their incomes, and reduce the costs of healthy foods.
- **Increase support for programs that improve farmers' access to finance.** Smallholder farmers, especially women, generally have lower access to capital, resources, feed, and seed markets – leaving them vulnerable to climate change. Increased access to financing would enable them to invest in their livelihoods, including crops and household purchases that would improve household nutrition.
- **Support initiatives that strengthen agricultural data gathering, climate monitoring systems, and related investments in human resources.** Climate information services and local traditional knowledge can help farmers improve their farm management practices and make cropping decisions.
- **Invest more in solutions that enable regional food trade.** Enabling regional food trade can improve market demand, profits for the intermediate sector, and access to healthy diets while potentially reducing food loss. Regional food trade can be strengthened through infrastructure investments, regional trade agreements, and harmonized regulations.

II. CONTEXT

Despite significant improvement in reducing global hunger and undernutrition over the past few decades, progress has stalled even before the confluence of global crises since 2019, including the COVID-19 pandemic, inflation, international conflicts, and climate change. These crises have erased more than a decade of progress, with current rates of undernourishment hovering at the same prevalence rate as in 2010. Currently, 10 percent of the world's population experiences hunger, 2.4 billion experience severe and moderate food insecurity, and 3 billion people cannot afford a well-balanced, healthy diet that includes whole grains, fruits, vegetables, and animal-sourced foods (FAO 2023c).

Multiple forms of malnutrition are higher in low- and middle-income countries where large proportions of the population rely on rain-fed agriculture to make a living. In these contexts, exposure to climate events stays high while coping capacity remains low, thus increasing the overall vulnerability (Popkin, Corvalan, and Grummer-Strawn 2020; Fanzo et al. 2018; Myers et al. 2017; Tirado et al. 2013). In Sub-Saharan Africa, undernourishment has risen to 22.5 percent, the same level seen in 2005, marking a significant setback after a period of progress. In this region, weather shocks have reached 30-year highs, and the continent's smallholder farmers – who produce 80 percent of the food consumed (Herrero et al. 2017) – lack the tools and resources to adapt. Women are disproportionately affected, experiencing higher food insecurity than men (FAO 2023c).

Climate change affects all, and some substantially more than others

We are in the climate change era, where experiencing extreme weather and changes in seasons are the new norm. Climate change shocks directly and immediately affect agriculture and markets, crop, aquaculture and livestock productivity, labor productivity (morbidity and mortality), and ecosystem functionality (FAO 2023b; Fanzo et al. 2018; Myers et al. 2017). Climate change indirectly affects health and nutrition through changes in food prices, off-farm opportunities, health and disease ecology, biodiversity loss, migration, and infrastructure loss (FAO 2023b; Morris et al. 2017; Myers et al. 2017). Together, these effects dramatically reduce food and nutrition security in low- and middle-income countries (LMICs) through multiple pathways. In LMICs, smallholder farmers produce a majority of the food consumed and are on the front lines of climate change (Fanzo et al., 2018; Myers et al., 2017). Poor, rural, and peri-urban populations in these countries who have contributed least to the climate crisis will be the ones who will suffer most from climate-related food insecurity and malnutrition (Lipper and Cavatassi 2024; Ambikapathi et al. 2024).

It is well known that agriculture and food systems, especially from industrialized nations, are significant contributors to climate change, biodiversity loss, and other environmental impacts. Because smallholder farmers are responsible for producing most food in LMICs, these shocks fall disproportionately on them, potentially placing them at a heightened risk of adverse health, hunger, and nutritional outcomes. Smallholder farmers are also net buyers of food. **Climate change shocks are also non-linear; they could have a slow onset or be rapid and can accumulate over time, reducing the resiliency of a community and a household.**

KEY TERMS

Food security focuses on food availability, access, and stability.

- Food security is often operationalized as food quantity or in dietary terms, referred to as energy or caloric-sufficient diet. In the donor community, it is often referred to as hunger, which is the discomfort resulting from skipping meals or not having enough food (focusing on quantity rather than quality, diversity, or cultural acceptability).

Nutrition security refers to food security with adequate nutritional status and access to health services that reduce multiple forms of malnutrition.

Malnutrition is defined as undernutrition, micronutrient deficiency, and overweight/obesity.

Healthy diet refers to an energy and nutrition adequacy that promotes health and prevents malnutrition and diet-related non-communicable diseases (such as obesity, hypertension, and diabetes). A healthy diet consists of servings of whole grains, fruits, and vegetables, as well as animal source foods, while keeping intake of sugary, salty, and energy-dense ultra-processed foods low.

Sources:

FAO and WHO. 2019. Sustainable healthy diets – Guiding principles. Rome.

White House National Strategy on Hunger, Nutrition and Health.

Historically, increasing agricultural productivity has been a significant driver of poverty alleviation and reductions in hunger worldwide. It has also contributed to easing pressures on additional land expansion. While attainable yields across most of the world have been increasing over the past several decades, the gap between real and attainable yields appears to be increasing in Sub-Saharan Africa and South Asia for many crops (Gerber et al. 2024). Various causes of these yield gaps include access to seeds, agricultural inputs, and markets. Climate change may reduce attainable and realized yields in many regions, with disproportionate impacts likely for vulnerable producers in LMICs. Additional investments in both the development of climate-smart agriculture and in scaling up improved agronomic practices will be critical for increased agricultural productivity in Sub-Saharan Africa and South Asia. If this isn't achieved, continued low-productivity agriculture will create challenges toward achieving food security and poverty alleviation goals and contribute to added environmental pressures from increased land expansion and increased emissions (Dzanku, Jirström, and Marstorp 2015; Campbell et al. 2016; van Ittersum et al. 2016; Springmann et al. 2018). Conversely, narrowing yield gaps could help to increase domestic food supplies and make for more food-secure food systems (van Ittersum et al. 2016).

Multiple forms of malnutrition under the new regime of persistent shocks

Our current state of food systems is leading to multiple forms of malnutrition – undernutrition, micronutrient deficiencies, and obesity (Popkin, Corvalan, and Grummer-Strawn 2020). The current food systems dynamics and trends of the food system result in almost 1 billion people suffering from hunger and another 1 billion affected by obesity. Even in the absence of climate change, these food system trends persist. Despite producing sufficient calories, we have a very unequal global food security situation with profound health and economic consequences. The common determinant among all forms of malnutrition is access to healthy diets. Globally, poor diets (diets low in whole grains, high in sodium, low in fruits and vegetables) are responsible for one-fifth of mortality, and these are much higher in LMICs (Afshin et al. 2019). Thus, focusing on improving access to healthy diets a critical strategy to target multiple forms of malnutrition.

Multiple forms of malnutrition, including micronutrient deficiency, undernutrition, and obesity, place an enormous burden on low- and middle-income countries' economies. Historically, investments in nutrition were driven by considerations of human development, labor, and economic productivity, especially in early child diets and nutrition (Hoddinott 2016; Hoddinott et al. 2013; Victora et al. 2021). More recently, another rationale has emerged, wherein investments in food systems of low- and middle-income countries are seen as vital due to the demand for healthy diets, which can serve as a significant source of livelihood, especially value-chain development (market and communications connectivity, processing sectors) (Barrett et al. 2022; Fanzo et al. 2017; Gelli et al. 2019). Therefore, U.S. investments in agricultural and value chain development to enhance access to healthy diets, as well as nutrition security abroad, can enhance economic growth in low- and middle-income countries and contribute to overall global food security. These investments need to be inclusive for benefits to be equitable, e.g. they could focus on employment and livelihood opportunities for women and youth, especially young women (Ambikapathi et al. 2024; Davis et al. 2023; FAO 2023a).

Nutrition security relies on a stable and sustainable food system to produce healthy, diverse diets that are affordable and accessible to all. Past global food policies, such as the Green Revolution, have contributed to greater food security but have also resulted in significant environmental impact (Clapp 2022; Clapp and Moseley 2020; Crippa et al. 2021). However, new shocks emerge as witnessed by the global polycrisis caused by COVID-19, conflict, and climate change (Fanzo 2022). Thus, enabling resilient food systems requires a whole of society and government (WOSG, next section) lens to food systems, i.e., collaborations between cross-sectoral agencies and enabling informational and capacity networks (Ortenzi et al. 2022). The primary emphasis lies in the WOSG's strategies, which aim to cultivate a system capable of withstanding various shocks, whether related to climate change or otherwise. Second, there are rank-order effects of shocks on nutrition, i.e., income loss due to climate change has a substantially more significant impact on nutrition security than loss of nutritional quality in crops under climate change. This varies contextually and can be used to set policy priorities. Thus, contextual research and development and routine monitoring systems for nutrition and diets are key to setting policy priorities. Third, cross-sectoral collaboration requires time, financial resources, and local and national capacity. Therefore, investments should be directed toward fostering longer-term perspectives. Lastly, investment delays for climate change actions are costly the longer we wait.

Without targeted and multi-prong actions to improve the local production, access, and affordability of healthy foods, current trends suggest a reversal of decades of progress

toward improved global health, nutrition, and food security. This policy paper synthesizes the impact of climate change on nutrition and provides evidence-based policy recommendations to inform and align U.S. climate and agriculture policy to advance nutrition outcomes for low- and middle-income countries.

We must consider the entire food system to examine the holistic impact of climate change on healthy diets and nutrition

A holistic approach is needed to transform food and agricultural systems for better dietary and nutrition outcomes. Given this current state of recurring crises, there is a growing consensus that food and agricultural development policies must move beyond food security and focus on enabling nutrition security and resilience, which requires whole of society and government (WOSG) strategies – an approach that's also domestically adopted by the U.S. to improve nutrition outcomes to increase resilience (Ortenzi et al., 2022)*. This involves sustained investments in National Agricultural Research and Extension Services (NARES) and U.S. foreign agricultural development programs and collaboration among various government agencies and stakeholders, including community members, civil society organizations, advocacy groups, media, academia, private industry, and intergovernmental organizations that focus on improving access to nutritious foods. Beyond collaboration, knowledge networks must be enabled within and between countries for mutual learning. As mentioned earlier, this is the key to strengthening both human capacity and infrastructure that is resilient towards any shocks – whether climate or non-climate-related.

What it means to take a holistic, WOSG food-systems approach

The food system refers to all activities and components that move food from farm to fork (Figure 1, (HLPE 2017)). Figure 1 illustrates the three main components of food systems, which include:

1.) **inputs** (seeds, fertilizer, feed, labor, extension/information service) and agricultural production;

2.) **storage** (cold chain, storage technology), processing (milling, fermentation, drying, cooling, canning), and distribution (transportation to retail markets);

3.) **food environments** (markets and retailing structures that involve marketing, availability, and accessibility) and household consumption of nutritious food, which includes drivers such as household income, intra-household allocation, values, family nutrition literacy, and other resources (e.g. time, fuel, water).

Food loss occurs at each stage, as food travels from farm to fork (blue arrows in the figure). This loss is much higher in LMICs due to a lack of basic on-farm storage, cold storage infrastructure, and transport. Food loss and waste account for an estimated 25-30 percent of the total food produced, according to the United Nations Food & Agriculture Organization (FAO), while rising temperatures can also lead to spoilage and contamination, compromising the overall quality of food (Fanzo et al., 2017; FAO, 2022; HLPE, 2017).

An integrated WOSG food systems approach considers how all components, agents, and institutions (e.g. including ministries, civil societies and communities, and other stakeholders in the agriculture, fisheries, education, health, social protection, gender, transportation sectors) contribute to improved access to healthy diets

Figure 1: Food system components

Source: HLPE 2017

*White House National Strategy on Hunger, Nutrition and Health.

while reducing the food systems' environmental footprint. This includes re-aligning food systems to produce more nutritious and diverse foods like legumes, vegetables and animal-sourced foods, reducing food loss and waste, and improving food safety across food value chains (Brouwer et al. 2021; Brouwer, McDermott, and Ruben 2020). Developing informational and capacity networks across groups such as farmer organizations, civil societies, and research and development institutions (NARES) to collaborate toward the national agenda on the supply aspects of nutritious foods. This could also involve task forces at regional and sub-regional entities that can translate national priorities into programs and policies. For example, the U.S. makes many extension services connected to research land-grant institutions in each state, allowing national agendas to be operationalized to local priorities. However, even in the U.S., there is a disconnect between agricultural systems and nutrition and environmental outcomes (Neff et al. 2009). Hence, the WOSG approach to food systems could be applied both domestically and globally.

III. HOW DOES CLIMATE CHANGE AFFECT NUTRITION?

Climate change affects food quantity, quality, and accessibility. While seasonal changes, flooding, and droughts may be normal functions of our ecosystem, climate change refers to long-term changes (e.g. decades, 50 years, centuries) in rainfall, temperature, wind patterns, and seasonal patterns (e.g., El Niño, monsoons, etc.) caused by higher carbon dioxide concentrations and other greenhouse gasses in the atmosphere. For example, this could be changes in the variability of extreme weather events happening more frequently, as we start seeing once-in-10-year events happening annually or a slow rise in rainfall changes or arid conditions. **The impact of these changes is non-linear, and can be devastating to local food and agricultural systems once beyond a certain threshold.**

Changes in extremes, such as the frequency, intensity, or duration of extreme weather events, reduce the resilience of households, communities, and countries. **In short, climate change can create a dramatic, magnifying impact on numerous natural hazards – including extreme floods, soil erosion, cyclone and hurricane activity, landslides, sea level rise and saltwater intrusion, frosts, droughts, heat waves, wind storms, and wildfires (Ranasinghe, Ruane, and Vautard 2021).** Figure 2 on the following page illustrates the changes in these climate hazards. Red represents situations under climate change, denoting changes in intensity, frequency, duration, change in seasonality, speed of onset, and the spatial spread of the climate hazards (Ranasinghe, Ruane, and Vautard 2021).

Climate change can impact smallholder farmers directly by reducing household-level food production and income, decreasing purchasing power for nutritious foods and overall food consumption, and increasing food insecurity (Fanzo et al. 2018). This problem worsens when community and market-level shocks also arise from the same climate change hazards, such as food price hikes, which further threaten access to quantity and quality of food due to reduced income and increased household needs (Brinkman et al. 2010; Brown 2014; Headey and Martin 2016; Tirado et al. 2013). **Farmers with few resources struggle to fully recover their livelihoods without adaptation, resulting in long-term poverty and food insecurity, mainly when shocks are prolonged or recurring.**

Figure 2: Climate Change Impact on Climate Hazard

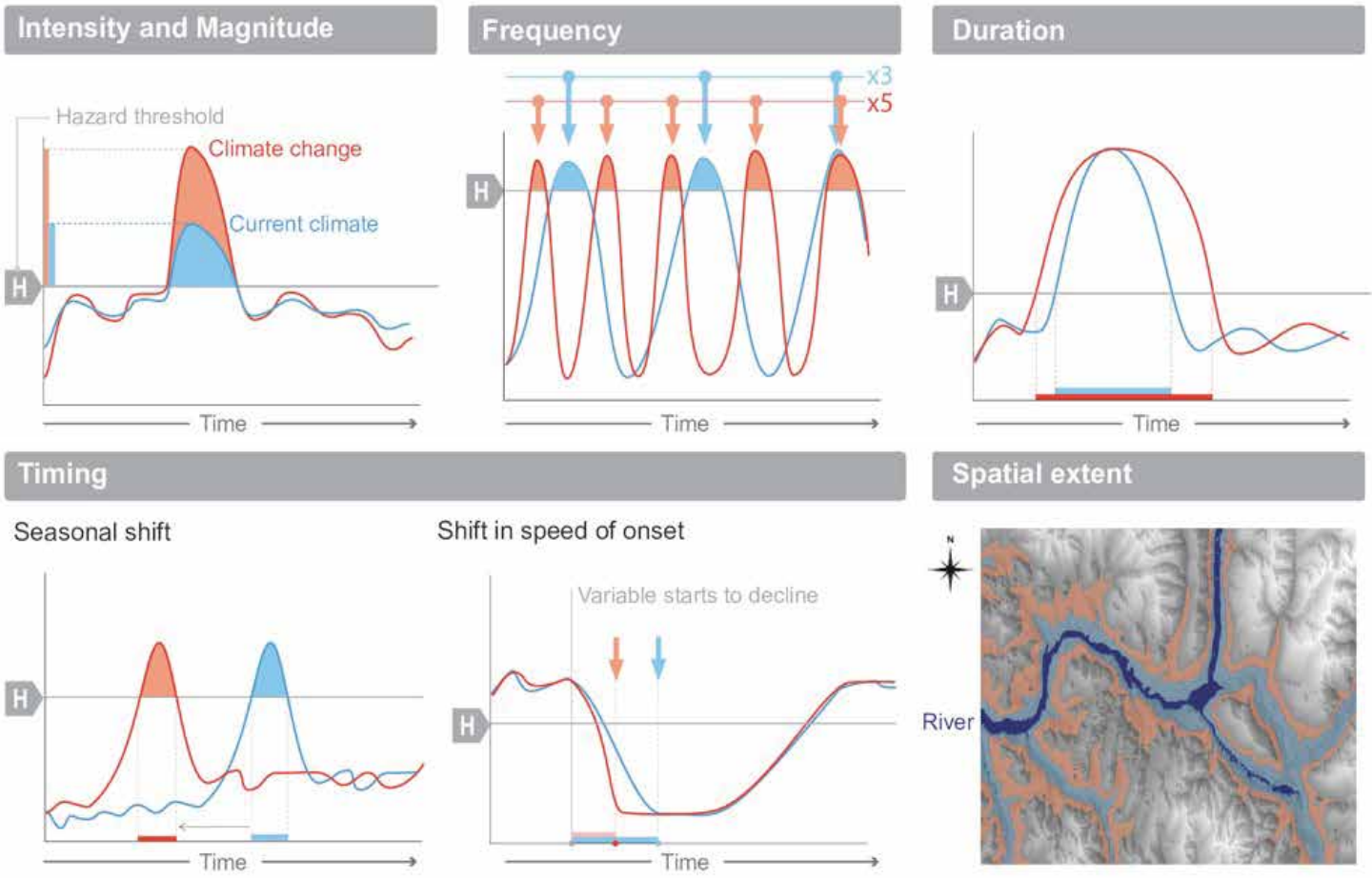


Figure from FAQ 12.3 Figure 1 in IPCC, 2021: Chapter 12. Types of changes to a region's hazard profile. The first five panels illustrate how climate changes can alter a hazard's intensity (or magnitude), frequency, duration, and timing (by seasonality and speed of onset) in relation to a hazard threshold (horizontal gray line, marked 'H'). The difference between the historical climate (blue) and future climate (red) shows the changing aspects of climate change that stakeholders will have to manage. The bottom right-hand panel shows how a given climate hazard (such as a current once-in-100-year river flood, geographic extent in blue) may reach new geographical areas under a future climate change (extended area in red).

LMICs are highly vulnerable to climate shocks. The capacity to adapt to shocks is based on social factors and assets available at the household, community, and national-level (Morton 2007; Fan and Rue 2020; Myers et al. 2017; Tirado et al. 2013). These include safety net programs, resilient infrastructure, affordable access to adapted seeds and livestock varieties, conservation agriculture practices, tools like soil monitors and irrigation, weather monitoring systems, and institutional capacity. In high-income countries, agricultural innovation and research and development are public goods, i.e., generally providing the tools needed to help food systems adapt, enabling farmers to have sufficient production and incomes while using fewer inputs like water, fertilizer, feed, and land. However, in LMICs where poverty and lack of local investment in innovation is systemic, smallholders generally lack access to even the most basic adaptation tools and productive inputs, limiting their capacity to adapt or alter their food production strategies. This makes the agricultural systems extremely vulnerable to weather and other shocks, especially in the Global South. These shocks disproportionately impact the nutrition of women (Bryan et al. 2024). Studies have shown that compared with men, women have higher labor time commitments (e.g., going further to access water for their households) and lower food security, with many eating less or forgoing meals to buffer other household members.

IV. OUR CHANGING GLOBAL FOOD SYSTEM:

Five major trends, climate change impacts, policy recommendations to improve nutrition outcomes

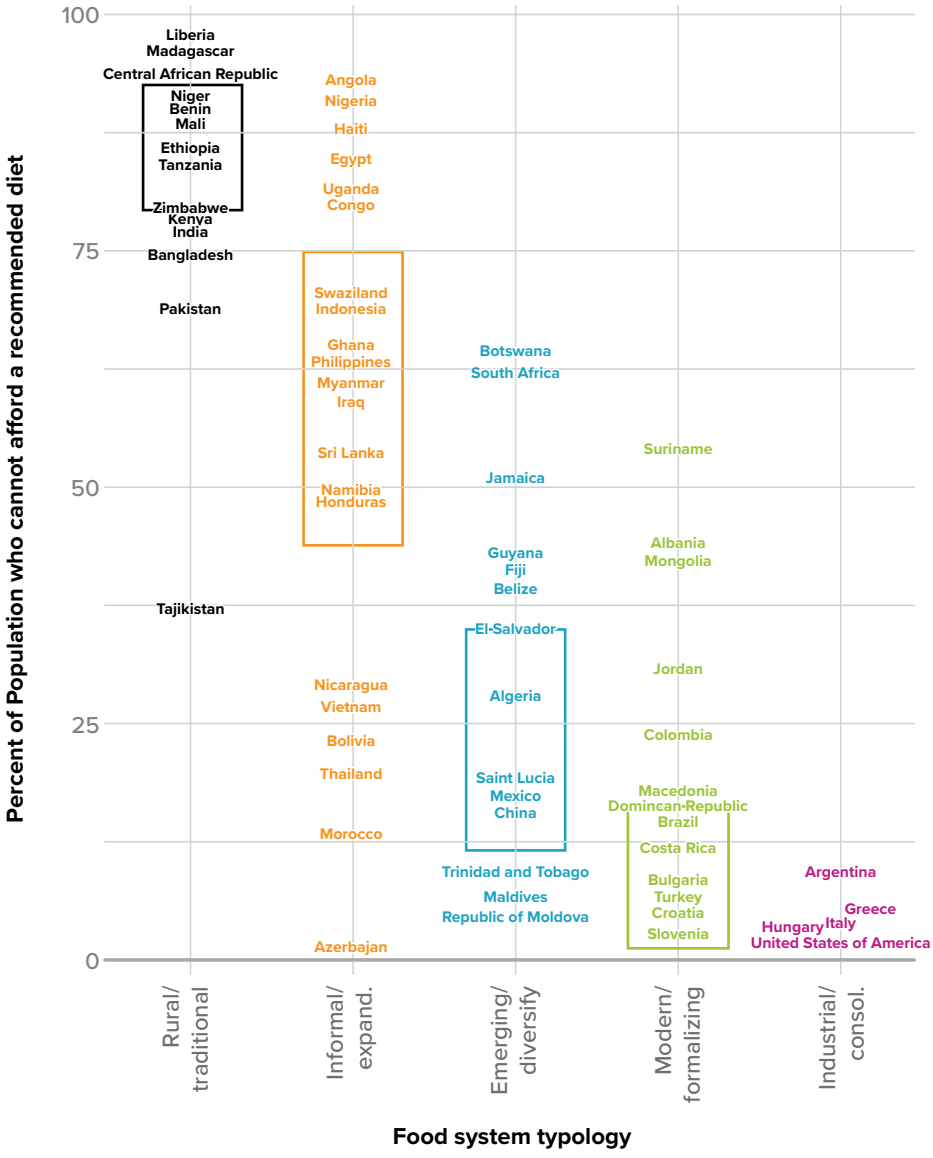
Adopting an integrated WOSG food systems approach to nutrition entails integrating agriculture, health, infrastructure, and nutrition policies to improve nutrition outcomes while reducing adverse environmental impacts simultaneously. Robust and effective food policy must recognize the complexity of food systems and the diverse impacts and challenges that they face, including climate change. A better understanding of how these multiple challenges interact with climate change is essential for identifying entry points for interventions in food systems. **To contribute to this better understanding, we highlight five major global food system trends observed over the last 60 years to inform the next generation of global food policies and identify key challenges and opportunities to improve nutrition under climate change.** This analysis focuses on Sub-Saharan Africa and South Asia, where food insecurity is the highest and future progress is the most challenged.

Underlying Trend #1:

Diet quality is a key factor that drives all forms of malnutrition and is determined by a mix of factors contributing to the consumption of both nutritious and unhealthy foods. Currently, 2.4 billion people are food insecure, and over 3 billion cannot afford a healthy diet (Herforth et al. 2020). Figure 3 shows the percentage of the global population that cannot afford the recommended healthy diet for selected country by their respective food system categories (Ramya Ambikapathi et al. 2022). Countries with informal food system types (i.e. the majority of countries in Sub-Saharan Africa and Southeast Asia) where small-holders produce the majority of the food have 76-85 percent of the population who cannot afford a healthy diet (Ambikapathi et al., 2022). In these countries, healthy foods are relatively expensive in large part due to the lack of local food system infrastructure connecting farmers to markets and processing sectors, especially for nutritious foods, and lack of investment in research and development for local, nutritious foods like fruits, legumes, vegetables, and animal-sourced foods, and innovations to adapt to pests, disease and weather shocks.

Figure 3: Population who cannot afford a healthy recommended diet by country and food system types (selected countries)

Source: Ambikapathi et al. 2022



Overall, this limits access to affordable, nutrient-dense foods such as fruits and vegetables, animal-sourced foods, and legumes. In many low- and middle-income countries, particularly in South Asia, this is compounded by the prevalence of cheap, unhealthy foods, including sugary, salty, and fatty foods (Headey and Alderman 2019).

In addition, the cost of a healthy diet is driven by different food groups, which vary by region; in Africa, the higher relative costs of protein-rich foods, fruits, and dairy drive the total cost of a nutritious diet; meanwhile, dairy and vegetables drive the cost of a healthy diet in Asia (Herforth et al., 2020). Seasonal food production (e.g., fruits and vegetables) can also affect the cost of a healthy diet (Herforth et al., 2020). Life stages and sex also affect the cost; adolescent boys and women who are pregnant, lactating, or menstruating have higher nutrient needs, and their cost of a nutritious diet is higher (Herforth et al., 2020). Lastly, variable income and gender wage gaps also affect the affordability between men and women, with women estimated to have lower affordability of healthy diets compared with men (Raghunathan, Headey, and Herforth 2021). It is important to emphasize the cost of healthy foods does not mean consumption; for example, even in the U.S., 95 percent of people can afford a healthy diet, but it does not translate to consumption due to physical and economic access. Cost is one large dimension, but accessibility is a major factor in improving healthy diet consumption.

Global demand for animal-sourced foods is expected to increase in low- and middle-income countries as they develop and per capita household income increases. Since the 1990s, consumption of animal-sourced foods has increased in Africa and Asia, mainly concentrated in dairy, poultry, and pork (Herrero et al. 2021). However, 800 million people living on less than $2 a day rely on staple-based diets, which puts them at a higher risk of undernutrition and micronutrient deficiency (Adesogan et al. 2020). The consumption of animal-sourced foods, which are nutrient-dense, can have a positive impact on nutritional and health outcomes (Beal et al. 2023). This is true, especially for children, because they have lower stomach volumes, and thus, adequate access to nutrient-dense foods such as animal-sourced protein is vital. On the contrary, excess consumption, especially among men from urban high-income settings, contributes to poor health and lower sustainability (Macdiarmid et al. 2012; Bassi, Maysels, and Anex 2022).

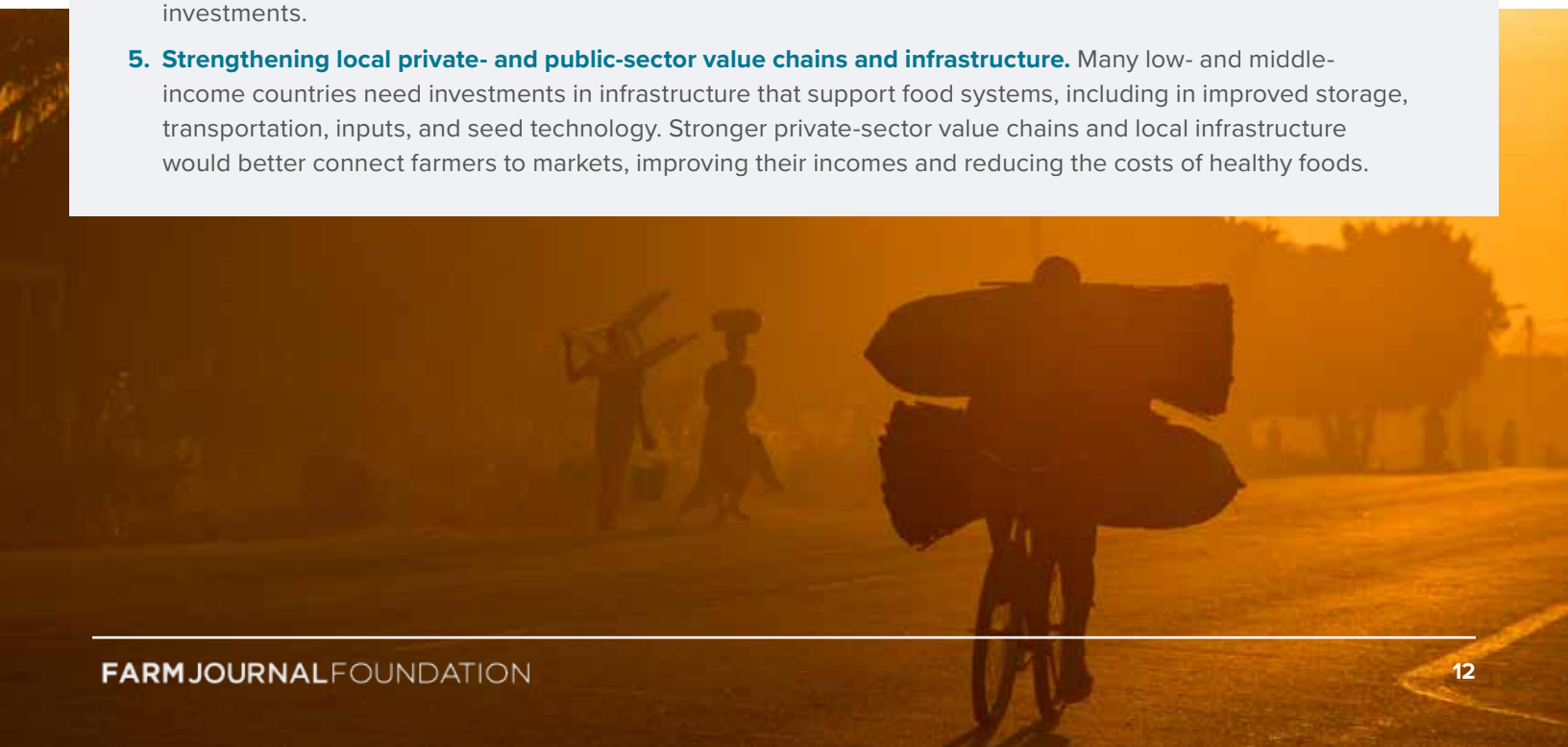
Low incomes impact the diet quality of all consumers, but women and children are disproportionately vulnerable due to more limited access to productive resources, intra-household allocation of diets, and the fact that they have higher nutrient needs due to the physiological processes of pregnancy, lactation, and growth to adulthood. Livestock production is also an essential source of employment, estimated to support 650 million small-scale producers (Herrero et al., 2021), and a critical resilience asset that farming households can use to mitigate risks under various shocks (Bryan, Theis, and Choufani 2017).

Climate change has a very acute, direct, and immediate impact on human health, diets, and nutrition. Direct hazards from extreme weather events impact morbidity, mortality, and incomes used to cover basic needs like housing, water, food, and access to healthcare services. Without tools and safety nets to adapt, extreme weather events can reduce crop yields and animal productivity, undermining farmers' own food security, their incomes, and the price of nutritious foods in local markets. When agricultural production declines, governments often resort to imports to compensate for food deficits, which are not sustainable enough for the governments to both pay for food and pay for investments towards strengthening in-country food systems.

Poor people in many countries spend about 50-75 percent of their incomes on food, so any food price spike or negative income shock due to climate change affects both the quality and quantity of diets (Bouis, Eozenou, and Rahman 2011). The impact of this is striking. During shocks, the share of income allocated to staples increases, thus leaving very little for nutritious foods, which has longer-term consequences for child nutrition. Research shows that rainfall variability and droughts are associated with reductions in children's linear growth (Le and Nguyen 2021). This is especially important for women, who are disproportionately at risk of food insecurity and are more likely to do nutritional buffering (consuming less so children and other family members can eat) for other household members under shocks as observed during food prices and COVID-19 shocks.

Underlying Trend #1 Recommendations: In rural settings, people rely on their own food production and local markets for their food consumption and nutrition. In regions where up to 80 percent of the food consumed comes from smallholder farmers, increasing investments in value chain infrastructure and smallholder resilience of healthy, nutritious foods (including local indigenous crops and animal-sourced foods) is critical – these investments can lead to higher incomes, strengthened local food systems, and improved food access and affordability of healthy diets. Moreover, data shows that increasing on-farm incomes has spillover effects, resulting in enhanced food security and improved levels of education and access to healthcare, particularly for female-headed households. Within this context, we propose the following recommendations:

1. **Providing greater access to safety-net services.** Increasing coverage of social protection programs such as insurance mechanisms, cash transfers, and school feeding programs, especially under shocks, can improve both nutrition security and healthy diets. In addition, promoting food price subsidies towards nutritious foods, especially under shocks, can incentivize healthy diets and encourage smallholder farmers to produce nutritious, diverse, locally adapted indigenous and staple foods. Lastly, health systems are critical in delivering nutrition programming and services, especially for maternal and child health. Primary health systems are the first level of care people go to right after climate change shocks. Sensitizing, enabling, equipping, and enumerating health systems to provide services, especially primary healthcare, under immediate climate events and other shocks will improve nutrition outcomes. The health system should also make climate monitoring services available and utilized.
2. **Improving gender equality in access to finance and hazard insurance.** Women are disproportionately affected by climate change and have differential responses to these events when it comes to their diets and nutrition, and female farmers also have lower access to credit than their male counterparts. Increased access to financing, especially for female farmers, would enable them to invest in their livelihoods, including crops and household purchases that would improve family nutrition.
3. **Investing in large-scale food fortification programs.** Large-scale food fortification can substantially reduce the cost of a healthy diet by 10-22 percent and is a critical approach for targeting vulnerable household members. In some countries, this can raise the total number of population who can afford healthy diets. For example, in Afghanistan, fortified wheat flour increased the proportion of the population who can afford healthy diets by 20 percent (WFP 2023; Bose et al. 2019).
4. **Supporting greater investment in food systems research, development, and human capacity.** NARES and surveillance systems for routine monitoring of diets and nutrition need more support. Human capacity and other enabling factors that foster local leadership are key to the sustainability and effectiveness of the investments.
5. **Strengthening local private- and public-sector value chains and infrastructure.** Many low- and middle-income countries need investments in infrastructure that support food systems, including in improved storage, transportation, inputs, and seed technology. Stronger private-sector value chains and local infrastructure would better connect farmers to markets, improving their incomes and reducing the costs of healthy foods.



Underlying Trend #2:

Food systems are gendered. Women play a central role throughout food systems, yet they experience numerous disadvantages that affect nutrition and mental health outcomes. The food system employs 66 percent of women in Sub-Saharan Africa and 71 percent in Southeast Asia (FAO, 2023a). However, women in agriculture work in disadvantageous conditions, with lower access to land, capital, inputs, extension services, digital technology, and seed varieties compared with their male counterparts, especially for cash crops (FAO, 2023a). These are not just in LMIC settings but also true in the U.S. context, where women are increasingly employed in agricultural systems but have lower access to capital and resources and make less money (Joseph, Roesch-McNally, and Looser 2024). For example, for every dollar a woman-run farm makes in the U.S., male-run farms make $2.50 (Joseph, Roesch-McNally, and Looser 2024).

Due to social roles, women are more likely to participate in the food processing sector, but evidence shows that they are likely to earn less, working in less profitable value chains. As mentioned earlier, the wage gap also affects the affordability of nutritious foods for women (Raghunathan et al., 2021). In addition, gender-based violence also limits women's physical and economic mobility. Globally, one-third of women experience gender-based violence (FAO 2023a). Exploitation and abuse in food systems occur when there are asymmetrical power relations (Forsythe 2023). Interhousehold and intrahousehold gender relations and norms further contribute to higher food and nutrition insecurity among women (FAO, 2023). This raises the question of how institutions and communities can reverse environments (informal and social norms) that put women at a consistent disadvantage, which results in poor nutrition and food security outcomes.

The most recent evidence from gender work-related climate-smart agriculture for nutrition highlights that "gender is often construed as a women's issue," which is often analogous to how "nutrition is construed as a women's domain (especially child nutrition)" (Allotey et al. 2022; Ampaire et al. 2020; Bilal et al. 2016; Bryan, Theis, and Choufani 2017; Rakotomanana et al. 2021). Numerous policy reviews across various contexts identify that gender is poorly understood among policymakers at the national level and only integrated because of international agenda and donor pressure, leading to ineffective implementation over the long run (Beattie and Sallu 2021).

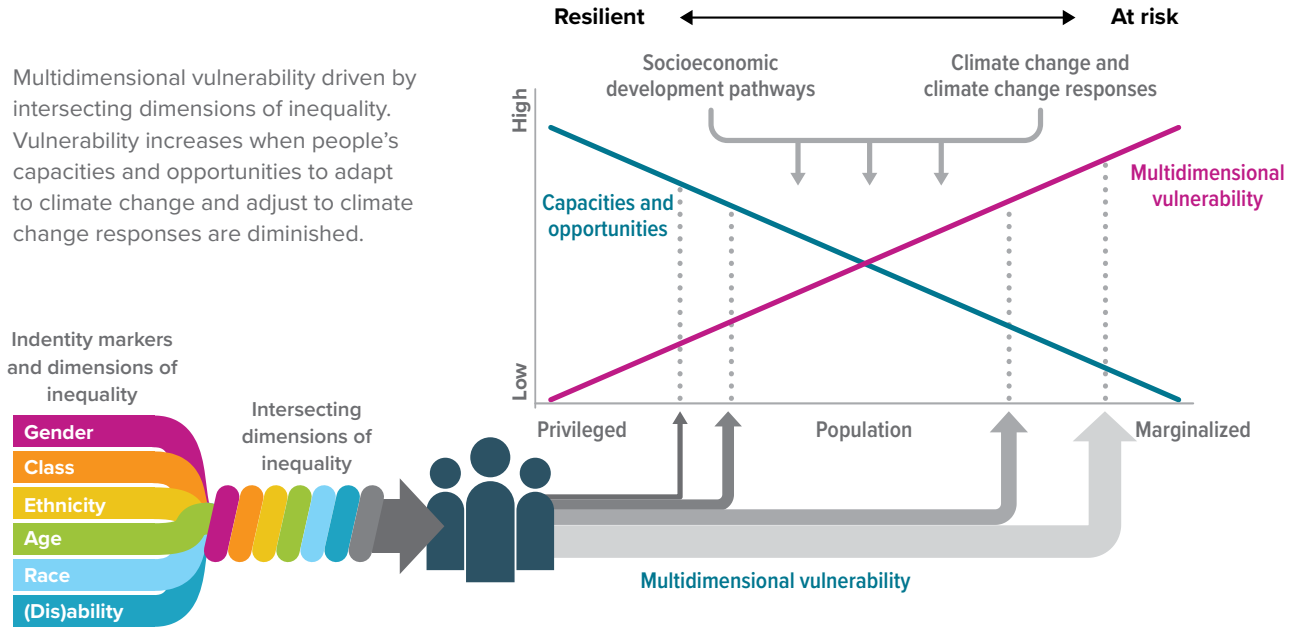
Climate change has a more severe impact on women and the poor, contributing to food insecurity, mental health challenges, and gender-based violence. There is a diversity of contexts that affects food and nutrition security

for women around the world under climate change. This is because the level of decision-making surrounding nutrition within the household for women varies by age, region, and caste/tribal identities, and more importantly, these dynamics also change with men's position, community, and institutional norms. Figure 4 illustrates these intersecting factors affecting vulnerability to climate change (Field and Barros2014). There are four primary dimensions through which climate change contributes to gender-adverse outcomes for women (Bryan et al. 2024). First, there are differences in exposure and sensitivity to shocks that occur at multiple scales and systems (health, education, food, etc.). Second, there are differences in coping capacities; for example, there is considerable nutrition buffering done by women, who tend to reduce their diet quality and quantity to support household needs, thus experiencing greater food insecurity risks under climate change despite exposure to the same external shocks as men. Third, there are gender preferences in responses and practices (e.g. climate-smart agriculture, adaptation practices). Fourth, there is the level of gender integration in implementation of policy, investments, and overall decision-making. A review of the investment portfolio of multilateral agencies shows gender is one of the least invested areas (Porciello et al. 2024).

Extreme weather events affecting food availability place an enormous caregiving burden on women in low-income households because women's primary role is often to procure water and food sources for the family (McKune et al. 2015). Shocks, including extreme weather events, exacerbate gender inequalities by diminishing access to resources, education, and capital, while amplifying labor demand and vulnerability to gender-based violence (Daalen et al. 2022; Forsythe 2023; McKune et al. 2015). Under such shocks, women and girls are the first to give up schooling, food, and other resources for the collective household welfare. These factors substantially affect their own health and economic productivity and have implications for maternal and child nutrition outcomes.

Figure 4: Gender, age, class, ethnicity, race, and other social positions intersect and affect vulnerability

Source: IPCC, Field and Barros et al, 2014.

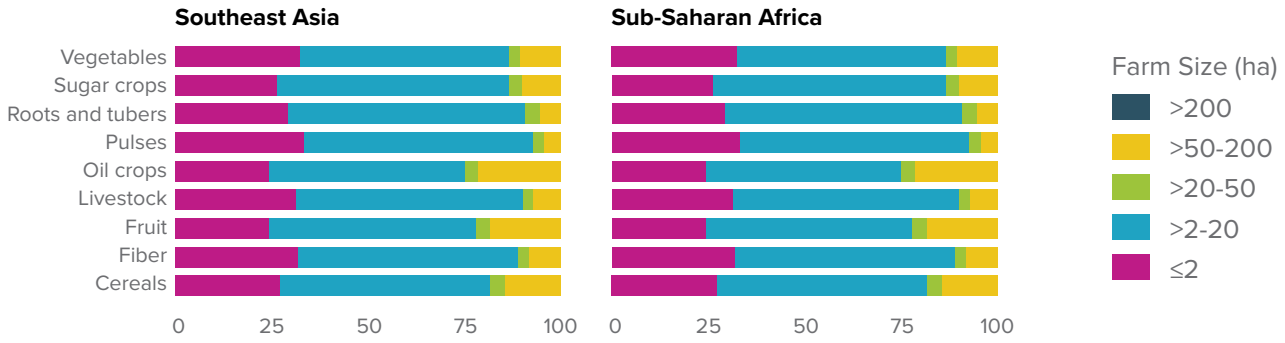


Underlying Trend #2 Recommendations: Family-system and gender-transformative programming is needed across the agricultural value chain, with nutrition policies that address social norms at the institutional level (e.g. financial institutions, markets, agricultural extension services, etc.). Gender-transformative approaches refer to the root causes of differences in relations, resources, and outcomes among gender, i.e., they engage men (even at the policy level), communities, and institutions to change relational norms and discriminatory practices constructively (FAO 2023a; Njuki et al. 2022). Family-system framework refers to interacting individuals who live together (related and non-related) and contribute to the family's economic, social, and nutritional well-being (Aubel, Martin, and Cunningham 2021). Family structures vary across Africa and Asia, and the family system is flexible to include those varying structures that shape diets and nutrition. It is also an important dimension of resilience under climate change. Although women are generally more disempowered than men, there are contexts where both men and women are equally disempowered. Thus, addressing these dynamics where both men and women are engaged is key to improving nutrition security and healthy diets for all (Martin et al. 2021). Within this context, the following recommendations are offered:

1. **Adopting family-systems frameworks and gender-transformative approaches in nutrition programming.** The family-systems approach refers to targeting the entire family's eating behaviors holistically such that these behaviors shape healthy consumption patterns for the future. This approach is inclusive, as it includes improving diets for men, the elderly, and other members of the family who are not typically engaged in nutrition programming. This would have multiple benefits, including increasing healthy diets, improving family nutrition, addressing mental health challenges, and reducing domestic violence, all of which are linked to climate change and poverty (Aubel, Martin, and Cunningham 2021; Casey et al. 2018; Forsythe 2023; Sparling et al. 2022). Gender-transformative approaches engage men and boys to reduce gender-based violence (FAO 2023a).
2. **Investing in value-chain sectors dominated by women and legal policies for personal safety and wage fairness.** In particular, investments in the vegetable and fruit value chain offer employment opportunities for women because these specific commodities have activities, such as cleaning, cutting, washing, and processing, typically ascribed to women. However, employment might still result in wage gaps and precarious employment if investments increase participation in informal sectors. Hence, policies should also ensure safety, protection, and fair wages, especially in sectors that predominantly employ women.
3. **Strengthening the collection of gender-disaggregated data across food systems.** For example, household surveys on agriculture mostly measure men's recall, while nutrition surveys mostly measure women's outcomes. Policymakers must be educated to understand that food systems are gendered and that sustainable and just food systems cannot be achieved without recognizing these varied lived experiences.
4. **Enhancing access to girls' education within the context of climate change.** Multiple shocks, whether climate- or pandemic-related, lead to school dropouts, especially among adolescent girls who get married at younger ages. This negatively impacts later-life economic mobility and maternal and child nutrition outcomes (Kidman et al. 2022; Yukich et al. 2021; Zulaika et al. 2022). Thus, routine monitoring and enhancing access to education under shocks is imperative, particularly for girls.

Figure 5: Production of food groups by farm size in Southeast Asia and Sub-Saharan Africa

Source: Herrero et al. 2019



Underlying Trend #3:

Most food crops, especially local nutritious ones, are produced by small- and medium-scale farmers in low- and middle-income countries; however, they lack incentives to produce nutritious crop varieties that can withstand shocks. Figure 5 shows the breakdown in crop varieties by farm size in Sub-Saharan Africa and Southeast Asia (Khoury et al. 2014). There are an estimated 608 million farms worldwide, of which 12 percent are in Sub-Saharan Africa, where 25-50 percent are under 2 hectares, while most of the remaining are small- to medium-sized farms (2-20 ha) (Lowder, Sánchez, and Bertini 2021; Samberg et al. 2016). Farm size and distribution are key factors, as economies of scale can constrain adopting specific practices or technologies that would otherwise improve productivity. Meanwhile, small farms (less than 2 hectares) are also more vulnerable to climate shocks, relying heavily on rain-fed agriculture, with seasonal patterns for agriculture production (Talukder et al. 2021).

There has been a significant increase in the per-capita availability of foods, calories, protein, and fats for consumption since 1960 globally, but food and nutrition insecurity persists due to historic global food policies and low agricultural research investments for smallholder farmers, particularly for indigenous crops that communities in LMICs depend on for food security, incomes, and nutrition. Staple crop yields have increased substantially worldwide since the 1960s, but these gains are concentrated in rice, maize, and wheat (Ramankutty et al. 2018) where only medium- and large-scale farmers have access to the latest productive and adapted varieties and advanced mechanization. This success was also limited to Asia and Latin America. The most significant increase in production is due to rising yields, and the harvested area comes from oilseed crops, which include palm oil, rapeseed/canola, and soybeans (Ramankutty et al. 2018). Despite increasing global food availability, food and nutrition insecurity remains a significant challenge, particularly in Africa and South Asia (FAO 2023c). Increasingly, the concentration of corporate power in grain, seed, and fertilizer sectors has also led to food insecurity globally (Martin and Clapp 2015). As net buyers, smallholder farmers depend on markets for food security. Thus, a holistic WOSG food system perspective is key to understanding how past dynamics have to led to present conditions.

In 2022, Sub-Saharan Africa exhibited alarmingly high severe/moderate food insecurity prevalence rates of 60.9 percent, while Southern Asia had a rate of 40.3 percent (FAO 2023c). Both non-climate and climate stressors contribute to significant food insecurity in Africa. Historical global food policies (e.g. colonial coercion to produce export crops over food crops, structural adjustment programs) have played a role alongside the shift away from traditional food crops due to monocropping and decreasing labor demands. Inadequate investments in local agricultural institutions supporting research and extension and the lack of policy support for smallholder farms, coupled with debt crises and the impact of climate change, also contribute to persistently low levels of local food production and high levels of food insecurity in Africa (Bezner Kerr et al. 2022; Bjornlund, Bjornlund, and van Rooyen 2022; Haggblade 2013).

There is a misalignment of research investments in sugar and oil crops compared to other nutrient-rich crops and a misalignment of agriculture production compared to food-based dietary guidelines (Alston and Pardey 2008; Astbury et al. 2021; Pingali 2015). The last 50 years saw significant growth in investments in staple crops worldwide compared with other more nutrient-dense crops such as vegetables, fruits, legumes, and nutrient-dense cereals (e.g. millet, sorghum) (Pingali, 2015). While critical for overall

Figure 6: Gaps between fruit and vegetable production, demand, and recommended consumption at global and national levels: an integrated modeling study

Source: Mason-D'Croz et al. (2019).

	Average fruit and vegetable availability (g/person per day)			Ratio of availability to recommended consumption											
				Excluding food waste			Including food waste								
							FAO estimate*			15%			33%		
	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050	2015	2030	2050
East Asia and Pacific	846	958	957	1.49	1.67	1.66	1.38	1.55	1.54	1.27	1.42	1.41	1.00	1.12	1.11
Europe	616	643	666	1.08	1.12	1.16	0.87	0.91	0.94	0.92	0.95	0.99	0.72	0.75	0.78
Former Soviet Union	529	611	656	0.94	1.07	1.15	0.82	0.94	1.01	0.79	0.91	0.97	0.63	0.72	0.77
Latin America and Caribbean	418	462	513	0.75	0.82	0.90	0.68	0.74	0.81	0.64†	0.70	0.77	0.50†	0.55†	0.60†
Middle East and North Africa	744	779	796	1.35	1.39	1.41	1.19	1.23	1.24	1.15	1.18	1.19	0.91	0.93	0.94
North America	659	716	726	1.16	1.26	1.27	0.84	0.91	0.92	0.99	1.07	1.08	0.78	0.85	0.85
South Asia	331†	540	1002	0.60	0.97	1.77	0.56	0.90	1.65	0.51†	0.82	1.51	0.40	0.65	1.19
Sub-Saharan Africa	211†	253†	318†	0.40†	0.47†	0.58†	0.38†	0.45†	0.55†	0.34†	0.40†	0.49†	0.27†	0.32†	0.39†
Developing countries	540	637	772	0.98	1.14	1.37	0.75	0.87	1.04	0.83	0.97	1.16	0.65†	0.76	0.92
Developed countries	621	660	680	1.09	1.16	1.19	0.93	0.98	1.02	0.93	0.98	1.01	0.73	0.77	0.80
Global	552	640	760	0.99	1.14	1.34	0.82	0.95	1.12	0.85	0.97	1.14	0.67	0.76	0.901

Ratio of availability to stringent, age-adjusted recommendation

0 2

food security (calories and source of whole grains), these investments do not fully address nutrition security. There is also a misalignment between many countries' agriculture production and domestic food-based dietary guidelines (Astbury et al., 2021). Figure 6 shows the supply of fruits and vegetables in lower-income countries in 2015 fell below dietary guideline recommendations, even under an unrealistic scenario with no food waste (Mason-D'Croz, Bogard, et al. 2019). This is true even in the high-income countries. The current supply of vegetables only meets half of the population's recommended intake (47 percent in Sub-Saharan Africa). The lack of targeted research and development (R&D) funding for fruits and vegetables has contributed to their lower productivity and resilience to pests and diseases and extreme weather events. Sustained investments in research and development toward a diverse set of nutritious foods and supply chains are required to bridge this gap. However, agricultural R&D spending in Sub-Saharan Africa is less than 1 percent of the region's total agricultural GDP – and is mostly in staples (Nin-Pratt and Stads 2023; Stads et al. 2023). This is despite substantial evidence that agricultural investments have broad economic and nutrition benefits, as child undernutrition reduces with an increase in agricultural R&D (Alene 2010; Alston and Pardey 2008; Mason-D'Croz, Sulser, et al. 2019).

Climate change has several direct effects both on crop production and the nutritional value of crops. Climate change's negative impacts on crop yields, feed yields, aquaculture, and livestock drive food insecurity (Bezner Kerr et al., 2022). Temperature increases impact planting calendars and contribute to greater water stress (Morton, 2007), impacting water availability. Livestock productivity decreases with elevated temperature, stressing the animals and lowering daily weight gain or other productivity measures like milk output and quality (Godde et al. 2021). Seasonal shifts due to rainfall and temperature negatively affect yields in Sub-Saharan Africa and Southeast Asia, where most agriculture is still rainfed (Bezner Kerr et al., 2022). Moreover, drought events are longer in duration and happening more frequently, delaying recovery for smallholder farmers and local food security. Research shows that farmers are already seeing declining crop yields due to climate change – in West Africa, yields have fallen by 5-20 percent for millet and sorghum due to extreme climate hazards (Bezner Kerr et al., 2022). **By 2030, West, East, and North Africa will face the most significant losses in producing cereal, meat, fruits and vegetables, and pulses (Wiebe et al., 2017). Meanwhile, Africa's Central, Western, and Eastern regions will also face the most significant losses in producing roots and tubers like cassava and potatoes, which are staple foods for millions of people** (Bezner Kerr et al., 2022).

Research shows that climate change also impacts the quality of crops. Beyond traditional yield measures, increased carbon in the atmosphere tends to contribute to the reduction of protein and minerals in plants while increasing the production of sugars and starches due to changing balances in nitrogen (key for protein) and phosphorous levels (Beach et al. 2019; Loladze 2014; Myers et al. 2017). For example, elevated levels of CO2 have been shown to decrease protein concentrations of wheat, barley, rice, and

potato crops by 10-15%. This dilution effect has been less observed in nitrogen-fixing crops (e.g., legumes, pulses), which can partly maintain their carbon and nitrogen balances. Between crops that use C3 photosynthesis (most food crops) and C4 photosynthesis (e.g., maize, sugarcane, sorghum), there are differences in carbon fertilization effects that also reduces benefits from elevated C02 (Cao, Li, and Liu 2022; Wang et al. 2021; Zulaika et al. 2022) (Cao et al. 2022, Wang et al. 2012). However, overall changes in vitamins, of which carbon is an essential building block, are more ambiguous, with studies for different crops suggesting that some vitamins could increase in some crops and decrease in others (Beach et al. 2019). The higher concentration of heavy metals or other toxins under climate change by crop also affects the overall food quality. **Increasing temperature can also increase arsenic or toxins in rice, but the mechanisms and impact on different varieties remain unknown** (Ziska 2022).

It is essential to recognize that micronutrient content can vary across different regions (Gashu et al. 2021), due to different agricultural practices (Montgomery and Biklé 2021), and across crop varieties (Marles 2017). In many cases, these differences may be more significant than changes suggested by carbon fertilization studies. This highlights the importance of paying more attention to holistic food system policies, considering whole-of-diet changes, and researching crop genetics that consider outcomes beyond traditional breeding objectives (e.g., higher yields, pest resistance, appearance, local grower (especially women) and consumer preferences, conveniences such as frequency of harvest and labor needs). For example, women farmers prefer traits that enable ease of cooking over yield, and some may prefer ease of harvesting labor over nutrient content (Teeken et al. 2018). It is also important to note traits that promote shelf stability may have a tradeoff with nutrient content. Trait preferences for increased income, i.e., frequent harvest, might not coincide with trait preferences for higher nutrient content. Researchers should consider nutrient traits when improving crop varieties to ensure nutrients are not lost in the process

There is compelling evidence of the risk of "global breadbasket failures" for maize, wheat, and soybeans (for animal feed) – creating significant repercussions for global food and nutrition security (Bezner Kerr et al., 2022). This is due to three key factors. First, current global consumption heavily relies on a limited number of cereal crops. Second, these cereals are primarily produced in a small number of countries, such as the United States, Argentina, European nations, Russia, Ukraine, China, India, Australia, Indonesia, and Brazil. Lastly, climate variables have a spatial connection in these regions, with disruptions of the polar vortex in America linked to other circulation-ocean dynamics (such as El Niño and La Niña or monsoons) in South America, Australia, and the Pacific (Domeisen, Garfinkel, and Butler 2019; Gaupp et al. 2019; Hasegawa, Wakatsuki, and Nelson 2022). Simultaneous crop losses due to climate change in these regions (and other shocks, such as the Russia-Ukraine war) are leading to significant shifts in food insecurity rates globally, as we saw in 2022. In the context of U.S. farmers, sophisticated climate modeling information and forecasting are available in granular and commodity-specific crops that are shared through extension systems. **The availability of these climate information services for U.S. farmers is a public good that benefits food and nutrition security, and can be replicated in other countries for global nutrition security, especially for smallholder farmers. Increasingly, this information also needs to be scaffolded into the health system to mitigate the direct impact of climate change on health.**

Connectivity to global markets has trade-offs during shocks; while connectivity can improve food security due to access to markets, it can also transfer shocks from other regions of the world (whether climate or non-climate) to poor countries. The 2008 food price crisis is an example of a confluence of factors occurring elsewhere that profoundly affected food insecurity through sharp increases in wheat and rice prices. Multiple factors have been attributed to this: use of food for fuel in the U.S., population growth, poor weather conditions, and declining investments in agricultural research and development (Brinkman et al. 2010; Watson 2017; Martin-Prevel et al. 2012). This dramatically increased malnutrition and hunger in poor urban, peri-urban, and rural populations in LMICs and political unrest across the world (Gustafson 2013). And not surprisingly, these had a gendered impact on women's dietary and nutrition outcomes (Kumar and Quisumbing 2013). A critical lesson from this crisis is the need for high-frequency food prices, dietary data, and nutrition surveillance systems for resilient and timely decision-making.

Climate extremes also impact pollination activity, reducing yields, particularly for nutritious fruits and vegetables. Elevated temperatures influence fruit taste, texture, and color quality. Extreme weather events, like flooding and soil erosion, can result in deteriorated soil health, a crucial determinant of yield and resilience against such events. **In general, total factor productivity—measuring agricultural products (crops/livestock) and resources (labor, land, input)—is substantially lower for Africa and Latin America under the context of climate change** (Bezner Kerr et al. 2022).

Underlying Trend #3 Recommendations: Climate change has multiple impacts on nutrition in low- and middle-income countries, affecting crop yields and quality, farming livelihoods, and purchasing power for nutritious foods. The following recommendations include a number of ways to support smallholder livelihoods and nutrition outcomes against the backdrop of climate change:

1. **Increasing research investments for food crops beyond major staple grains and tailoring research for different geographies.** For major cereal crops, research and innovation are primarily focused on crop management practices (e.g. irrigation, inputs, breed varieties), which can have a positive impact on crop productivity; however improvement in these areas may not offset yield losses due to climate change for Sub-Saharan Africa and Southern Asia (Domeisen et al., 2019; Gaupp et al., 2019; Hasegawa et al., 2022). Switching to other staples such as sorghum and millet can be both nutrition-sensitive and drought-sensitive, but trade-offs for labor productivity, available technology, and feasibility, especially for small-scale farms (typical of Sub-Saharan Africa region) need to be considered (Davis et al. 2019), along with demand-side considerations. Investments in plant breeding and modern biotechnology to develop drought-resistant and nutrition-sensitive varieties are critical, as is increased attention to local farmer and consumer preferences to ensure adoption and ensuring that small- and medium-scale producers, particularly women, can access these innovations. Importantly, research should reflect the trains that women farmers need most, such as traits that reduce labor and inputs.
2. **Investing in R&D to improve nutritious food value chains.** Supporting the value chains for livestock, legumes, fruits, and local vegetables can generate increased employment across various sectors that support agriculture, like transportation and processing, and (See Trend #4) across food systems, while increasing dietary diversity, household income, and the supply of nutrients available for consumption in local communities. Scaling the adoption of crops biofortified with iron, zinc, and vitamin A can also help address micronutrient deficiencies in vulnerable populations.
3. **Increasing investments in national diet and nutrition surveillance systems and the associated human capacity in LMICs.** This would enable stakeholders to make timely decisions under shocks.
4. **Increasing focus on "forgotten crops."** One advantage of fruit, vegetable, and legume crops is the abundant variety of cultivars that can be evaluated for various climate-tolerant characteristics, as well as their nutrient content and cooking/taste preferences. Nevertheless, many of these crops remain underutilized and forgotten in the current environment. Recent work from a candidate pool of 138 forgotten African crops showed that 58 crops (9 cereal, 17 fruits, 23 leafy vegetables, 7 pulses) are climate-resilient and nutrient-rich (van Zonneveld et al. 2023). Prioritized investments in researching these forgotten crops and partnerships that explore market, supply chain, and household demand factors can provide additional insights into uptake and consumption. This has the potential for significant positive intended effects on both nutrition and livelihoods in the context of climate change.
5. **Operationalizing national targets for climate adaptation incentivizes governments to invest in research and extension to help smallholders.** Public agricultural research is significantly underfunded, however research to adapt local nutritious crops and improve access to climate-resilient seeds is critical transforming local food systems. Investing in enabling systems and mechanisms that increase seed availability today, as opposed to in the future, would have the maximum impact because it would enable farmers to adapt to climate change that is already occurring. Each 10-year delay in investment in adaptation solutions results in a loss of $300-$600 million USD in benefits for farmers (Cacho et al. 2020). Similarly, providing extension tools as a public good to facilitate the adoption or scaling of conservation agriculture practices could also help reduce risk, manage water, improve soil, and increase productivity and incomes in the face of climate shocks.
6. **Enabling financial mechanisms to incorporate nutrition into national climate pledges.** Highlighting public expenditures towards agriculture and nutrition under countries' climate pledges, adaptation targets, or nationally determined contributions could lead to more robust policy framing towards improving nutrition outcomes. Many regional commitments and policy agendas (e.g., Malabo declarations, African Union Agenda, Comprehensive Africa Agriculture Development Programme) reinforce these policy options, such as increasing agricultural expenditure and improving food and nutrition security indicators under climate change. However, clear global targets for climate adaptation and financing remain a key challenge for these countries in meeting their targets. Accountability mechanisms for all countries, including the U.S., will go a long way in achieving these targets (Covic et al. 2021).

* Nationally determined contributions, or NDCs, refer to "countries' self-defined national climate pledges under the Paris Agreement, detailing what they will do to help meet the global goal to pursue 1.5°C, adapt to climate impacts and ensure sufficient finance to support these efforts." United Nations Framework Convention for Climate Change.

Underlying Trend #4:

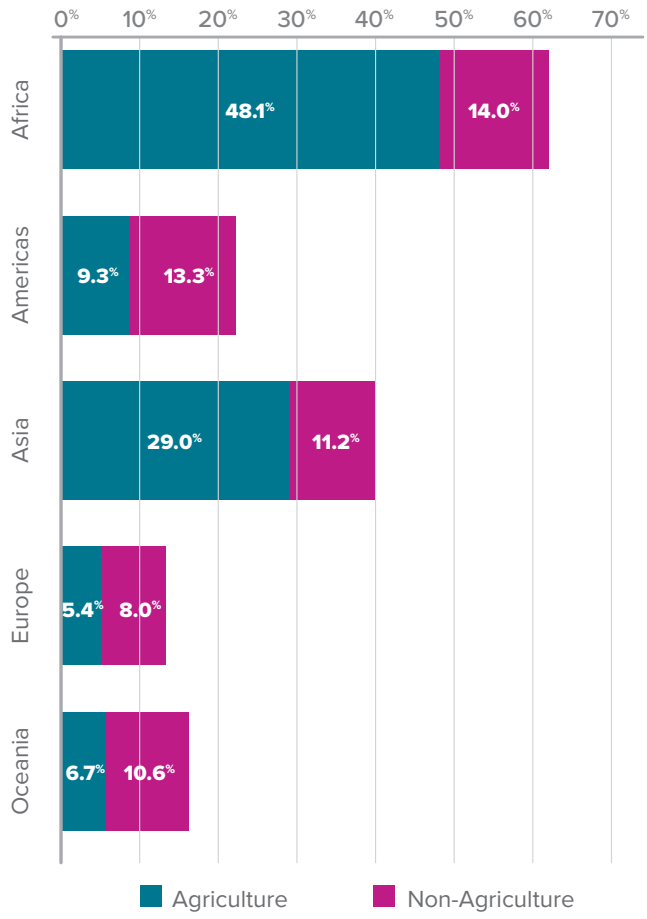
Three demographic factors underpin food system dynamics in Africa: (1) agriculture remains the primary source of employment, (2) there are high levels of employment in the informal sector, particularly among women, and (3) there is a substantial youth population. Globally, 1.23 billion people are employed in the food system, translating to approximately 3.83 billion family members who rely on livelihoods connected to the food system – most of which are in production agriculture. In Africa and Asia, 62.1 percent and 40.2 percent of employment are in the food system (see Figure 7) (Davis et al. 2023).

Most informal livelihoods lack employment-related social protection (e.g. healthcare, paid leave, and insurance). Specifically, 86 percent and 68 percent of employment in Africa and Asia are considered informal, respectively (Bonnet, Vanek, and Chen 2019). The prevalence of informality is generally higher among women in low- and lower-middle-income countries (Bonnet, Vanek, and Chen 2019). However, informality in food systems does have some positive implications regarding climate resilience. Informality plays a significant role in enhancing resilience and mitigating food insecurity during shocks through access to diverse networks of supply chains, partnerships with various agents and middlemen, and self-governance within the food supply chain and food environments. (Battersby 2016; Blekking et al. 2020; Crush and Young 2019; Vorley 2023).

Informal food systems are still the main source of nutritious foods for the majority of people living in LMICs. This is because nutritious foods from informal systems are often more affordable, compared to formal markets, and thus more accessible to low-income consumers, who are generally more nutritionally vulnerable and less resilient to climate shocks. The informal sector often represents the sole livelihood option for many individuals in Sub-Saharan Africa and South Asia. Hence, tailoring nutrition and climate-focused solutions with this in mind is critical. It is also important to note that the median age in Sub-Saharan Africa is 19 years of age (for comparison, the U.S. median age is 38 years), necessitating age-appropriate health services (i.e. reproductive and mental health), a healthy food environment, and an employment sector with living wages that can support buying power for good nutrition (Blum 2007; Filmer and Fox 2014; Neufeld et al. 2022).

Figure 7: Employment in food systems out of total employment by region (2019). Non-agriculture refers to workers in food processing, distribution, retail, and service.

Source: Davis et al, 2023.



Climate change has acute short-term and medium-term impacts on farm and off-farm labor. In contrast, persistent extreme climate events have longer-term impacts on migration, assets, and labor productivity. Households that rely on nature-based livelihoods (e.g. agriculture, livestock, aquaculture, and forestry) are more vulnerable to climate change. Coastal communities are additionally exposed to tropical storms and increased saltwater intrusion from rising sea levels. Saltwater intrusion can affect future soil and water quality, contributing to farms and aquaculture operations going fallow for extended periods (Gopalakrishnan et al., 2019). Climate change also affects labor allocation; for example, seasonal shifts in rainfalls can increase women's time spent securing water for the household. High temperatures and humidity directly affect labor productivity (Bezner Kerr et al., 2022) and increase mortality risks (Newth & Gunasekera, 2018). Migration can be viewed as an adaptive response to climate change. Migration of family members, typically young adult males, often follows exposure to extreme weather events and crop and livestock failure for those relying on agriculture for their livelihoods. Existing evidence indicates that migration patterns tend to respond more to gradual and chronic climate processes (e.g., rising temperatures, extended or repeated droughts) as opposed to rapid and acute events like floods because of limited resources available for making migration decisions in the latter scenarios (Kaczan & Orgill-Meyer, 2020).

Underlying Trend #4 Recommendations: Changing workforce demographics, especially in Africa, need to be taken into account as governments and the international community structure solutions to support nutrition within the context of climate change. A multifaceted approach is needed, with solutions including:

1. **Strengthening agricultural data gathering and climate monitoring systems.** Many countries in Sub-Saharan Africa need improved human capacity for data gathering (e.g. agricultural census) and climate monitoring systems and services that serve small and medium farms (Vermeulen et al., 2012). Climate information services, coupled with local traditional knowledge and extension, can help farmers improve their management practices and make cropping decisions.
2. **Identifying financing mechanisms for governments to increase access to safety net and social protection programs, such as debt relief and other sources of financing.** Increasing coverage of social protection programs such as insurance mechanisms, cash transfers, and school feeding programs, especially under shocks, can improve both food security and healthy diets. In addition, promoting food price subsidies towards nutritious foods, especially under shocks, can incentivize healthy diets and encourage smallholder farmers to produce nutritious, diverse, locally adapted indigenous and staple foods.
3. **Increasing access to capital.** Smallholder farmers, especially women and youth, generally have low access to capital, resources, feed, and seed markets – leaving them vulnerable to climate change. To address this challenge, insurance tools, climate-adaptive extension services, and low-cost, low-technology climate-smart practices and adapted productive inputs (e.g., low-energy bulbs for poultry farmers) should be developed in the context of both women and men farmers. These are policy interventions that can be bundled to respond to contextual climate factors (Liverpool-Tasie, Sanou, and Tambo 2019; Vermeulen et al. 2020).
4. **Increasing investments in social protection programs.** For poor farmers and food system workers in the informal sector, social protection programs and livelihood diversification are critical pathways out of poverty and food insecurity, especially within the context of climate change (Canelas and Nino Zarazua 2022; Costella et al. 2023). Social registries and other digital mechanisms for cash transfers, especially for the informally employed, are critical to effectively target social protection programs under climate change and other economic shocks (Guven, Jain, and Joubert 2021).

Underlying Trend #5:

Agri-food value chains are increasingly important entry points for driving changes in diets, livelihoods, and food waste and loss. In Sub-Saharan Africa, regional food systems (compared to national) are essential units of scale for market demand and food loss reduction. The agri-food value chain has significantly contributed to transforming food systems and shaping diets, primarily through the supermarket revolution, food service revolution, and the recent quiet revolution of growth of small and medium enterprises (Barrett et al., 2022). The supermarket revolution involves the introduction of larger-scale retailers and grocery stores as the primary food source for urban and peri-urban consumers, shifting away from traditional or market retailers, especially for grains and processed products (Barrett et al., 2022). The food service revolution refers to changes in the intermediate sector to meet the demand of food consumed away from home – which is rising for populations in low- and middle-income countries (Barrett et al., 2022; Reardon et al., 2021). Lastly, the quiet revolution refers to the increasing role that micro, small, and medium enterprises play in the logistics of processing and transporting food (Barrett et al., 2022). A substantial focus of the U.S. Agency for International Development's (USAID) Feed the Future initiative is on investing in empowering these food systems agents. Current evidence suggests that these actors play a significant role in shaping diets – both by improving access to diverse foods as well as unhealthy processed foods (Reardon, Liverpool-Tasie, and Minten 2021; Rischke et al. 2015). These transitions are all taking place rapidly across Sub-Saharan Africa (< 10-15 years). **The speed of these transitions presents both policy challenges and opportunities for achieving healthy diets in shorter time frames. The main policy challenge is the availability of high-quality, real-time infrastructure to assess the changes in midstream activities in the food systems.**

Meanwhile, addressing food loss has emerged as a critical target area for improving food security, food safety, and climate change mitigation, and increasing incomes (Cattaneo et al. 2021; Sheahan and Barrett 2017). An estimated third of all food, in terms of quantity, is lost in Sub-Saharan Africa alone (Sheahan & Barrett, 2017). In particular, fruits and vegetables form a substantial and highly variable percentage of this loss because of their perishability. From a food safety standpoint, there is a rising need for standardized regulations, particularly when food quality cannot be easily discerned by visual inspection (such as mold, spoilage, or bruising).

Nutrition buffering as it contributes to in-utero food insecurity additionally has intergenerational implications on birth outcomes and future educational attainment (Fanzo et al., 2018) (Fanzo et al., 2018; Randell & Gray, 2019). Extreme weather events affecting food availability place an enormous caregiving burden on women in low-income households because women's primary role is often to procure water and food sources for the family (McKune et al., 2015). Shocks, including extreme weather events, exacerbate gender inequalities by diminishing access to resources, education, and capital while amplifying labor demand and vulnerability to gender-based violence (Daalen et al., 2022; Forsythe, 2023; McKune et al., 2015). Under such shocks, women and girls are the first to give up on schooling, food, and other resources for the collective household welfare. These factors substantially affect their own health and economic productivity and have implications for maternal and child nutrition outcomes.

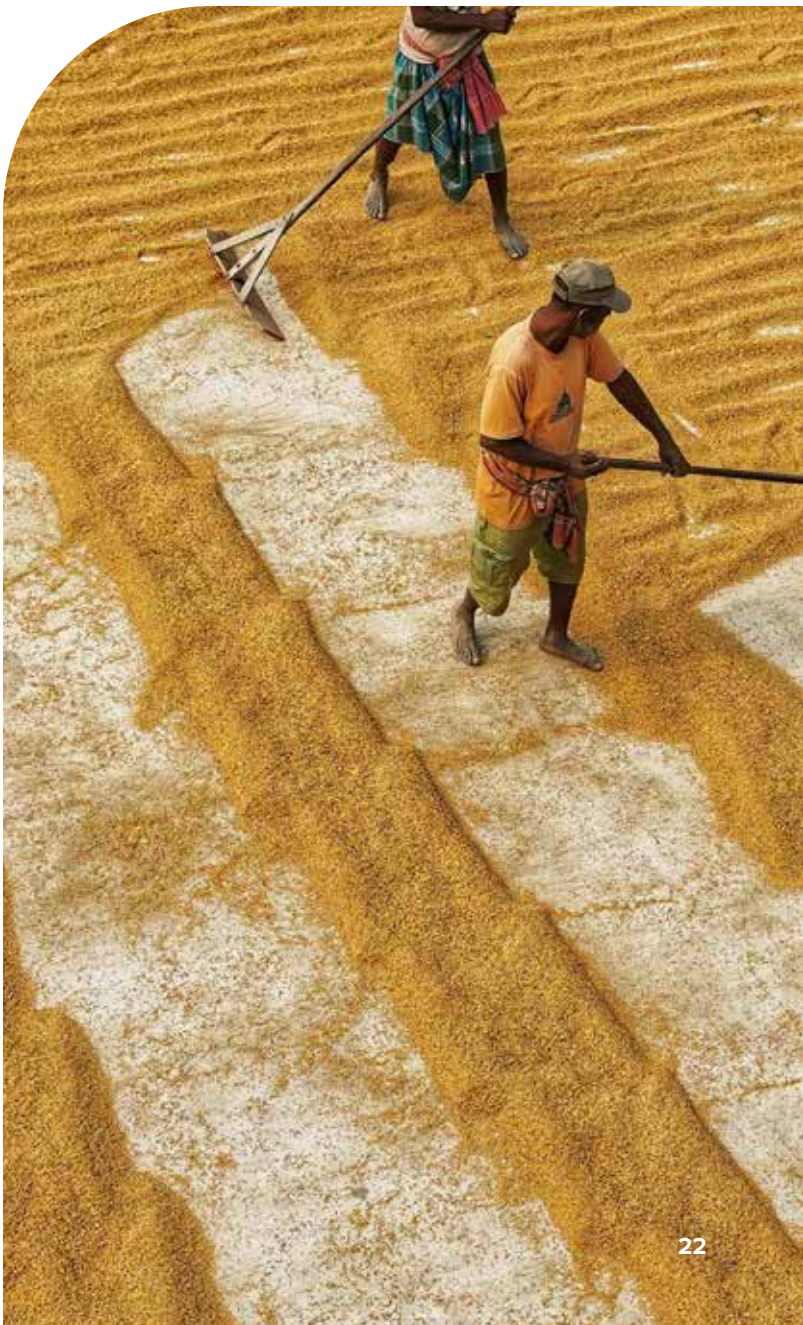
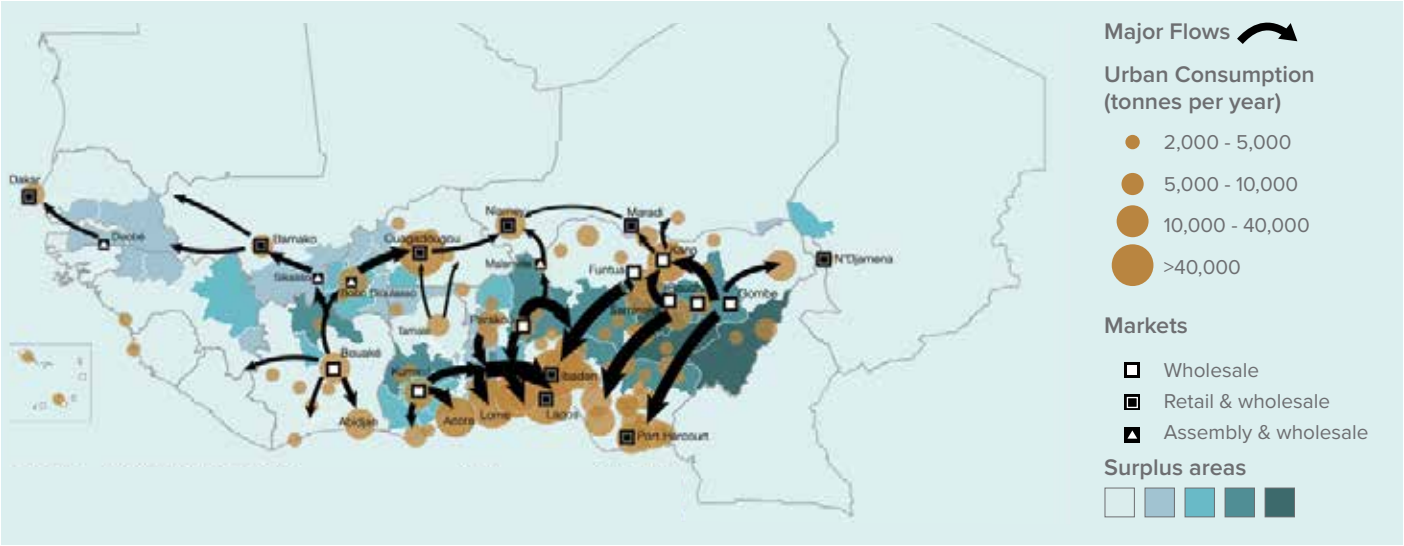


Figure 8: Regional food flows for maize in West Africa

Sources: Vorley et al., OECD (2013)



African food systems have a significant regional element, where flows of food trade, migration, and other elements increase the food system's resilience and affordability of a healthy diet (Allen and Heinrigs 2016; Egbendewe et al. 2017; Haggblade 2013; Sokourenko et al. 2022; Vorley 2023). Figure 8 shows how maize flows between countries in West Africa to meet food demand – the vast majority of these trades are informal, providing a critical node connecting smallholder farmers to markets (Vorley, 2023). Food systems and outcomes vary regionally. For example, the North African region is relatively food secure, with affordable fruits and vegetables, while the biggest nutrition challenges are anemia and diet-related non-communicable diseases such as diabetes (Sokourenko et al., 2022). In West Africa, a region known for its rich crop diversity and diverse food supply chains, the issue of post-harvest loss continues to pose a significant challenge due to the lack of strong infrastructure (e.g., roads, ports, energy) leading to high transport and other costs. The region also suffers from a complex array of different types of malnutrition, presenting a formidable hurdle. This includes concurrent challenges such as food insecurity, hunger, the elevated expense of a nutritious diet, a high prevalence of child stunting, and diabetes. Among the primary environmental concerns are soil quality and opening up new land for cultivation, which carries a substantial environmental footprint (Sokourenko et al. 2022).

In East Africa, there is an inadequate supply of fruits, vegetables, and pulses and a high degree of unaffordability when it comes to healthy diets, largely due to lower incomes. Here, food insecurity, hunger, child undernutrition, anemia, and adult hypertension remain critical challenges. These are largely because of a lack of infrastructure to reduce perishability, i.e., markets for nutritious foods tend to be local. Thus, a balance of local market connectivity to larger markets is key to smoothing inadequate availability and access to nutritious foods. In areas with high undernutrition rates, identifying small processing sectors for nutritious foods can also help with seasonal smoothing. From an environmental perspective, soil quality deterioration and biodiversity loss pose significant challenges (Sokourenko et al. 2022). In Central African countries, the supply of pulses and vegetables remains low, contributing to the high unaffordability of healthy diets (Sokourenko et al. 2022). At the same time, multiple forms of malnutrition, especially hunger, non-diverse diets, women and child undernutrition, women's anemia, and diabetes remain key challenges. Meanwhile, land use change for agriculture, subsequent loss of biodiversity, and high emissions from land use change further contribute to climate change (Sokourenko et al. 2022).

Climate change has a short- to medium-term impact on the food supply chain sector and a long-term impact on roads and infrastructure. Elevated temperature and humidity increase food-borne pathogens and mycotoxins and reduce the nutritional quality of foods. Inadequate cold chain infrastructure contributes to widespread food waste and loss and increases the risk of food-based pathogens, which are expected to become a bigger problem with rising temperatures (Bezner Kerr et al., 2022)**. In addition, more intense and frequent extreme weather events can affect transportation infrastructure in the longer term.**

Underlying Trend #5 Recommendations: Climate change creates challenges for food supply chains, particularly in Sub-Saharan Africa, where food systems vary significantly by region. Addressing these issues, supporting nutrition outcomes, and reducing food waste and loss will require solutions, including:

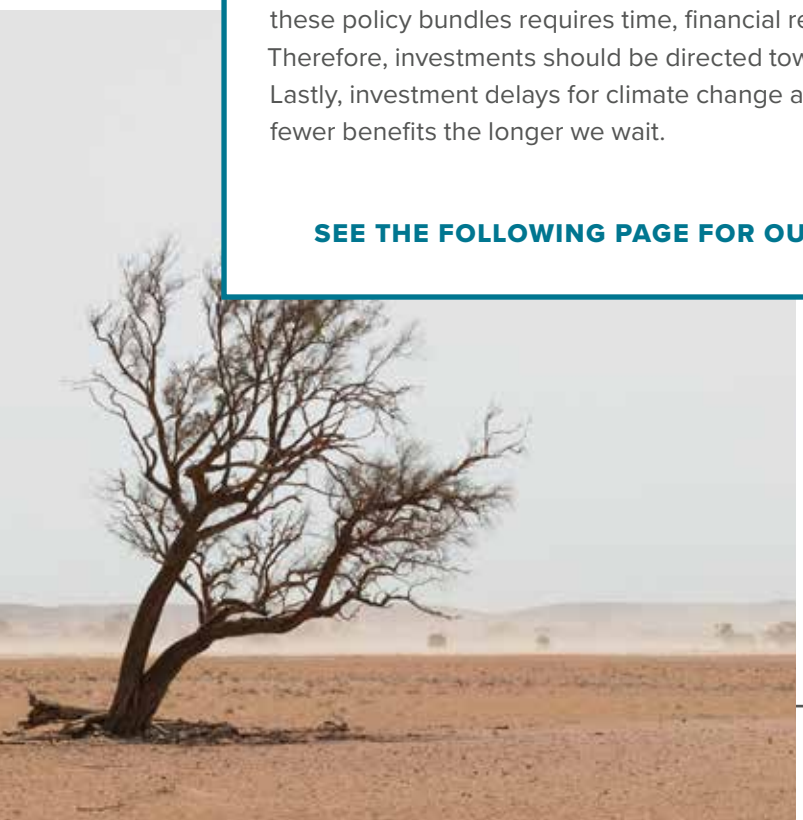
1. **Investing in local capacity and infrastructure.** Investments in infrastructure for storage and distribution, enabling regional trade, processing sector and increasing scientific capacity are all key to addressing climate change challenges for the intermediate sector. Specifically, improving access to electricity and cold storage capacity could increase market functionality and connectivity and improve resilience.
2. **Prioritizing the reduction of food waste and loss.** Food losses are directly linked to farmer and business profitability. Two primary policy avenues to address challenges related to food loss stand out. First, stakeholders across the supply chain need access to improved technologies, such as innovations that extend food shelf life, enhance stability, and effectively decrease or delay losses (e.g. canning, drying, and processed foods), as well as innovations that lower harvesting costs and help reduce post-harvest losses. Even basic local food processing can lead to numerous benefits, including creating jobs and reducing cooking times and fuel consumption for staples. This modest step would be important for women and families who do not have reliable access to electricity.
3. **Enabling regional food trade (i.e., trade with nearby nations) can improve market demand, profits for the intermediate sector, and access to healthy diets while potentially reducing food loss** (Allen & Heinrigs, 2016; Egbendewe et al., 2017; Haggblade, 2013; Sokourenko et al., 2022; Vorley, 2023). Regional food trade can be strengthened through regional scientific and infrastructure (e.g. roads, ports) capacity, regional trade agreements, and harmonized regulations (Allen & Heinrigs, 2016; Haggblade, 2013; Sokourenko et al., 2022). The U.S., for example, was a supporter of the African Continental Free Trade Agreement that aims to improve connectivity and trade flows within African countries. Also, supporting and strengthening institutions and initiatives like the Economic Community of West African States (ECOWAS) and Common Market for Eastern and Southern Africa (COMESA) can improve capacity. The U.S. Feed the Future initiative, currently focused in 20 countries on value-chain development, could be expanded to promote more regional flows, infrastructure, and markets.

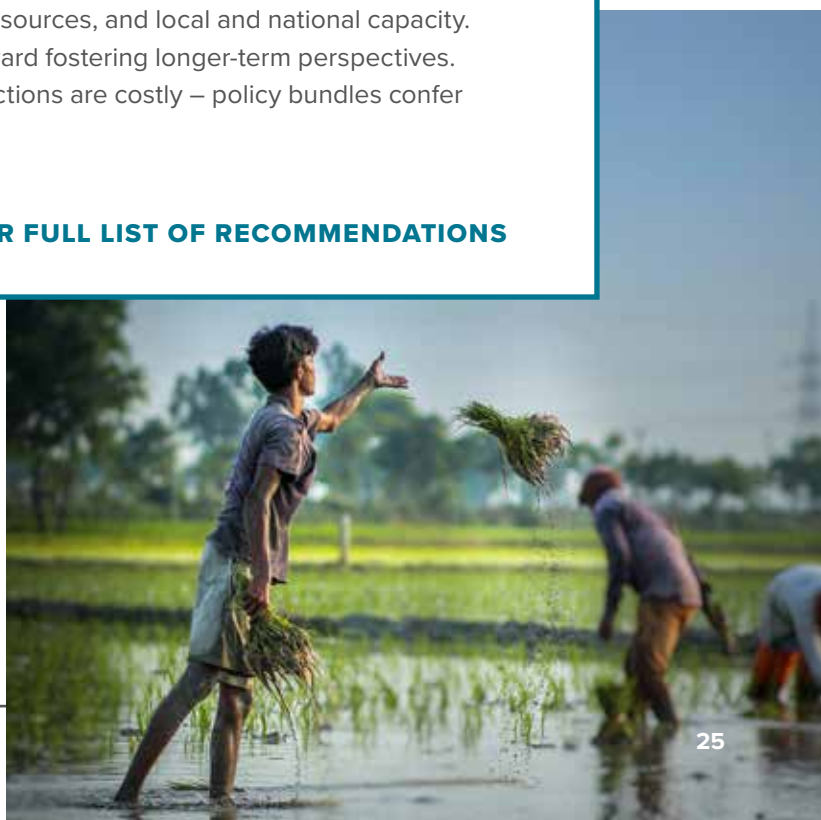
V. KEY RECOMMENDATIONS

Low and middle-income countries have less adaptive capacity and are more vulnerable to climate change. In Sub-Saharan Africa, micro-scale farms of less than 2 hectares provide 30 percent of the food, while small- to medium-sized farms (2 to 20 hectares) contribute another 50 percent of the food crops. (Herrero et al., 2017). Climate change impacts smallholder farms by reducing household-level food and livestock production and incomes, decreasing purchasing power to buy nutritious foods (Fanzo et al., 2018; Myers et al., 2017). This problem worsens when community and market-level shocks also arise from the same climate change hazards, such as food price hikes, which further threaten access to quantity and quality of food due to reduced income and increased household needs (Brinkman et al., 2010; Brown, 2014; Headey & Martin, 2016; Tirado et al., 2013).

There are three key takeaways from this policy report. First, there are climate and non-climate-related impacts on food systems. The global food systems trends that enable sub-optimal nutrition outcomes with negative environmental externalities highlight the need for policy bundles that improve access to healthy diets, which requires a food systems approach (from agriculture, innovation for adaptation, processing/distribution, food consumption) and a whole of society and government approach. Secondly, cross-sectoral collaboration through these policy bundles requires time, financial resources, and local and national capacity. Therefore, investments should be directed toward fostering longer-term perspectives. Lastly, investment delays for climate change actions are costly – policy bundles confer fewer benefits the longer we wait.

SEE THE FOLLOWING PAGE FOR OUR FULL LIST OF RECOMMENDATIONS





Key Recommendations:

Given this context, the U.S. government should consider the following policy recommendations to support global nutrition security:

- **Support greater investments in agricultural research and development.** This includes R&D at NARES. To address challenges from both malnutrition and climate change, research funding should be focused on the following: solutions for retaining or enhancing nutrient content where possible, food crops beyond major staple grains, tailored research to support smallholders in different geographies, solutions to improve value chains for nutritious foods (e.g. animal-sourced foods, legumes, fruits, and local vegetables) and reduce food loss and waste, and forgotten crops that may have nutrition and climate benefits.
- **Invest in programs that benefit women's nutrition and women working in agriculture and food systems.** As discussed, women's nutrition and buying power are disproportionately affected by climate shocks. To address this issue, family-system and gender-transformative programming is needed across the agricultural value chain, with nutrition policies that address social norms at the institutional level (e.g. financial institutions, markets, agricultural extension services, etc.). There are multiple ways to support women in the agri-food value chain, including by investing in value-chain sectors (e.g. fruit and vegetables) that are dominated by women, strengthening the collection of gender-disaggregated data in the agri-food sector, and enhancing access to girls' education within the context of climate change, which can have an enormous impact on later-life economic mobility and on women and child nutrition outcomes.
- **Incentivize governments to expand access to technical assistance and extension services to enable farmers to adopt climate-smart practices.** In particular, gender-responsive extension and technical assistance can facilitate the adoption or scaling of conservation agriculture practices, which can help reduce risks, manage water, improve soil, and increase productivity and incomes in the face of climate shocks.
- **Provide adequate financing for agricultural development programs, especially those that take a whole-of-society-and-government approach.** Programs such as the U.S. Feed the Future initiative support agricultural-led growth and increased incomes by helping to build more resilient food systems. Feed the Future and similar programs aimed at addressing the root causes of hunger and malnutrition within the context of climate change deserve more support.
- **Identify financing mechanisms for governments to increase access to safety net and social protection programs.** Increasing coverage of both climate-sensitive and nutrition-sensitive social protection programs such as insurance mechanisms, cash transfers, and school feeding programs, especially under shocks, can improve both food security and healthy diets. In addition, promoting food price subsidies towards nutritious foods, especially under shocks, can incentivize healthy diets and encourage smallholder farmers to produce nutritious, diverse, locally adapted indigenous and staple foods.
- **Invest in programs that help strengthen private- and public-sector value chains and infrastructure.** Investments in infrastructure that support agriculture, including in improved storage, transportation, inputs, and seed technology, can better connect farmers to markets, improving their incomes and reducing the costs of healthy foods. Investments in infrastructure can also help reduce food loss and waste.
- **Increase support for programs that improve farmers' access to finance.** Smallholder farmers, especially women, generally have lower access to capital, resources, feed, and seed markets – leaving them vulnerable to climate change. Increased access to financing would enable them to invest in their livelihoods, including crops and household purchases that would improve household nutrition. These programs also need to embed gender-transformative approaches, i.e. changing destructive social and informal norms that hinder women's access, especially young women.
- **Support initiatives that strengthen agricultural data gathering, climate monitoring systems, and related investments in human resources.** Climate information services and local traditional knowledge can help farmers improve their farm management practices and make cropping decisions. These services should be available to health and other systems for disaster preparation and planning activities.
- **Invest more in solutions that enable regional food trade.** Enabling regional food trade can improve market demand, profits for the intermediate sector, and access to healthy diets while potentially reducing food loss. Regional food trade can be strengthened through infrastructure investments, regional trade agreements, and harmonized regulations. One solution may be expanding the U.S. Feed the Future initiative to promote more regional trade, infrastructure, and markets.

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