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Climate Change, Food Systems, and Nutrition:

Challenges and Opportunities for Children's Health in Sub-Saharan Africa

CAMBER COLLECTIVE

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Executive Summary

Through qualitative research, we identify three primary challenges impacting agricultural food systems and nutrition in Sub-Saharan Africa, all of which are further exacerbated by climate change:

Population and urban growth: By 2030, Africa's population is expected to increase by 42% over its 2015 population (1) and the population in Sub-Saharan Africa will have doubled by 2050.

Strained food systems: Sub-Saharan Africa's continued malnutrition challenge is driven in part by food systems which cannot meet the needs of its populations.

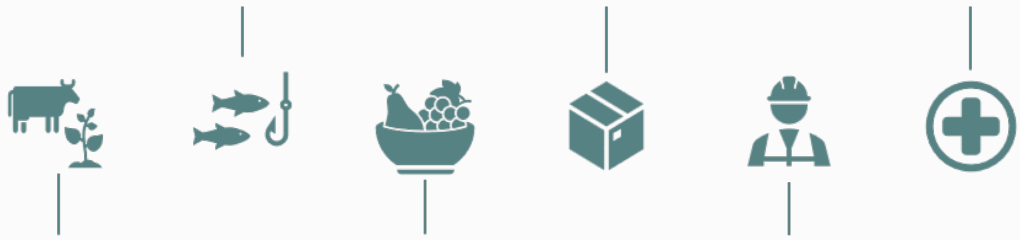
Income inequality: Some of the highest GDP countries in Sub-Saharan Africa, also have the highest prevalence of income inequality.

Climate change, through conditions of acute weather events and slow-onset effects, produces the following direct effects:

Reduced biodiversity – marine and terrestrial ecosystems are affected

Inefficient food storage – changing seasonality of crops exacerbates the challenge

Increased disease and food safety challenges – risk of pathogen exposure grows



Crop & livestock failures – both abiotic and biotic effects impact yields

Reduced nutrient bioavailability – atmospheric CO_2 leads to less nutritious staple crops

Disruption of infrastructure and labor – harms food supply chains and production

Societal implications follow from the direct effects of climate change conditions:

Strife, destabilization, and migration

Disruption of global markets and supply chains

Governance limitations and systemic inequities

Increased strain on women and caregivers

The coalescence of societal implications, direct effects, and climate change conditions—exacerbated by food systems—impacts nutrition:

Access to nutritious food: By 2050, climate change will result in additional price increases of 5-25% for the most important agricultural crops (62)

Utilization of nutritious food: More prevalent infectious diseases and worse water quality reduces the capacity to utilize nutritious food

Availability of nutritious food: Reduction in food system productivity due to climate change limits the availability of nutritious food

Food systems-related drivers of climate change include the following reciprocal impacts:

We identify key insights about the challenges posed by climate change and food systems in Sub-Saharan Africa:

The nexus between climate change, food systems, and nutrition is *not adequately recognized* and resourced

Impactful action requires extensive, *catalytic collaboration and commitment* by a vast collection of sectors and stakeholders

Effective interventions will require *forward-thinking policies* and supportive government structures

Food system solutions require *innovative technologies and abundant capital investments* which are tailored to the African context

Synthesizing the challenges surfaced in the report, we identify seven opportunities for impact:

1. Coalition Building: International Climate, Food Systems, Nutrition Collaboration and Advocacy
2. Impact Investment: Convergence of Climate, Food Systems & Nutrition
3. National Food Systems Support: Efficiency and Resilience
4. Decreasing Impact of Reduced Nutrient Bioavailability
5. Incentivizing Low Footprint, Resilient and Adaptive Agro-Practices for Smallholder Farmers
6. Urban-Focused Behavior Change: Sustainable Consumption Patterns
7. Innovation: Sustainable, Scalable Storage and Transport Solutions

Introduction

Climate change and food systems are inextricably linked. In fact, a study on the effects of climate change (2) found that a 1 °C increase in temperature in developing countries lowers agricultural output growth by 2.7%, leading to estimates of economic growth reductions by an average of 1.3 percentage points for each degree of warming. **Sub-Saharan Africa is the most vulnerable region to climate change**, due to precipitation and temperature variability and patterns, as well as food and water insecurity (3). The socio-demographic and economic tendencies in Sub-Saharan Africa (SSA) further intensify the impacts of climate change. The extreme growth in population and demand for water and food will also escalate in tandem. Further, prolonged extreme events like droughts are expected to exert additional pressure on already scarce water resources and reduce crop yields (4). These insecurities will eventually affect all aspects of food production systems and sustainability, and hence increase the risk of malnutrition in the region.

The farming and agro-sector, particularly in the SSA region, is at the forefront of ensuring food security and providing sustainable jobs. The sector also employs around two-thirds of the region's labor force. However, **the yield potential of many African crops is not fully realized, with inadequate water and nutrients limiting crop production**. Lack of rainfall in many areas has dramatically reduced crop yields, particularly for rainfed agriculture, which makes up the majority of total agricultural production. In addition, food systems impact the environment and contribute to climate change. Approximately 24% of total greenhouse gas emissions (GHG) are attributable to the food system, driven primarily by land use, on-farm fertilization and energy use, waste, and consumption patterns. Increases in population and rising rates of animal-source protein are expected to increase this impact (5). High levels of uncertainties surrounding climate change and agricultural food systems further exacerbates the negative impact on crop production in Africa, where many regions are already vulnerable to climactic variability. As climate change intensifies, crop production in such regions is likely to become threatened further (6).

African agriculture's ability to adapt to climate change is challenged by the prevalence of small-scale farmers, who have few financial resources, limited access to infrastructure, and, often, a lack of access to information about climate change. **Sub-Saharan Africa is already vulnerable to the developing risk of sustainable food production, and without the right solutions and approach, these threats are expected to intensify**. As temperatures increase, the risk to food security in the region will become dangerously severe, with limited hope for risk reduction (7). The culmination of these factors results in losses of potential income for farmers and debilitates any investment opportunities and growth potential. The continent is currently adapting to climate change, but the long-term effects of adaptations may not be enough to offset longer-term climate change. Farmers in Africa have adopted advances in conservation and agro-ecological practices, such as agricultural forestry and contouring. These practices have two benefits: they lower carbon emissions while adapting to climate change, and they offer more economic opportunities for poor farmers. However, there are challenges associated with their widespread adoption. Insecurity of land tenure, difficulties in knowledge-sharing, and limited financial resources are among the factors that make agriculture in sub-Saharan Africa more challenging (8).

According to the Intergovernmental Panel on Climate Change (IPCC), temperature rising is not only unambiguous, but is proven to be largely caused by human activity over the past five decades (9). These findings clearly show the increasing impacts of anthropogenic climate change on malnutrition. Findings by the World Health Organization (WHO) estimate that the number of people to be affected by hunger will surpass 840 million by 2030, while 135 million already suffer from acute hunger and 250 million are on the brink of starvation (10). The IPCC's projections identify that approximately 183 million additional people will be at risk of hunger by 2050, compared to a world with no further climate change expected, and that pastoral systems and low-income consumers are most at risk (9).

African women are considered the nurturers and caregivers in most families across the region. As such, women are even more vulnerable to the ramifications of climate change because they bear an immeasurable burden of responsibility for not just livelihood agriculture, but also nutritional capacity. Nutritional efficiency is adversely correlated to both the overutilization of soil and the impact caused by changes in the climate (11).

Improving the socio-economic capabilities of the agro-sector is crucial to achieve agro-food security, fulfill corresponding nutritional requirements for the fast-growing population of the region, and meet targets of climate related goals. Failure to do so will only exacerbate the problem further through undernutrition, urban migration, health-related sicknesses, and more.

Challenges and Impact on Food Systems & Nutrition

This section presents selected challenges and the corresponding impact on food systems and nutrition. According to the Food and Agriculture Organization (FAO) of the United Nations (12), agro-food security and nutritional security are a subcategory of livelihood, which encompasses a range of basic needs and aspects of subsistence and survival. While some food-insecure farmers may still be able to provide for their basic health needs, current climate change projections jeopardize potential for future production and thus the possibility of a sustainable livelihood.

The rate of economic development in Sub-Saharan Africa is outpacing the region's ability to feed itself and address malnutrition. Malnutrition has always been a pervasive challenge for the region. Despite several advancements and efforts, many Africans still struggle to meet their nutritional needs and SSA is one of only two regions in which the number of undernourished individuals has increased since the early 1990s. In 2019, an estimated 21% of children worldwide under five years old—around 144 million—were developmentally stunted. Of this number, 36% of them live in Sub-Saharan Africa (13). Furthermore, according to the United Nations, 38 million people in Nigeria, Somalia, South Sudan, and Yemen are facing severe food insecurity, while Ethiopia and Kenya have experienced significant droughts (14). **The interconnected challenges posed by food systems, malnutrition, and poverty are devastating the region of the Sub-Sahara**. These are the result of corruption, underdevelopment, weak economic institutions, poor oversight, and the governance of leaders within the region.

Despite the abundant wealth of natural resources, many countries within the region remain very poor, with per capita incomes among the lowest in the world (15). In 2021, the United Nations reported that 490 million people live under the poverty line, 478 million of whom live in extreme poverty (16). **Poverty is the principal cause of malnutrition in Africa** and is predominantly caused by harmful economic systems, population growth, and environmental factors (15), all of which directly and indirectly contribute to the failures brought about by climate change and its impacts on agricultural food systems and nutrition. Based on informal interviews and discussions with farmers, subject matter experts, and foundation representatives across the region, we identified three predominant challenges: population and urban growth, an extremely strained food system, and income inequality.

POPULATION AND URBAN GROWTH

More than half of the world's global population growth by 2050 is expected to occur in Africa, with the highest growth driven by the poorest countries (e.g., Niger). By 2030, Africa's population is expected to reach 1.68 billion people – an increase of 42% over its 2015 population of 1.19 billion (1) – and **the population in Sub-Saharan Africa will have doubled by 2050**. Additionally, urban areas currently contain about 472 million people – a figure projected to double over the next 25 years (17). These increasing trends in population

Figure 1: Countries with the highest burden of malnutrition (Accounts for 90% of global burden) (90)

and urbanization will necessitate transformative changes to already strained food systems, especially in countries where food insecurity is already high.

STRAINED FOOD SYSTEMS

Sub-Saharan Africa's continued malnutrition challenge is driven in part by **food systems that cannot meet the population's needs**. Deficiencies and inefficiencies in the supply chain (e.g., lack of capital, infrastructure, and food loss) prevent sufficient food systems. Additionally, many rural populations are vulnerable to yield variability as they depend on their own agricultural output for food. Population increases will drive total need for nutritious food, while rapid urbanization will strain supply chains and increase demand for processed, out-of-season, and high-value foods like meat and dairy (18).

INCOME INEQUALITY

Existing challenges in income inequality facing the African continent may be exacerbated by development. Some of the highest GDP countries in Sub-Saharan Africa have the highest income inequality. Furthermore, the poverty-reducing power of growth is lower in Sub-Saharan Africa relative to other developing countries. **Income inequalities have a direct downstream impact on malnutrition** (*See Figure 1*) and exacerbate efforts to reduce poverty. The most vulnerable to rising malnutrition from growing inequality in East and West Africa are likely to be poor urban dwellers (19).

Climate Changes Worsens Existing Challenges to Food Systems and Nutrition

Climate change has been proven to exacerbate malnutrition in Africa, and the **impact of this will be disproportionately felt by vulnerable populations**. It is also a risk multiplier to development challenges, such as population growth and urbanization, strained food systems, and economic inequality, and aggravates the preexisting undernutrition problem already facing the region. Climate change continually decreases the availability, access, and utilization of nutritious food through decreased crop productivity, strained infrastructure, and food storage, and increases disease (*See Figure 2*). The outcome is a more expensive diet, composed of a less diverse range of food sources of increasingly lower nutritional value and absorption capacity.

In two districts of Ethiopia, climate change is projected to negatively affect between 51% and 78% of smallholder farms in warm regions and between 10% and 22% of smallholder farms in cool regions by 2030 (20). Furthermore, it is currently exposing communal farmers in Zimbabwe to unfamiliar harsh conditions that, exacerbated by their limited adaptive capacity, increase their vulnerability to food insecurity and poverty (21). Africa's development underscores the **need for food systems that can support the health of a population with a high prevalence of malnutrition, while also reducing the climate burden.**

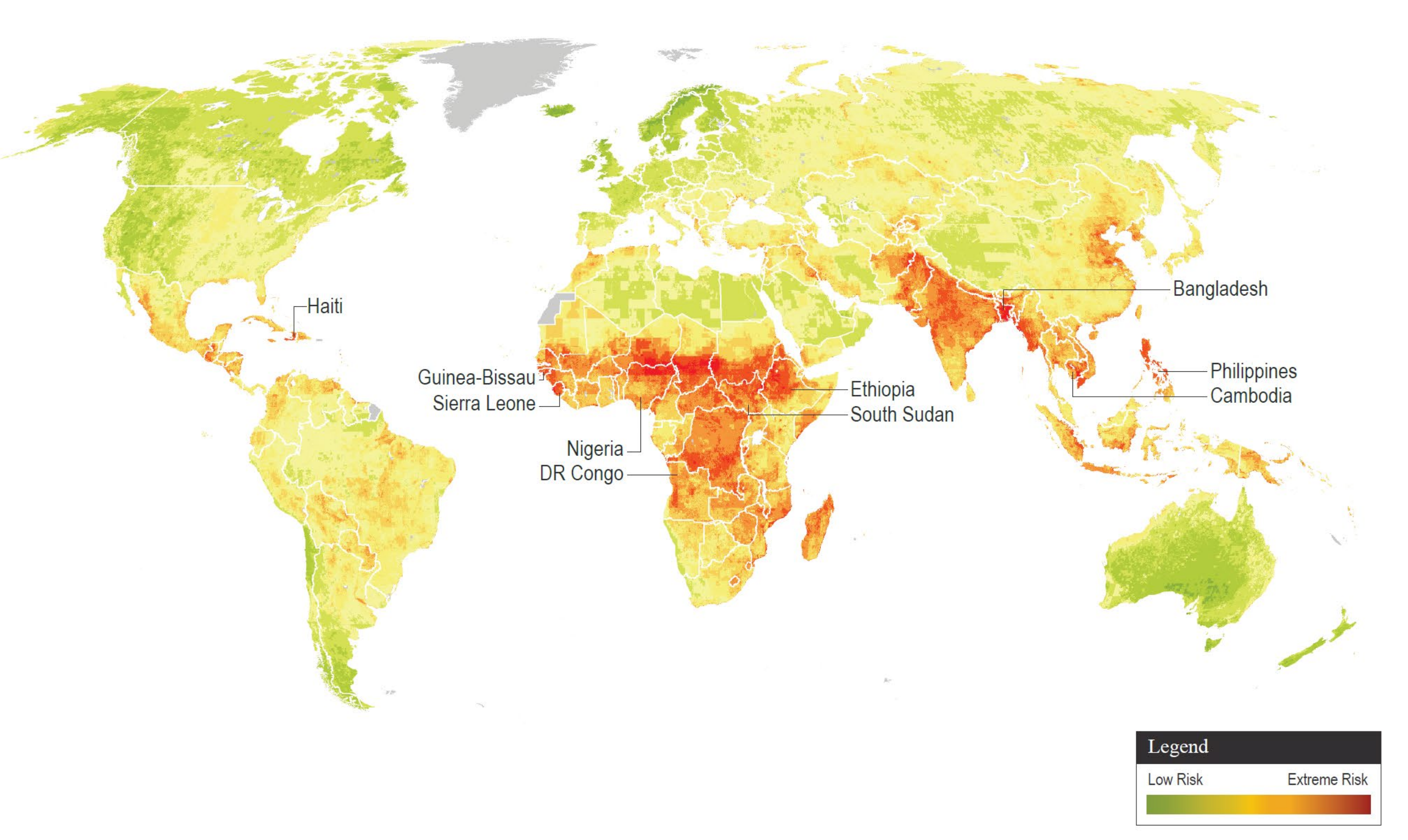


Figure 2: Global Impact of Climate Change (89)

Climate Change and the Correlating Impact on Agro-Livelihood

In this section, we present the main conditions brought on by climate change: acute weather events and slow-onset effects (see Conditions). Next, we detail the resulting direct effects of crop and livestock failure, reduced biodiversity, reduced nutrient bioavailability, inefficient food storage, disruption of infrastructure and labor, and increased disease and food safety challenges (see Direct Effects).

CONDITIONS

We begin this section by analyzing the main conditions (acute weather events and slow-onset effects) precipitated by climate change and exacerbated by food systems.

Acute Weather Events

Acute weather events are extreme weather and climate events triggered by global warming. Such events include heatwaves, heavy rainfall, droughts, and floods that occur with increased frequency and intensity due to higher-than-normal temperatures. According to the United Nations Office for Disaster Risk Reduction, **the global frequency of weather-related disasters has increased by 46% since 2000**. It is estimated that between 1 to 4 billion drought exposure events and 2.3 billion flood exposure events will occur by the end of the century. From 2000 to 2016, the number of people exposed to heatwave events increased by approximately 125 million (22). Flooding impacts food production by oversaturating and destroying crops, decreasing labor availability and productivity, increasing exposure to food-borne and vector-borne illnesses, and damaging food system infrastructure (washouts and food storage). Extreme flooding can raise rice prices, leading to significant increases in underweight children under age 5 (23). Africa faces the highest risk of more severe and protracted droughts and periods of extremely low and extremely high rainfall (24).

Example: Children Born in Droughts in Ethiopia and Kenya

Drought disasters in Ethiopia affect children acutely. In Ethiopia, children born during a drought are 36% more likely to be malnourished and 41% more likely to be stunted than their counterparts not born during a drought. In Kenya, children born in drought-prone areas are 50% more likely to be stunted and 71% more likely to be severely stunted (25).

Slow-Onset Effects

Slow-onset effects describe longer-term changes in the climate, including sea level rise, increasing ambient temperatures, ocean acidification, and desertification. The planet's average surface temperature has risen by around 1°C in the last two centuries driven largely by increased atmospheric CO_2, while its over land temperature has increased further. Most warming has occurred in the last 35 years with the top 5 hottest years occurring since 2010 (26).

Increased temperatures affect a variety of factors throughout the environment. These include crop failure, insects, and microorganisms that both hinder and facilitate crop growth (e.g., bees and fungus); dehydration of the land making it less arable; increased water conduciveness due to higher water temperatures; increased vector-borne disease prevalence due to increased temperatures; and decreased labor force productivity. According to the IPCC, an increase of 2°C ambient temperature without adaptation will depress production of wheat, rice, and maize (with high confidence). **Global warming, without adaptation, of 2˚C would put over 50% of Africa's population at risk of undernourishment** (27).

Increases in ambient temperature and drought have seen two of the most significant water sources in Africa drastically affected: Lake Chad receded from 25,000km² in the 1960s to 1,350km² in 2005, while Lake Victoria lost 90% of its water by evaporation over the same period (28).

DIRECT EFFECTS

Synthesizing research from the previous section and analysis of the conditions above, we present the direct effects (crop & livestock failures, reduced biodiversity, reduced nutrient bioavailability, inefficient food storage, disruption of infrastructure and labor and increased disease and food safety challenges) also precipitated by climate change and worsened by the reciprocal effect of food systems. See Appendix B for detailed table summarizing the impact of direct effects of climate change on malnutrition in the African context.

Direct Effect A – Crop & Livestock Failures

As weather patterns change, crops, fisheries, and livestock are directly (e.g., increases in ambient temperature or drought) or indirectly (e.g., changes to the biosphere which impact their disease exposure and natural lifecycle) affected. While not always leading to outright failure, changing weather patterns also decrease crop and livestock productivity (e.g., heat stress). Projected climate scenarios agree that predicted changes in temperature and rainfall will lead to significant reductions—particularly in (sub)tropical areas—in staple crop yields, seafood stock yields, and livestock productivity, all of which are important for human populations (29). Across Africa, by 2050 sorghum and millet yields are forecasted to decrease by 15% and 10%, respectively. Additionally, some important cash crops, such as coffee and cocoa, will no longer flourish in parts of their present growing areas (30).

Abiotic Effects on Crop, Fishery, and Livestock Yield

Abiotic climate change effects refer to impacts to non-living components of an ecosystem (e.g., ambient temperature and water-related weather events) and impact the growth and overall productivity of crop, fishery, and livestock yields.

- Increases and decreases in precipitation: Droughts may decrease the water availability for domesticated plants and animals, reducing the yield from both food sources and destroying crops altogether, particularly in rain-fed farming systems. Increases in rain, especially through flooding, may damage crops. Approximately 80% of Africans remain dependent on low-yielding, rain-fed agriculture (31).
- Ambient temperature increases and heatwaves: As temperatures rise, heat stresses certain plants, corals, and livestock, decreasing their yield or even leading to failure when temperatures exceed the failure point temperature of certain crops and corals. In the case of corals, their failure decreases algae outputs and impacts marine food chains.

Example: Increased Temperatures Impacting Crop Yield

Tomatoes and beans have lower failure point temperatures than staple crops and are more vulnerable to heat stress (32). As temperatures rise, their yields are expected to reduce. Already, climate change is estimated to have depressed the growth in staple crop yields of maize by 3.8% and wheat by 5.5% globally (33). Warming of less than 2 degrees Celsius could reduce total crop production by as much as 10%. For higher levels, yields may decrease by around 15–20% across all crops and regions (31).

Biotic Effects on Crop, Fishery, and Livestock Yield

Climate change-related biotic effects are impacts—both positive or negative—to biological components of an ecosystem and are facilitated by abiotic changes in weather patterns, such as the increased range of pathogens.

- Change in pests: Warming temperatures increase survival of insect pests (34). As an environment becomes more conducive to pests such as corn root worm (Diabrotica) in crops, the rate of herbivory increases which leads to crop failure (34; 35).
- Increase in pathogens: Warming temperatures also drive shifts in the latitudinal range of harmful crop (e.g., fungal soybean rust), fishery, and livestock (e.g., viral blue tongue disease and viral rift valley fever) pathogens (35). For example, current annual losses due to fungal infestation alone are estimated to reduce global dietary energy availability by approximately 8.5% (34).

- Decrease in pollinators: Biotic changes in climate may negatively affect pollinators. A reduction in animal pollination decreases yields of numerous pollinator-dependent food crops (often small- and medium-scale farming).

Direct Effect B – Reduced Biodiversity

Changes in temperature, precipitation, and atmospheric CO_2 are straining ecosystems and species life cycles, forcing migration, and decreasing overall abundance. As atmospheric CO_2 continues to increase, significant changes in vegetative cover will occur and put some species at risk of extinction. The amount of CO_2 absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year. Since the industrial revolution, the acidity of surface ocean waters has increased by approximately 30% (36). The oceans have absorbed much of this increased heat, with the top 700 meters of ocean showing warming of more than 0.22°C since 1969 (37). It is important to note that, while certain plants and animals will adapt to acute and slow-onset events, overall, the global impact on crops, livestock, and fish is projected to be negative.

Marine Impact

Increases in water temperatures are causing coral bleaching and marine species migrations. Increases in atmospheric CO_2 are decreasing oceanic pH levels (acidification), which affects calcification processes for shelled marine life and bleaches coral reefs. Both phenomena disrupt fragile marine food webs and ecosystems (38).

- Increases in water temperature: Increases in water temperatures result as oceans absorb most of the excess heat from GHG emissions. Warmer waters can directly affect the development and growth of marine species and cause coral bleaching, which in turn impacts coral reef ecosystems that are home to most of the ocean's biodiversity and a critical human food source. Warmer waters (which also affect nutrient rich ocean currents) threaten to cause mass migration of marine species in search of the right conditions for feeding and spawning, as well.
- Ocean acidification: Oceans absorb over 25% of anthropogenic CO_2 emissions as a result of vast increases in atmospheric CO_2. Acidification directly impacts sea life that build shells or shelter of calcium carbonate (e.g., corals, crabs, and some microscopic plankton) that are an underpinning of the marine food web. These shell- and shelter-building organisms provide critical habitats and food sources for other organisms. Increased acidification can also limit the ability of certain fish to detect predators, disrupting the food chain (39).
- Exacerbator of land-based activities: Increases in ambient temperature and atmospheric CO_2 amplify the impact of existing stressors on coastal and marine environments from land-based activities (e.g., urban discharges, agricultural runoff, plastic waste) and of the continued, unsustainable exploitation of these systems (e.g., overfishing, deep-sea mining, and coastal development) (40). The multidimensional destruction of the marine ecosystem will have profound effects on food sources.

Terrestrial Impact

Increases in ambient temperatures and acute weather events are straining non-domesticated flora and fauna and may impact the balance of the terrestrial food system, with particular impact on pollinators, edible plant diversity (particularly those that provide unique micronutrient, soil nutrient, and medicinal value), and populations that rely on hunting and foraging.

- Increases in ambient temperature: Increases in overall temperature amplify the likelihood of failure for wild flora that have low failure point temperatures. Additionally, ambient temperature increases impact pollinators and shifts the range of pests and pathogens that can harm wild flora and fauna, thus disrupting ecosystems.
- Increases and decreases in precipitation: Droughts, flooding, and other similar events stress and destroy wild flora and fauna.

Direct Effect C – Reduced Nutrient Bioavailability

Increases in atmospheric CO_2 (as a direct result of human activity and as a cumulative effect of the planet's decreased capacity to absorb it) will decrease essential nutrients found in crops, particularly domesticated varieties. Forecasted levels of elevated CO_2 emissions by 2050 are projected to contribute to substantial declines in the micronutrient (i.e., vitamin B, zinc, iron) and protein content of staple grains (41). Approximately 130 to 200 million people will be placed at new risk of micronutrient deficiency by 2050 due to anthropogenic emissions of CO_2 (42). Elevated levels of atmospheric CO_2 are projected to contribute directly to decreases in nutrient availability in staple crops.

- Decreases in essential vitamin content: Studies have shown that as CO_2 levels rise, vitamin C decreases in some fruits (e.g., tomatoes) (41). Studies found that elevated CO_2 concentrations in rice contributed to 17% less vitamin B1 (thiamine), 17% less vitamin B2 (riboflavin), 13% less vitamin B5 (pantothenic acid), and 30% less vitamin B9 (folate) (43).

- Decreases in zinc: Elevated levels of CO_2 have been shown to decrease zinc in certain staple crops by around 15%. The declines in zinc content are expected to place around 30 million Africans (an increase of approximately 4%) at new risk for zinc deficiency and will exacerbate existing deficiencies for millions more by 2050 (44).
- Decreases in iron: Elevated levels of CO_2 in staple grains have shown a 4 to 14% decrease in dietary iron (34; 45).
- Decreases in protein: Elevated levels of CO_2 have been shown to decrease protein concentrations of wheat, barley, rice, and potato crops by around 10 to 20% and soy by around 1% (46; 45).
- Decreases in additional micronutrients: Projected levels of 2050 atmospheric CO_2 may lead to 5 to 10% reductions in the concentration of phosphorus, potassium, calcium, sulfur, magnesium, copper, and manganese in a wide range of crops (45).

The most at-risk populations for both zinc and iron deficiencies are found in Africa as they often have higher levels of predisposition, limited access to foods and plants that are rich in these micronutrients, and diets low in animal protein. Roughly 1.4 billion children ages 1 to 5 and women of childbearing age live in countries where current anemia rates exceed 20% of the population and where dietary iron (given future CO_2 projections) intake is expected to decrease by 3.8% (45).

Direct Effect D – Gaps and Inefficiencies in Food Storage

As weather events become more extreme and unpredictable, food storage systems are increasingly strained. The need for effective food storage to fill gaps between progressively more variable growing seasons is rising. Climate change is making seasonal patterns more unpredictable and therefore increasing vulnerability to malnutrition in certain populations in East and West Africa.

Seasonal Food Gaps

Climate change is increasing the variability of seasonal patterns for crop growth. This, coupled with insufficient storage, leads to increased vulnerability to climate events. Vulnerability is particularly acute in regions where the rains are highly seasonal, and rain, rather than irrigation, is the main source of water for agriculture. The period between planting and harvesting is often known as the "hungry season."

- Lack of adequate commercial canning and storage facilities: Commercially, infrastructure gaps in preservation techniques lead to a glut of food during harvesting season (and shortly thereafter) and a dearth of food products at other times of the year. This has a significant impact on food prices and wages for supply chain workers, especially farmers, and is a major determining factor of household food accessibility.
- Limited small scale and commercial refrigeration: Individual households often lack the appropriate food storage (i.e., refrigeration) infrastructure, leaving them vulnerable to fluctuations in market prices and nutritious products (retail) or climate change-related seasonal changes in crop yields (subsistence farmers). Floods and heatwaves can spoil food and lead to an increase in food waste when adequate food storage techniques are not available, especially at the food production level (i.e., on-farm). In places with limited access to energy, refrigeration options are often limited.

Example: Tomato Harvest in Nigeria

In northern Nigeria, yearly tomato harvests are enough to meet consumption demands for the entire country. However, due to inadequate storage techniques and infrastructure, Nigeria, on average, is a yearly net importer of tomatoes (47).

Direct Effect E – Disruption of Infrastructure and Labor

Acute weather events (e.g., floods, droughts) damage supply chain infrastructure, while heatwaves and ambient temperature increases contribute to decreases in labor production. In 2017, 153 billion hours of labor were lost due to excessive heat, representing an increase of more than 62 billion hours since 2000 (48). Within African food systems, food transportation moves large volumes at a time, has limited alternative routes, and is dependent on the timing of the growing and harvest seasons. An increase in the frequency and intensity of extreme weather events will most likely continue to increase the frequency of food supply chain disruptions (49). Transportation will continue to grow in importance as supply chains become more globalized and attempt to meet demand.

Disruption of Labor

Ambient temperature increases and acute heatwaves directly impact work production. In general, as temperature increases, work production decreases. Rising temperatures may breach physiological limits, making sustained work increasingly difficult or even impossible. Labor loss disproportionally affects poor populations given their propensity for outdoor work.

- Agriculture sector labor loss: As temperatures rise, agriculture labor loss directly affects supply chains and increases prices, which decreases household purchasing power. For agriculture-related small- and medium-sized enterprises (SME) and subsistence farmers, decreases in productivity may lead directly to food insecurity.
- Non-agriculture labor loss: Temperature increases may affect overall work production for non-agriculture SMEs and self-employed households, which can have a direct impact on individual household economic stability and purchasing power.

Example: Heat Stress in West Africa

Global warming heat stress in West Africa could lead to the loss of approximately 5% of working hours in 2030, equal to around 9 million full-time jobs. African tropical or subtropical regions are expected to suffer greatest productivity losses. Agricultural workers are expected to be the worst affected, accounting for 60% of working hours lost to heat stress in 2030 (50).

Disruption of Infrastructure

Acute weather events damage important physical infrastructure, which is a critical component of food supply chains.

- Roads/Transport: Washouts caused by floods often render food transportation between different stages of the supply chain (farmer -> packing plant -> retail -> end user) impossible. Areas with already poor infrastructure and insufficient response mechanisms to acute weather disasters are even more vulnerable. Disruption of infrastructure impacts end user nutrition in multiple ways, including indirectly through price increases and directly through food availability.

Direct Effect F – Increased Disease and Food Safety Challenges

Climate change exacerbates disease by creating environments that are more conducive to vector-borne illnesses, water-borne illnesses, food-borne illnesses, and allergies/respiratory issues. These conditions often prevent the body from efficiently utilizing nutritious foods, while also decreasing labor availability and the capacity of caregivers to tend to their children. Temperature increases alone (without changes in precipitation patterns) have led to increases in the transmission of multiple vector-borne diseases in Africa. Highland areas that were once immune to lowland diseases are becoming more susceptible (48). Water-borne diseases are also becoming more prevalent. Increases in disease will impact low-income populations that already experience a large burden of disease.

Increased Exposure to Disease and Infection

As ambient and water temperatures warm, the environment becomes increasingly conducive to pathogens (e.g., parasites, bacteria, viruses, and infections).

- Vector-borne illnesses (e.g., malaria): As ambient temperature rises and occurrences of heavy rainfall increase, environments become more conducive to mosquito-borne illnesses. In 2016, the highlands of sub-Saharan Africa saw a 28% rise in the vectorial capacity of malaria. Also in 2016, transmission of the dengue fever virus was the highest on record. Current projections estimate the population at risk of malaria to increase by 1.6 million by 2030 and 1.8 million by 2050 (48).
- Food-borne illnesses (e.g., salmonella, E. coli, mold, mycotoxin): As ambient temperature increases and heatwaves occur more frequently, food becomes more susceptible to diseases. Salmonellosis, for example, has been found to increase by 12% for each degree increase in ambient temperature above 6°C (51). Additionally, climate change has been found to expand the geographical range where mold growth and mycotoxin production can occur on crops. Exposure to these toxins can result in illness and death (52).
- Water-borne illnesses (e.g., cholera): The increasing unpredictability and intensity of precipitation patterns will have an impact on water-borne diseases. High temperatures and large fluctuations in rainfall are projected to increase the burden of diarrheal diseases in low-income African regions by approximately 2 to 5% in 2020 (53). Low bouts of

Example: Infrastructure in South Sudan

In South Sudan, poor road infrastructure (e.g., tarmac roads) is a major barrier to nutritious food access and availability. Transportation is required for food to move long distances to meet demand and to supply areas with food shortages. Even minor weather events render major thoroughfares impassable. During the rainy seasons, certain communities may be cut off from non-subsistence and imported food sources, important to balanced diets, for weeks (49).

rainfall often stress water infrastructure (or lack thereof) leading to increases in water-borne diseases, as well. Additionally, as ocean temperature increases, oceans become more susceptible to pathogens. Increased ocean temperatures are leading to increased prevalence of Vibrio spp. in shellfish, as well as increases in the epidemic suitability of Vibrio cholerae (53; 54).

- Allergies and respiratory infections: Increase in ambient temperature and changes in precipitation will increase certain allergens (e.g., ragweed). The effect will be two-fold: increased allergens will not only have an impact on labor and productivity but also may impact the body's utilization of nutritious foods. Increases in temperature and decreases in precipitation may also impact fine particles and synthetic allergens in the air, leading to increased risk of respiratory infections.

Example: Disease Incidence in South Africa

A study of climate data and children's health in South Africa found that 38% of diarrhea, respiratory infection, asthma, and malaria disease incidence in children under 13 occurred because of the combined influence of temperature and rainfall (55).

Societal Implications & Nutritional Impact

In this section, we present the societal implications (see Societal Implications) of the direct effects of climate change discussed in the previous section. These societal implications, in turn, reduce access to nutritious food and further propagate into adverse health issues for people—particularly children—in the region (see Nutritional Impact).

SOCIETAL IMPLICATIONS

In the previous section, we presented the climate change conditions exacerbated by food systems and the corresponding direct effects. Based on these, we identified corresponding societal implications that include: (i) strife, destabilization, and migration; (ii) disruption of global markets and supply chains; (iii) governance limitations and systemic inequities; (iv) increased strain on women and caregivers. See Appendix C for detailed table summarizing the impact of societal implications of climate change on malnutrition in the African context.

Societal Implication – Disruption of Global Markets and Supply Chains

Changes in crop production, food waste, supply-chain infrastructure, and the capacity and health of the labor force are caused by direct effects of climate change. These impacts disrupt market stability and affect prices (i.e., access and availability of food and health items).

- Relationship with strife/conflict and reduced economic opportunity: The 20 most populous countries in Africa are net importers of grain and thus are vulnerable to imported food price volatility from direct effects of climate change (e.g., crop failure). This vulnerability can then lead to social unrest (e.g., Sudan) and conflict when prices rise, and governments are unable to mitigate the effects (49). Studies predicting the impact of climate change on food prices produce varied results. That said, there is consensus that climate change will lead to increased food prices by 2050 (33). On the African continent, maize, rice, and wheat prices are projected to raise by 4 -15%, sweet potato and yams by 26%, cassava by 20%, millet by 5%, and sorghum by 4% (56).

Societal Implication – Governance Limitations and Systemic Inequities

Climate change exacerbates shortcomings in domestic institutions and governance (e.g., poor or lagging policy, infrastructure limitations, institutionalized biases) that disproportionately impact marginalized and vulnerable populations.

- Slow changing/inadequate policies: Climate change strains domestic political environments that lack resources (e.g., financial or political-will) to make necessary adjustments to policies that exacerbate or do not actively combat the direct effects of climate change (e.g., slow-changing protectionist policies). The effects of climate change are intensified when farmers are cut off from much needed imported products that are important to maintaining productivity levels.
- Exacerbator of systemic inequities: Climate change exacerbates institutional and systemic inequities

(e.g., economic, political, social), which increases the strain on marginalized and vulnerable populations. For example, minority agriculture communities may lack access to financial markets, rendering them less capable of enduring large gaps in productivity.

Societal Implication – Increased Strain on Women and Caregivers

Climate change exacerbates water scarcity, health challenges, and food insecurity issues, which often predominately affect women and caregivers in Africa (58).

- Increased workloads: Women often carry the responsibility of tending/buying/preparing food and collecting water. Increases in work levels related to these tasks decrease time available to nurture and nourish their children or take care of themselves.
- Decreases in health: Health issues (e.g., vector-borne disease) due to direct effects of climate change that affect caregivers and nursing mothers impact child nutrition.
- Decreases in economic opportunity: Increased workloads, decreases in household purchasing power, and worse overall health significantly reduce opportunities to engage in income-generating activities (e.g., work, education).
- Agency and vulnerability: Women often have low agency and are most vulnerable to food insecurity and health issues, which can have a direct effect on infants, especially in households in which male providers are absent.

The Interconnectedness of Direct Effects, Societal Implications, and Nutritional Impact

For example, a recent civil conflict in South Sudan was largely caused by competition over livestock, which have become more valued as a climate adaptation strategy following decreases in crop production, and thus overall food availability (subsistence and retail). Additionally, almost 50% of harvests were destroyed in areas of violence during the conflict. Food prices increased and purchasing power decreased as markets were disrupted due to crop destruction. Violence and lack of access and availability to food necessitated mass displacement of households, including women and caregivers. Displacement then led to lower or nonexistent incomes. This system of interconnected factors led to large increases in food insecurity and malnutrition during the conflict (49; 57).

NUTRITIONAL IMPACT

Here we present the repercussions based on the coalescence of the societal implications (Societal Implications), direct effects (Direct Effects), and climate change conditions (Conditions) exacerbated by food systems. The culmination of these elements results in impacts on: (i) access to nutritious food; (ii) utilization of nutritious food; and (iii) availability of nutritious food.

Nutritional Impact – Access to Nutritious Food

Demand for nutritious foods is experiencing shifts driven by ability to pay, changing preferences, higher prices due to production challenges, and inaccessibility due to displacement. Global climate models suggest that by 2050 climate change will result in additional price increases of 5 to 25% for the most important agricultural crops – rice, wheat, maize, and soybeans – and drive meat prices higher due to feed price increases (59). The combination of reduced or stable purchasing power with rising prices will especially affect the poor. Sub-Saharan Africa already sees higher prices of nutritious foods (60) and additional price increases will further strain access. **Climate-related price increases could increase the number of malnourished children under the age of 5 by 20% by 2050** relative to a world without climate change (61). Higher food prices contribute directly to lower food demand, which is projected to decline by 1.5% by 2050 in Sub-Saharan Africa. Climate change-related reduction in access will disproportionately affect already vulnerable low-income and low-agency populations.

Nutritional Impact – Utilization of Nutritious Food

Human absorption of nutrients is impacted by food safety issues, reduced water availability and quality, and morbidity associated with increased disease. Climate forecasts anticipate that environmental stresses (e.g., droughts, floods) paired with increasing temperatures will increase the risk of infectious vector-borne diseases and poor water quality. Children in Sub-Saharan Africa continue to see elevated risk of vector-borne disease in addition to the highest rates of undernutrition, globally. Forecast **increases in disease rates attributable to climate change are expected to exacerbate already increasing rates of undernutrition** (62). Diarrheal disease will increase, primarily impacting low-income populations, and food-borne disease increases have already been observed (63). Increased incidence of diarrheal disease and other vector-borne illnesses impact the capacity to absorb nutrients in consumed food. The WHO estimates that climate change will cause around 250,000 additional deaths per year from malnutrition, malaria, diarrhea, and heat stress between 2030 and 2050 (63).

Nutritional Impact – Availability of Nutritious Food

Supply of nutritious foods may be influenced by reduced yield due to water challenges, poor soil and land degradation, pests and disease, and post-harvest losses. Upstream effects of climate change are expected to have devastating impacts on global food production. Agricultural output in developing countries is expected to decline by 10 to 20% by 2080 (64), while trade in cereal crops and livestock is projected to increase, and thus raise dependence on food imports for most developing countries (60). **Reductions in productivity related to upstream climate effects are expected to create substantial challenges as stressed food systems are forced to meet caloric needs of Sub-Saharan Africa's growing populations**. The prevalence of undernourishment has been on the rise. In Sub-Saharan Africa, prevalence of undernourishment was 23% in 2018—after increasing year-over-year since 2015—and is now 1% higher than in 2010 (62). Climate stresses will continue to strain the food system. Driven by decreases in food production, climate change is expected to increase the percentage of the population at risk of hunger in Mali from 34% to between 64 and 72% by 2050 (65).

The Interrelatedness of Nutritional Impacts and Foundational Influence of Availability

While climate change has a significant effect on all 3 drivers of nutrition (access, utilization, and availability), nutrition availability—due to climate change's impacts on food systems—has the most outsized adverse nutrition outcomes. In many cases, the (un)availability of nutritious food underpins challenges in access. In agriculture-dependent and less wealthy economies, affordability is strongly linked to unpredictable or insufficient availability. Similarly, challenges in utilization of nutritious food are related to availability through food safety issues. While food safety issues are only one contributor to problems utilizing nutrition, they are a projected major effect of climate change and are underpinned by the availability of non-toxic foods. Utilization challenges are also driven by the health care system, which exists outside of the food system.

Reciprocal Effects of Food Systems on Climate Change

Global food systems threaten ecosystem stability and resilience, and directly contribute to climate change. **Food systems constitute the single largest driver of environmental degradation and transgression of planetary boundaries**. A radical transformation of the global food system is urgently needed, or the world risks failing to meet the UN Sustainable Development Goals and the Paris Agreement (66). The sum of global food system activities contributes to around 24% of all anthropogenic greenhouse gas (GHG) emissions. Around 50% of agriculture's overall emissions are caused indirectly, mostly from land conversion such as forests and wetlands used for agriculture. Globally, only around 28% of ice-free land remains with minimal or no human use. Indirectly, agriculture, forestry, and other land use (AFOLU) activities accounted for around 13% of carbon dioxide (CO_2), 44% of methane (CH_4), and 82% of nitrous oxide (N_2O) emissions from human activities globally from 2007 to 2016. Whilst the majority of non-land use conversion emissions occur at the agricultural level, the production stage also directly contributes. On-farm sources of emissions are responsible for around 50% of agricultural production's global overall emissions. Emissions from all processes after food production are responsible for another 5 to 10%.

Three main GHGs associated with food systems, each have different warming effects:

- Carbon dioxide (weak per-unit warming effect) - large amounts of CO2 are released, meaning its impact is large despite low relative potency
- Methane (strong per-unit warming effect)
- Nitrous oxide (very strong per-unit warming effect)

Foods with the highest overall GHG impact are ruminant meat (e.g., beef, bison, and lamb), followed by other meat (including seafood) and animal products (eggs, milk). Livestock are by far the biggest contributor to food-related GHG emissions (contributing around 15% of human-caused emissions). Plant-based foods generally have the lowest impacts, and the entire plant-based foods supply-chain generally causes fewer GHG emissions. The GHG footprint is substantially increased by the use of fossil fuel intensive processes such as long transport distances (e.g., long-haul flights) or growth in heated and lit greenhouses. **Emissions from agricultural production are projected to increase, driven by population and income growth and changes in consumption patterns** which have a significant impact on overall GHG emissions (67; 68). See Appendix D for detailed table summarizing the impact of food systems on climate change in the African context.

CONSUMPTION PATTERNS

Description and Trends

Demand drives food supply and there is growing demand for animal-based, processed, and nonseasonal foods due to population growth, rising living standards and purchasing power, and globalization (see Figure 3, for example). Food consumption patterns are influenced by increasing urbanization, which often comes with

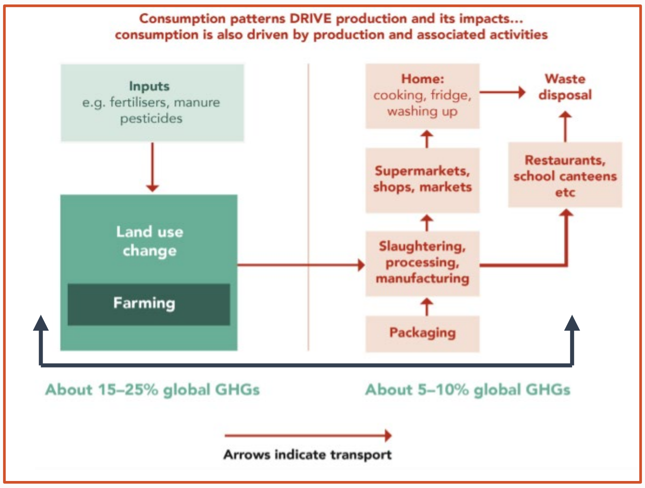


Figure 3: Food System's Contribution to Global GHG Emissions (68)

increasing incomes, allowing for diets richer in processed foods. Rising incomes are associated with higher consumption of animal-derived foods and highly processed foods, which carry a substantially higher climate impact (69). **The UN forecasts that demand for meat, milk, and eggs in Africa will almost quadruple by 2050, driven by population increases and rising living standards** (70). Animal products are important sources of nutrition, and animal husbandry is central to the livelihoods of large groups of African people. Enteric fermentation during livestock animals' digestion is the largest source of emissions from agriculture on the continent (~50%) (71).

Evidence of Effect on Climate

Meat and dairy livestock contribute around 15% of anthropogenic GHG emissions (72). They often produce high levels of nitrogen oxide (N_2O), phosphorus, CO_2, and methane (CH_4) through feeds, manure and urine (especially under unmanaged and waterlogged conditions), enteric fermentation (CH_4), and conversion of forest to additional grazing land (see Figure 4). Both **meat and dairy require more resources and drive larger emissions** of CO2, phosphorus, nitrogen, and methane than plant-based alternatives (72). Upstream, the production and processing of animal feed (including land use) also leads to N_2O and CO_2 emissions. Much of the world's grain production is used to feed animals, with up to one-third of arable land dedicated to producing feed for animals (72).

While the seafood supply chain generally requires less energy and natural resources and thus has a lower footprint than terrestrial-based foods, the seafood supply chain still has a material impact on climate change. Cultivation of shrimp and carnivorous finfish are the most energy consuming activities in aquaculture (fish farms). Shrimp aquacultures need constant aeration and water exchange, and they are often destined for export markets (increased transport). Additionally, as wild catches, shrimp have a low ratio of protein energy to industrial energy required to catch and process them. Carnivorous fish require the energy associated with processing and transporting feed, as opposed to omnivorous fish (e.g., carp) (73).

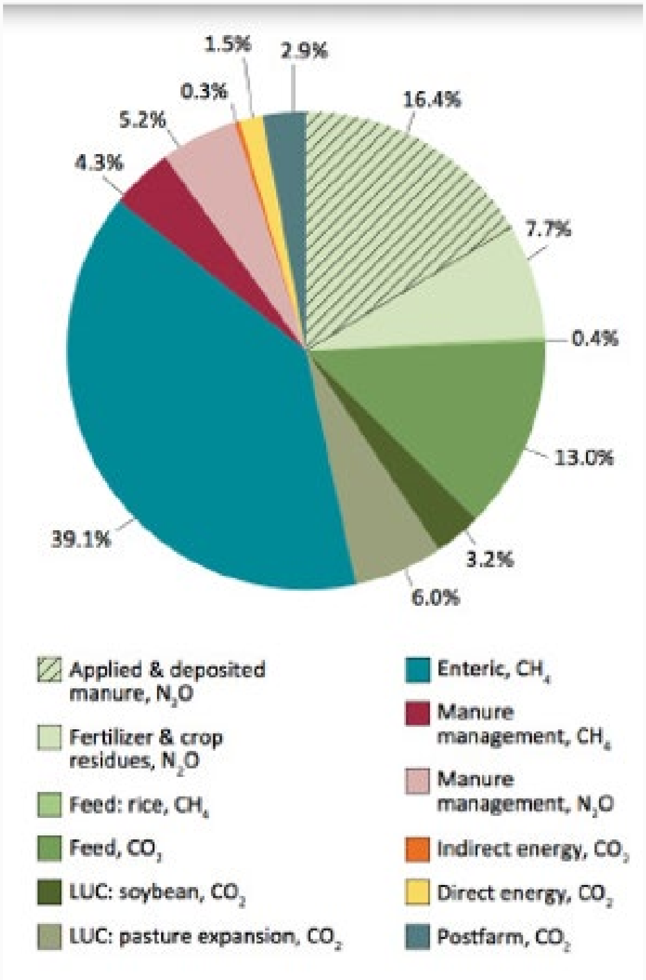


Figure 4: Total Global Livestock-Related Emissions from Direct and Indirect Sources (72)

In addition to animal-based foods, increases in rice (CH_4) and legume (N_2O) cultivation contribute to increased atmospheric N_2O and CH_4 concentrations (72; 67). The demand for more heavily processed foods—which often require higher energy usage than non-processed alternatives—is increasing globally (69). Non-seasonal fruits and vegetables produce impactful GHG emissions when grown in greenhouses, preserved as frozen, or transported by air. See Figure 5 for a breakdown of GHG emissions associated with one serving of several common foods.

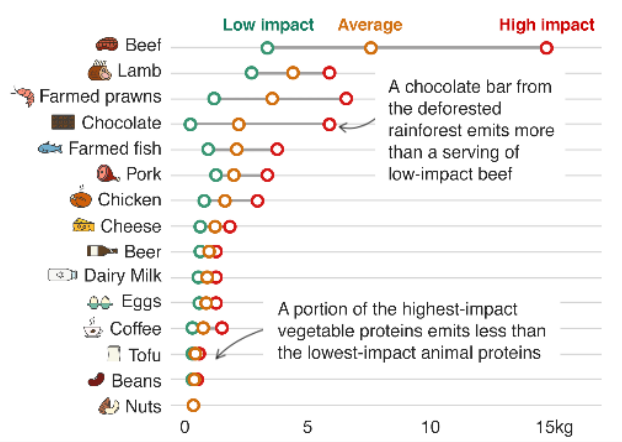


Figure 5: Kilograms of GHG Emission per Serving (74)

LAND USE

Deforestation

Description and Trends

Forests and trees mitigate climate change by storing carbon. Deforestation for agriculture and related purposes not only decreases the planet's natural ability to regulate atmospheric carbon but also releases carbon into the atmosphere. **Agriculture is the principal cause of the deforestation currently taking place in the world** (about 80% of deforestation), primarily in tropical and subtropical areas (75). Forests are critical as carbon sinks, having absorbed some 30% of CO_2 emissions in the last two decades (76). The conversion of natural ecosystems makes up roughly one-third of the increased CO_2 in the atmosphere since preindustrial times (33). The proportion of Congo Basin forests at risk of deforestation ranges from 64% in the Central African Republic to 92% in the Republic of Congo and extensive deforestation is already evident in Cameroon. Sub-Saharan Africa alone contributes approximately 1.4 Gt of indirect GHG (land change and forestry), making up around 40% of global totals of indirect GHG emissions (77; 78).

Evidence of Effect on Climate

While deforestation decreases the planet's natural capacity to store atmospheric CO_2, additional CO_2 is released when forests are converted to fields and pastures (e.g., drained peatlands, cleared for logging) or degraded due to unsustainable management. **Deforestation is responsible for about 50% of CO_2 emitted through total global agriculture land use** (67; 72). Tropical deforestation alone accounts for around 15% of global greenhouse emissions (67) and livestock and related uses are a prime driver of deforestation (79).

Cultivation of Land

Description and Trends

Uncultivated land covered with vegetation protects against climate change due to plants locking carbon into the soil after absorption. Farming practices that disturb the soil (e.g., tilling) and contribute to overall soil denegation (e.g., short rotation monocultures) release carbon into the atmosphere. Change in land use affects soil fertility, thus decreasing native plant density and their absorption of CO2 (natural soil sequestering). Globally, large areas of agricultural land currently operate under monocultures, with short rotations and high impact techniques (e.g., sharp plow and deep tillage, burning) (80). In fact, **soil management is the second largest direct source of GHG emissions from agriculture in Africa** (71). However, farmers in traditional agroecosystems, specifically in Africa, often support healthier soil sequestration by maintaining high varietal and species diversity on their farms and across communities and regions (higher for staple than non-staple crops) (80).

Evidence of Effect on Climate

Livestock and related-use amounts to approximately 70% of global agricultural land. Emissions from field crop production are heavily derived, among other factors, from crop residue decomposition, tillage operations, and soil carbon gains or losses from various cropping systems (e.g., high frequency) (81).

FOOD PRODUCTION

On-Farm Energy Use

Description and Trends

Large-scale greenhouses, tractors, and irrigation pumps use energy from fossil fuels (e.g., heating and lighting), which contribute to GHGs. In 2010, an estimated 950 million tons of carbon dioxide equivalent (CO_2e), **about one-seventh of total agriculture GHG emissions, resulted from global on-farm energy use**. Transportation and manufacturing of farm tools contribute a lower but still significant amount (about 2 to 5% of total agriculture GHG emissions) (33). Projecting the impact of on-farm and agriculture tool manufacturing energy use and emissions is challenging given the uncertainty surrounding improved technology innovations in renewable energy sources and energy efficiency, as well as the uptake within Africa (33).

Evidence of Effect on Climate

Coal accounts for around one-fourth of agriculture-related on-farm energy use emissions. Additionally, diesel (e.g., tractors and mining phosphate) may account for around one-third of all agriculture-related energy use emissions (33). Further, even fully local supply chains can be highly energy intensive due to the use of polytunnels and greenhouses to grow crops can be highly energy intensive (82).

Fertilizer and Herbicide/Pesticide

Description and Trends

Synthetic and organic fertilizers, pesticides, herbicides, and other chemicals directly release GHGs when used and manufactured and through knock-on effects of disrupting and degrading native plant, marine, and soil carbon storage systems. Fertilizing crops with nitrogen, phosphorus, and potassium is vital to achieving high yields, yet **fertilizer (e.g., manure, synthetic fertilizers, and crop byproducts) and pesticides/herbicides are significant contributors to agriculture's GHG emissions**, with N_2O emissions from synthetic and organic fertilizers being the single most significant contributor (33; 82). Additionally, both CO_2 and N_2O emissions are also released in processes related to the manufacture and use of these products. Synthetic fertilizer emissions are projected to increase from 2.6% to 14% of total agricultural emissions in Africa by 2030 (83).

Evidence of Effect on Climate

Fertilizers can result in the emission of climate change-causing gas nitrous oxide (N_2O), which is around three-times more impactful on global warming than CO_2 (77; 78). In 2010, **soil fertilization, including both organic and synthetic fertilizers, was estimated to have accounted for approximately 1,289 million tons of carbon equivalent GHGs** (CO_2e), which is about one-sixth of total direct (not including deforestation and related land use change) GHG emission by the agriculture sector (33). See Figure 6 for a breakdown of the fertilizer-related processes contributing to GHG emissions.

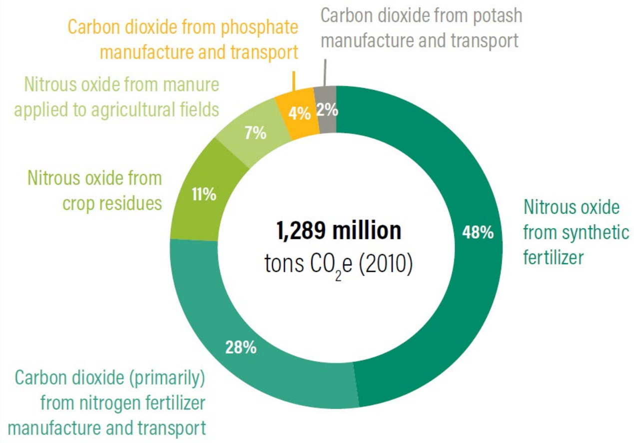


Figure 6: Fertilizer-Related Processes as a % of Total Estimated Fertilizer GHG Emissions (30)

POSTPRODUCTION

Food Storage

Description and Trends

Food storage (e.g., refrigeration) contributes directly to climate change via the utilization of energy sources (i.e., fossil fuels and other chemicals) that emit GHGs. Increasing transportation and demand for non-local foods, as well as increased desire for out-of-season and frozen foods are leading to increases in cold storage and thus heightened GHG emissions. In turn, higher ambient temperatures necessitate greater energy usage to keep food from spoiling.

Food Processing

Description and Trends

Food processing (i.e., canning and packaging) increases GHGs due to material extraction, packaging manufacturing, and overall energy use (72). Food systems currently consume an estimated 30% of the world's available energy, with **more than 70% of that share being consumed post-harvest** (84).

Food Transport

Description and Trends

Food transport will most likely increase as food systems become more sophisticated, road infrastructure and interconnectedness improve, and purchasing power and demand for specialty or out-of-season foods increases. In the case of fisheries, as stocks continue to become depleted, boats are forced to travel farther and with more equipment, increasing fuel usage per kilo of fish (85).

Combined Effects

Evidence of Effect on Climate

Freezing food requires energy and packaging. In a study estimating the global impact of frozen vs fresh carrots and broccoli, both **frozen varieties had higher GHG emission impacts than fresh due to energy used for freezing and cold storage** (72). Packaging also contributes significantly to GHG emissions of bottled drinks and other products. A study of the tuna industry illustrated the impact of processing on seafood by showing that all forms of packaging increased tuna's GHG emissions, with plastic pouches leading to the largest increase in emissions (72). Food system transportation is required at almost every level of the supply chain, from transport of raw materials to processing to retail to waste. **Food transport in high-income countries accounts for around 10 to 12% of total CO_2 emissions by food systems** (75; 67; 72), whilst air freight is the most GHG-intensive mode of transport (72).

Studies in LMICs found that transport (along with other stages of the supply chain such as processing) have a very small relative impact on GHG emission (yet they will mostly likely increase). This reflects more localized, less industrialized systems (i.e., more locally produced food is consumed) (72). However, increased urbanization and purchasing power in Africa is driving increased demand for diets richer in processed, out-of-season or nonlocal, and frozen foods (69). This trend will amplify the climate impacts of food transport in Africa.

Food Loss & Waste

Description and Trends

Food loss and waste at all stages of the supply chain lead to inefficiencies that necessitate additional food production to meet demand. As a result, additional fuels, harmful additives (e.g., fertilizers), and precious resources release GHGs as they are utilized to compensate for food loss and waste. In addition, food waste itself also releases GHGs (79). Food loss and waste represents around a third of global food production (85). Converted into calories, this amount is equivalent to **around one-quarter of the world's food supply lost somewhere between farm and fork** (33). Food loss in sub-Saharan Africa is around 23% of total food produced, 39% of which comes during production and 37% during handling and storage. Africa makes up about 11% of global GHG emissions from waste. In low-income countries, the highest losses are in SME agriculture and fishery production and processing (86).

Evidence of Effect on Climate

Food loss and waste consumes about one-quarter of all water used by agriculture each year and requires an area of agricultural land greater than the size of China (33). The energy required for the production, harvesting, transportation, and packaging of wasted foods generates more than 3.3 billion tons of CO_2 annually, making **food wastage the third highest global emitter after the US and China** (79). Further, food loss and waste generate about 8% of global greenhouse gas (GHG) emissions annually (33) and decomposing matters also contribute to CH_4 releases into the atmosphere (77; 78).

Opportunities for Development: Creating an Enabling Environment

An environment that fosters intelligent and systematic collaboration among governments, NGOs, and other stakeholders is crucial. This can then enable the necessary collective investments in resilient, adaptable, and equitable food systems that both support healthy populations and mitigate the impact on the climate.

From the research summarized thus far, we identified the following key insights regarding opportunities for development:

- Acute needs in health and human development have created an existing atmosphere in which **the nexus between climate change, food systems, and nutrition is not adequately recognized and resourced.** Further research and consideration of the current and projected effects are needed to reduce uncertainty and build intelligent, data-driven policies and interventions.
- Adaptation to and mitigation of the widespread projected effects **require extensive, catalytic collaboration and commitment by a vast collection of sectors and stakeholders**. Elevation of the nexus of climate and nutrition into regular development discussions amongst donors, governments, and other development actors is critical.
- Developing food systems in Sub-Saharan Africa already face added challenges associated with effects of climate change. Thus, **effective interventions will require forward-thinking policies and supportive government structures**.
- The nexus of climate change and nutrition poses challenges to food systems, which will require **innovative technologies, bold solutions, and abundant capital investments that are tailored to the African context** and allow growth to leapfrog less efficient stages of food systems development.

Based on our in-depth analysis, we identified 7 potential opportunity areas (*See Figure 7a*) for consideration by corresponding stakeholders that includes both public and private institutions and persons. Below, we expand upon these opportunities by mapping the anticipated impact on climate change and malnutrition (*See Figure 7b*), gaps, opportunities, and illustrative investments. See Appendix E for potential partners for each opportunity area.

OPPORTUNITY 1, COALITION BUILDING: INTERNATIONAL CLIMATE, FOOD SYSTEMS, NUTRITION COLLABORATION AND ADVOCACY

Timeline to Impact	Short (0-2 yrs)	Med. (2-5 yrs)	Long (5+ yrs)
Existing Global Engagement in Opp. Area	Lower		Higher

The Gap

International coordination to address the nexus of climate, food systems and nutrition is nascent, ad hoc, and disjointed. Furthermore, there is not yet full consideration and commitment by key philanthropic and humanitarian organizations on this critical subject. Donors and development agencies are often engaged in near-term investments that deliver nutritious foods to

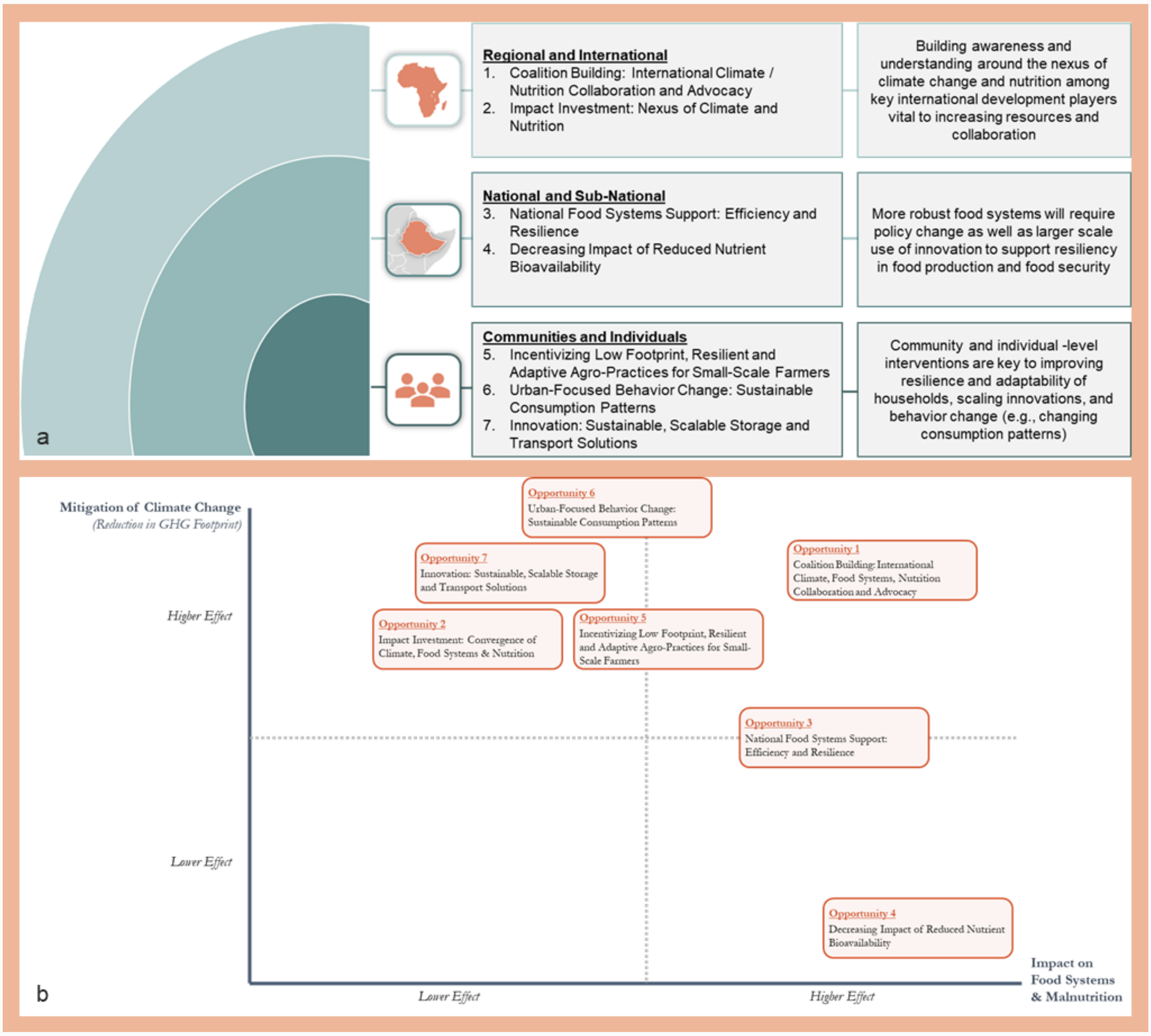


Figure 7: a) Levels of Engagement & Associated Opportunities; b) Mapping Opportunities, Anticipated Impact on Climate Change and Malnutrition

high-need adolescents and children but are **not building climate resistance and adaptation into the existing food systems**. International organizations that work in food systems and malnutrition lack clear climate mitigation policies.

The Opportunity

<u>Convene donors, NGOs, and other international partners to increase awareness of the intersection of climate, food systems and nutrition, elevate the need for internal policy around this subject, and build strategy for catalytic, collaborative efforts</u>. While short-term interventions to resolve acute food shortages and malnutrition will remain an important part of malnutrition prevention during acute emergencies, the nature of the intersection of climate, food systems and nutrition challenge necessitates strong collaboration within the international community. Resource-heavy, long-term strategies are needed to construct resilient food systems that maximize nutritious food output using minimal inputs. Effective approaches will be rooted in individual and collective policies, commitment, and resource allocation.

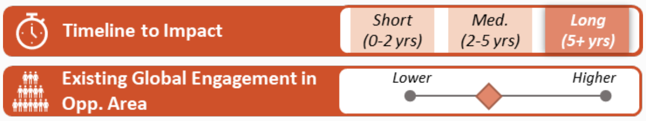
Development of a coalition to elevate the importance of these intersections will be a critical first step in mobilizing resources, initiating policy discussions, and developing collective objectives that are realistic, adequately resourced, and have broad-based support within the development sector. Successful creation of a coalition would highlight and legitimize the nexus of climate change and nutrition as an area for action and create an enabling environment that amplifies efficiency and effectiveness of interventions at points of influence.

Illustrative Investment

Convene a coalition to elevate the convergence of climate and agro-livelihood:

- Convene and expand a coalition of organizations working on these issues, including leading philanthropies, humanitarian organizations, and research institutions. This can be done under a unified title with mandate to prioritize the integration of climate and food systems livelihood policies among coalition members, including within existing programs or expanding programs when applicable.
- Emphasize providing long-term solutions to specific burdens of climate change in Sub-Saharan African, with full consideration of the GHG footprint of food system programs and all organizational activities.
- Advocate collectively for policy and resource expansion among global, regional, and national organizations and stakeholders.
- Provide funding for continued research and evidence generation on the convergences of climate and food-security, as well as for understanding impacts specific to African women and girls.
- Establish planetary health diet as foundation of coalition's advocacy work around healthy and resilient diets, food system adaptation and optimization, and climate change mitigation.

OPPORTUNITY 2, IMPACT INVESTMENT: CONVERGENCE OF CLIMATE, FOOD SYSTEMS & NUTRITION



The Gap

Domestic and regional resources in addition to global NGO funding alone cannot adequately fund projects required to effectively build resilience, adaptation, and to mitigate climate change within African food systems (31). **Without private investment, optimization and innovation will likely lag the impact of climate change and GHG mitigation thresholds**. Impact investing in Sub-Saharan Africa is constrained by a shortage of investable opportunities and a limited understanding of how large private sector investors can use impact investment to drive socioeconomic progress.

The Opportunity

<u>Support the creation of mechanisms by which for-profit investors can invest in bold large-scale investment areas supporting climate-intentional food system transformation in Sub-Saharan Africa</u>. Large-scale food system transformation investments (e.g., R&D-heavy innovations and infrastructure projects) at the climate and nutrition nexus provide the potential scale and impact that for-profit funds require. Impact investing within Sub-Saharan Africa has increased, yet appetite to invest still outpaces opportunities to do so (87). Further, large funds are often constrained by the size of investment opportunities. If challenges at the nexus of climate change and nutrition, especially food system transformation, are properly positioned as both a social concern and innovative development opportunity, corresponding capital needs can be a viable investment option.

Development of a robust social impact investment mechanism is needed to bridge the gap between the desire of large private investors for catalytic, impactful projects and the need for innovative ideas and initiatives that seek to make food systems more resilient and adaptative and mitigate their impact on climate change in the form of GHG emissions.

Illustrative Investment

Support development and scale of a funding mechanism for large for-profit investors:

- Build a multi-sector funding mechanism based on established effects of climate change and food system impact on climate change. The mechanism would target large-scale catalytic investments aimed at transforming supply chains or specific aspects of supply chains (e.g., innovative fertilizer technologies, sustainable energy, and sustainable food storage infrastructure) to increase resilience and adaptability of food systems in Africa while mitigating the burden on climate change.
- Include partnership with communication firms and thought leaders to advocate for expansion of investment and to inform investors about needs and trends at the nexus of climate change and nutrition.

Create mechanism and pooled fund for African philanthropy to fill need for investment below size threshold of global investment funds:

- Provide opportunity for smaller investors to fund projects at the nexus of climate change and nutrition that could make more targeted impact and more frequent investments. Additionally, this mechanism would be more flexible and better positioned to react to emerging trends and challenges, and to incorporate gender lens investing.

OPPORTUNITY 3, NATIONAL FOOD SYSTEMS SUPPORT: EFFICIENCY AND RESILIENCE

Timeline to Impact	Short (0-2 yrs)	Med. (2-5 yrs)	Long (5+ yrs)
Existing Global Engagement in Opp. Area	Lower		Higher

The Gap

While climate change policies are seeing increasing attention in national contexts, there is still limited recognition and understanding of food system vulnerability to climate change. Many governments and supporting funders in Sub-Saharan Africa **are focused on interventions that resolve malnutrition on a case-by-case basis, often working within existing food systems** to deliver these interventions. Food systems and corresponding effects of climate change differ by countries and regions, and thus require targeted approaches at a national and sub-national level.

The Opportunity

<u>Build partnerships with governments (along with other international organizations) to provide technical assistance and financing to better understand the nexus of climate change and nutrition within their countries</u>. Then, apply that knowledge to build tailored, sustainable food systems via targeted policies and investments. This approach addresses the need to identify climate-related weaknesses or inefficiencies in domestic food systems. Further, providing technical assistance then supports the development and implementation of solutions targeted at food system vulnerabilities in a changing climate. Policy changes and financial support will be critical to ensuring that investments in food systems design see uptake and scale.

For example, a system that does not provide adequate access to high-yield seeds could be improved to increase access to those seeds, potentially reducing the effect or probability of crop failure. Other efforts could target policy change around land use to require that agro-forestry measures prevent ecosystem destruction and desertification for livestock.

Illustrative Investment

Provide technical assistance and subsequent policy and financial support with 1-3 pilot countries to accelerate development of sustainable food systems:

- Secure partnership with one or multiple countries (possible regional approach) that meet government effectiveness threshold (e.g., high political will). Build committee of research and technical organizations to provide knowledge base and country-specific assistance.
- Conduct rigorous research to build country-specific knowledge of food systems (e.g., inefficiencies and climate hotspots) and underlying policies at the nexus of climate change and nutrition. Use research as the foundation for data-driven technical assistance to design more sustainable food systems and draft complementary and effective legislation. Financial support could be provided to assist in the redesign of sustainable food systems. Policies targeted might include dietary guidelines, import/export policies to incentivize local production, food safety guidelines that anticipate climate-related challenges, and food production regulations that create incentives for low-impact farming methods.

Develop a diagnostic tool or framework to be used to support evaluation of country food systems alongside climate sustainability:

- Develop a diagnostic tool that can be deployed to measure critical elements of food systems, including climate change resilience, points of efficiency and inefficiency, and GHG footprint.

OPPORTUNITY 4, DECREASING IMPACT OF REDUCED NUTRIENT BIOAVAILABILITY

Timeline to Impact	Short (0-2 yrs)	Med. (2-5 yrs)	Long (5+ yrs)
Existing Global Engagement in Opp. Area	Lower		Higher

The Gap

Climate change's impact on macro and micronutrient content in widely consumed foods such as wheat, will underpin the realized severity of malnutrition over the next century. The content of **critical macro and micronutrients such as zinc, iron, and key vitamins in staple crops is expected to decrease** significantly. Recent research anticipates that increased CO_2 concentrations will reduce protein content of rice, wheat, barley, and potatoes by between 6 and 14% (41). Declines in zinc content are expected to place around 30 million Africans (an increase of approximately 4%) at new risk for zinc deficiency and will exacerbate existing deficiencies for millions more by 2050 (41; 45). These changes will acutely affect many African populations, where staple crops occupy the largest share of the average diet.

The Opportunity

Develop means of measuring and mitigating losses in nutrient bioavailability in critical staple crops to help alleviate the impact of reduced nutrient bioavailability. A regular assessment of changes in crops' nutrient content will not only show how climate change is affecting critical crops but will also help smallholder farmers and larger producers maximize nutritional content of foods by selecting most resilient varietals. Technological advancements (e.g., bio-fortification) may increase crop resilience and decrease overall projected negative nutrient effects of increased atmospheric CO_2.

This targeted intervention helps to ensure that available foods are nutritious, thereby supporting the nutritional efficiency of staple crops without requiring shifts in consumption patterns toward potentially more GHG-intensive foods (e.g., more animal products consumption to support protein intake).

Illustrative Investment

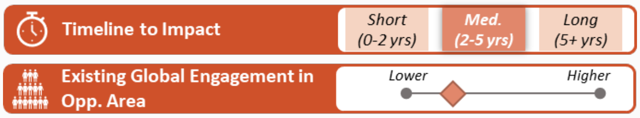
Develop and implement testing methodology for measuring crop changes:

- Increase the scale of existing tests to conduct more regular monitoring of the nutritional profile of key crops, ideally identifying a partner that can take a scalable methodology to critical geographies and conduct regular monitoring activities. Such testing will not only inform populations reliant on staple crops of the impact of climate change on their crops and diet but also serve as a means of tracking the effects of climate change over time on crops.

Bio-fortification or breeding of crops that are less sensitive to atmospheric increases in CO_2 (and other direct effects of climate change):

- Partner with global agriculture and nutrition actors to contribute to existing biofortification and crop-breeding efforts, accelerating scale-up and awareness and providing supplementary financing for smallholder farmer access. Beyond mitigating effects of climate change on nutritional content, crops can be made to be more resilient to climate-related weather events (e.g., heatwaves).

OPPORTUNITY 5, INCENTIVIZING LOW FOOTPRINT, RESILIENT AND ADAPTIVE AGRO-PRACTICES FOR SMALLHOLDER FARMERS



The Gap

On-farm practices—specifically cultivation methods, land use, and livestock-related processes—comprise the African supply-chain's greatest direct contributor to GHGs. Over 80% of Africans remain dependent on low-yielding, rain-fed agriculture, making them very vulnerable to the effects of climate change. Unfortunately, **small farmers and community associations, a large portion of the agriculture industry, lack the necessary resources** and access to financial markets that would allow them to build more resilient, adaptive, and efficient food production practices (31). Climate change impact projections and growing food demand make on-farm interventions vital in order to meet demand, adapt to increased crop failure and market fluctuations, and develop with a reduced carbon footprint

The Opportunity

Support and create interventions that incentivize sustainable land use and farming methods through combining the promise of increased yields and incomes with an emphasis on techniques that improve resilience and adaptability to climate change (e.g., climate-smart agriculture). A still nascent farming industry creates opportunity for growth to be sustainable (i.e., leapfrogging). Additionally, given the market share of African agriculture is small-scale farming, interventions are necessary to provide often illiquid and cash-strapped farmers with appropriate resources.

Interventions that incentivize innovative technologies and improved techniques by smallholder farmers will optimize food system output, lower the burden of climate change, and decrease food system's overall and increasing footprint. Crop and livestock failure, for example, can be averted through more efficient farming techniques and training that help support crop health and prevent soil depletion (e.g., crop rotations). In addition to downstream impacts on malnutrition, these interventions would be most impactful by minimizing contribution to anthropogenic climate change. More efficient land use (e.g., agroforestry), lower on-farm food waste, and more sustainable on-farm energy-use would all lead to lower GHG emissions for a given level of output.

Illustrative Investment

Develop funding tool for smallholder farmers and community associations to promote growth through sustainable systems (e.g., climate-smart agriculture):

- Provide access to targeted financing tied to sustainable farming practices to incentivize and support small-scale farmers and community organizations in increasing productivity and incomes. Financing should ensure equal access and gender equity as key components. Activities to be incentivized could include agroforestry and minimum tillage farming, low footprint fertilizer use, decreased footprint livestock techniques (e.g., managed grazing) and increased crop rotations and polycultures.

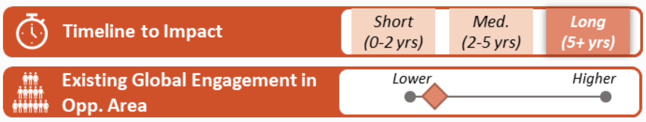
Develop or scale adaptable and sustainable agriculture training and education programs:

- Layer in training and education programs to build farmer knowledge of climate, food systems, nutritional impact, and resilience. Training should include adaptable and sustainable solutions. Programs could also include environmental education, technical training, and behavior change elements.

Advocate for policy shifts that incentivize and support climate-smart agriculture for small-scale farmers:

- Focus on domestic policy shifts that incentivize and support climate-smart agriculture to maximize the impact of financing and training interventions. Policy examples include subsidizing certain farm equipment, import/export policies, and disincentivizing land conversion (e.g., increased areas of protected land).

OPPORTUNITY 6, URBAN-FOCUSED BEHAVIOR CHANGE: SUSTAINABLE CONSUMPTION PATTERNS



The Gap

Projected trends in African population growth, urbanization, and purchasing power will not only increase the burden on the existing food system but are also expected to change consumption patterns. Expected **increases in consumption of processed and high-value foods (e.g., beef) will lead to a larger GHG footprint of food systems** as well as heightened prevalence of obesity. Consumption habits that favor healthy levels of macro and micronutrients will support healthier and more resilient populations, while also mitigating the negative effects of changing consumption habits on climate change.

The Opportunity

<u>Influence consumer choice toward more climate-conscious food and production options by raising awareness of the impact of dietary choices on climate change</u>. There is an opportunity to provide consumers—specifically urban consumers—with knowledge to encourage educated consumption decisions based on a obtaining the suitable level of macro and micronutrients and the food's GHG footprint (i.e., a planetary health diet). A planetary health diet supports adequate nutrition via optimal nutrient intake, which enhances resilience and economic output (e.g., labor) by supporting overall health (both mitigating undernutrition and overnutrition). Additionally, a planetary health diet reduces the climate burden of food production.

Encouraging healthy, climate-conscious diets and empowering consumers with the knowledge to seek out those foods can help mitigate the climate burden of food systems. For example, substituting animal-source protein consumption with plant-based proteins can significantly reduce GHG emissions. Additionally, knowledge and health-seeking behaviors around food choice increase demand for nutritious foods (falling under the "Access" dimension of nutrition), reducing risk of micronutrient deficiencies and obesity, both of which are associated with changing diets as nations develop.

Illustrative Investment

Pilot a healthy, climate-intentional dietary campaign for urban centers:

- Collaborate with government to pilot a healthy diet labeling scheme, supported by robust research on the impact of food systems in a local context. Provide accurate (and easily understandable) GHG footprint information alongside nutritional information.

Introduce a complementary communications strategy to introduce the population to the labeling approach, while also raising awareness of the impact of consumption patterns and food systems on malnutrition and climate change. Develop metrics for tracking and evaluating dietary shifts and consumption patterns:

- Develop metrics to evaluate food consumption patterns against a sustainable diet. This rating would allow government and regulatory agencies to better understand and anticipate changes within the food system based on shifts in consumption and to compare those changes to an ideal diet.
- Adapt metrics to support dietary guidelines or other labeling systems. Utilize a consumer-facing labeling tactic to support increased awareness and informed decision-making regarding food's environmental footprint and nutritional health.

OPPORTUNITY 7, INNOVATION: SUSTAINABLE, SCALABLE STORAGE AND TRANSPORT SOLUTIONS

Timeline to Impact: Short (0-2 yrs) | Med. (2-5 yrs) | Long (5+ yrs)

Existing Global Engagement in Opp. Area: Lower — Higher

The Gap

Long periods of **drought and heatwaves exacerbate food storage inadequacies, leading to periods of low availability of nutritious food** and increased price limit access for households with low purchasing power. Seasonal food shortages lead to longer-term consequences connected to stunting and wasting in children, with particularly drastic impacts on malnourished pregnant women and their infants. Inadequate storage also decreases the income potential of farmers. Food loss and waste constitute almost 25% of African food production, occur predominantly as post-harvest loss (PHL) and during production, and are highly connected to inadequate storage along the supply chain (33).

The Opportunity

<u>Invest in accessible food storage infrastructure and bold, innovative technology to considerably reduce the frequency of climate change-related food shortages and food waste and loss</u>. In addition to increasing availability and access to safe and nutritious food, such an intervention would also stabilize markets and supply chains by reducing shocks caused by large-scale food loss. Investment in sustainable, scalable storage and transport would support resilient food systems at regional, national and community levels.

Existing viable food storage interventions are ad hoc and unscaled. Systematically implementing locally viable solutions at scale is necessary in order to confront this widespread and growing challenge. Scaled food storage improvements would support food system growth and resilience to anthropogenic climate change effects. Additionally, sustainable storage and transport systems would also mitigate the upstream effect on climate change by lowering GHG emissions associated with food loss and waste (i.e., less food production and overall energy needed, plus decreased direct GHG emittance from food waste).

Illustrative Investment

Research to understand best practice technologies and develop recommendations around the most climate resilient innovations suited to the African context:

- Conduct in-depth research to understand what current solutions are viable in which context, followed by investment in well-suited technologies. Could involve partnership with larger institutional investors.
- Leverage research findings to understand disruption of markets more clearly at regional, national and community levels.

Develop business incubator and accelerator funding mechanisms for African entrepreneurship concerning storage and transportation solutions and technologies, with an emphasis on providing opportunities for women:

- Foster additional African-specific innovations. Mechanism could be directly tied to existing African incubator and accelerator instrument or through university programs.

Invest to scale sustainable storage and transport solutions nationally or regionally:

- Scale low footprint storage technology and modernize transportation to better preserve harvested food. High loss/waste and capital cost for SMEs makes investment at this level top priority, though opportunity exists with farmers, communities, and large-scale businesses.

Conclusion

Drawing from the findings surfaced throughout this report, we present an analytical framework (see *Figure 8*) to conceptualize **the reciprocal effect of climate change on food systems and malnutrition**. We illustrate how climate change adversely affects adolescent and child health in Sub-Saharan Africa through the disruption of global food systems and food security. Further, we highlight how these effects disproportionately affect nutrition amongst vulnerable populations. In our framework, we present the cyclical nature of how food systems and the corresponding drivers of climate change result in acute weather events and slow-onset effects. Those conditions, in turn, lead to the direct effects that threaten agriculture and food systems. Finally, we illustrate the direct impact of those effects on nutrition, as well as the indirect impact via societal implications, and the resulting health outcomes (see Appendix A for a summary of the key takeaways).

Supporting Africa's food systems transformation will require knowledge and solutions that can overcome critical climate change impacts and inefficiencies to deliver nutritious foods to diverse populations, while also institutionalizing climate-intentional supply chains. Even though nutritional challenges are pervasive in the region, Sub-Saharan Africa's current contribution to global agriculture related GHG emissions is relatively low (88; 77; 78). As climate stress continues to test the limits of underdeveloped food systems and their ability to provide for a growing population, Sub-Saharan Africa's rapid development is anticipated to prompt new and significant food systems-attributed greenhouse gas emissions. Though the annual growth rate of emissions on the continent is approximately 3%, there are large uncertainties in current and future African GHG emission projections (88; 77; 78). The international community and domestic governments are primarily focused on delivering interventions that remedy Sub-Saharan Africa's current acute malnutrition challenges; however, we must also better understand changes in the food system due to climate related and design interventions to mitigate and/or adapt to those changes.

Research on the future impacts of climate change on malnutrition is limited. However, expected changes in climate patterns—some of which are already observed—support consensus around significant adverse effects to crop yields and the nutrient content of key staple crops, ultimately threatening food systems' ability to deliver adequate quantities of nutritious foods. Upstream effects on crop yields and nutritional content are suspected to already be contributing to outcomes such as market disruption and placing added strain on nations with poor governance. While expected to worsen as food systems are further stressed, societal implications of climate change are difficult to attribute exclusively to climate shifts given other contributing factors (e.g., politics). Finally, while Sub-Saharan Africa's current contribution to climate change is low compared to developed nations, anticipated population growth and rapid urbanization will accelerate Africa's contribution to global GHG emissions. Changing consumption patterns and food system inefficiencies that underlie the projected growth in African food systems' GHG emissions will also exacerbate challenges to land use and food loss/waste if not adequately addressed.

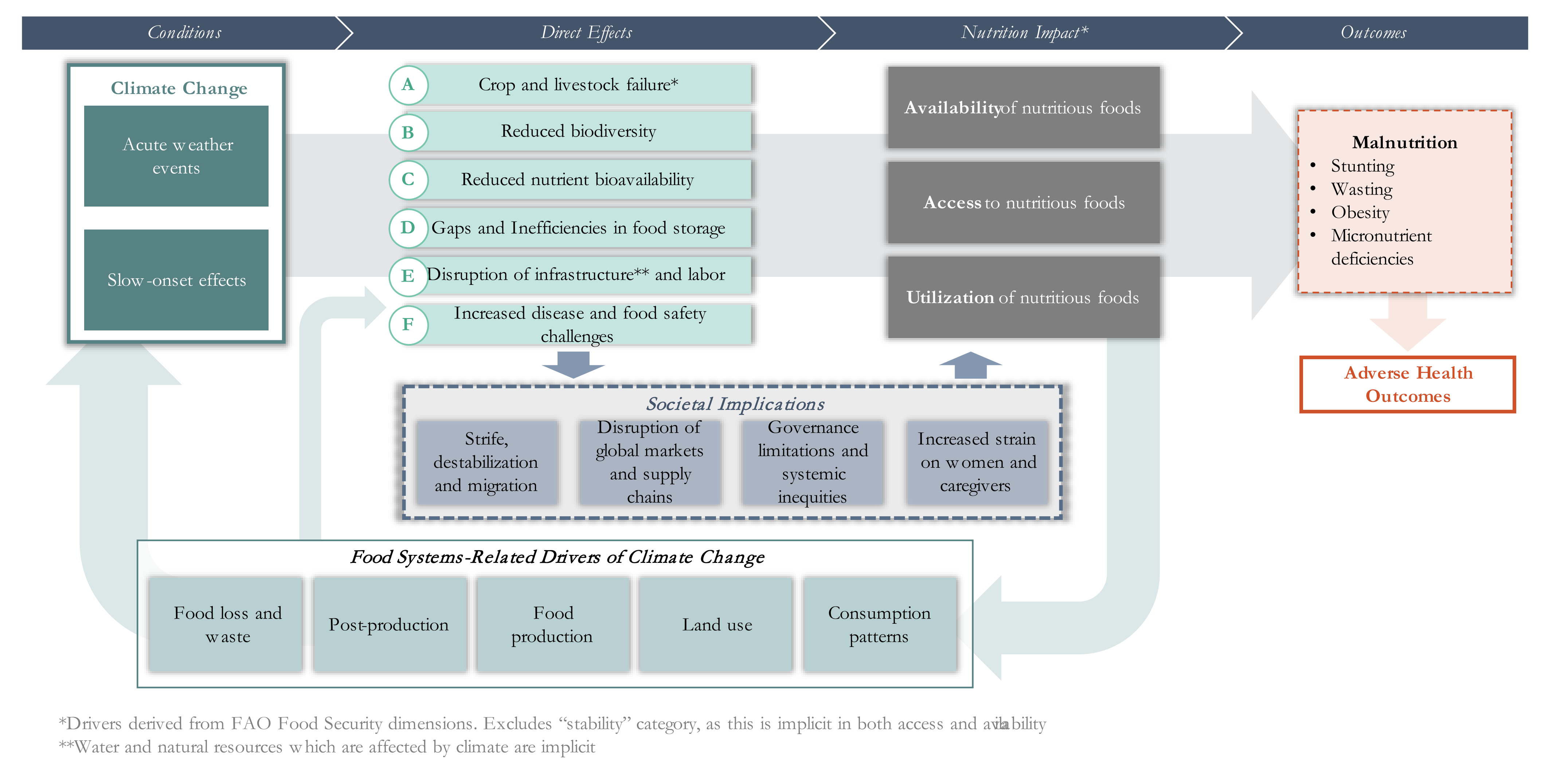


Figure 8: Analytical Framework

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APPENDIX A: SUMMARY OF KEY TAKEAWAYS

Direct Effects

Research which attempts to explain future impacts of a changing climate on malnutrition is limited. However, expected changes in climate patterns, some already observed, support general consensus around significant adverse effects to crop yields and the nutrient content of key staple crops, ultimately threatening food systems' ability to deliver adequate quantities of nutritious foods.

	Strength of Evidence	Expected Impact in 2050
Crop and livestock failure	◕	HIGH
Reduced biodiversity (non-domesticated)	◑	*Inconclusive*
Reduced nutrient bioavailability	◕	HIGH
Inefficient food storage	◕	MED
Disruption of infrastructure and labor	◑	MED
Increased disease	◕	MED

Societal Implications

Upstream effects on crop yields and nutritional adequacy are suspected to already be partially contributing to outcomes such as market disruption while placing added strain on nations which have poor governance. While expected to worsen as food systems are stressed, societal implications of climate change are difficult to attribute exclusively to climate shifts given other contributing factors (e.g. politics).

	Strength of Evidence	Expected Impact in 2050
Strife, destabilization & migration	◑	*Inconclusive*
Disruption of global markets and supply chains	◑	MED
Governance limitations and systemic inequities	◔	MED
Increased demands for women / caretakers	◔	MED

Food Systems-Related Drivers of Climate Change

While relative contribution to climate change is currently low compared to developed nations, anticipated population growth and rapid urbanization will greatly accelerate Africa's contribution to global GHG emissions through changing consumption patterns as well as food system inefficiencies which, if unchecked, will exacerbate challenges around land use and food loss/waste.

	Strength of Evidence	Expected Impact in 2050
Consumption Patterns	◕	HIGH
Land Use	◕	HIGH
Food Production	◕	MED
Post-production	◑	*Inconclusive*
Food loss and waste	◕	HIGH

= areas with greatest need for support

1. Tongwane and Mokhele. A Review of Greenhouse Gas Emissions from the Agriculture Sector in Africa
2. Climate Watch & FAOStat

APPENDIX B: EFFECT OF CLIMATE CHANGE ON MALNUTRITION | DIRECT EFFECTS

	H - High impact *M - Moderate impact* *L - Low impact* *? - Uncertain*	Key Takeaways for the African Context	Strength of Evidence (SoE)	Scarce / Moderate avail., or mixed conclusions / Well-supported	Impact on Nutrition Drivers*			Projected Impact*	
					Avail.	*Access*	*Util.*	*Expected Impact on Malnutrition in 2050*	
Direct Effects	Crop and livestock failure	Increased heat and variable precipitation will cause important staple crops to fail in Africa. Biotic effects (e.g. pathogens) will also impact yields.		Strong evidence that staple crop failure will accelerate due to climate change. Debate exists over adaption capacity of plants and livestock. Some plants in temperate regions will see increased growth rates, but global projections are a net yield loss.	H	H	L		Warming of less than 2°C could reduce total crop production by as much as 10%. For higher levels, yields may decrease by around 15–20% across all crops and regions in Africa.[1]
	Reduced biodiversity (non-domesticated)	Without paradigm-shifting behavior change and intervention, the earth will face extreme losses in biodiversity by 2050. Scientific community is calling for zero-expansion of agricultural land into natural ecosystems.		Scientific consensus that biodiversity loss is occurring at alarming rate. Plants, animals, and marine life are disappearing rapidly due to anthropogenic activity that is straining ecosystems in multiple ways. Limited evidence on nutritional impact.	L / H	L / M	L	?	The impact on malnutrition is uncertain – may be low for terrestrial-dependent and highest for marine-dependent food chains where food source is predominately undomesticated.
	Reduced nutrient bioavailability	Naturally occurring levels of critical micronutrients will decrease in key staple crops as CO_2 levels increase. Fortification for vulnerable may be necessary.		Multiple studies have demonstrated the effect of increased CO_2 on nutrient levels in staple crops. Projected 2050 atmospheric CO_2 levels well documented.	H	M	L		Critical staple crops may be ubiquitously affected - nutrient availability of protein, iron, and zinc could decrease by 19.5%, 14.4%, and 14.6%, respectively.[2] Without crop testing, decreases may go unnoticed.[2]
	Inefficient food storage	Seasonal food gaps underpinned by inadequate storage systems heavily stress food systems, leading to lack of food availability and high prices during the "hungry season".		Multiple studies within the African continent demonstrate the relationship between climate extremes and increases in acute child malnutrition (stunting / wasting), including the long-term effects to children born during these periods.	H	H	L		Without adequate storage infrastructure, availability will decrease, and prices will increase, reducing access. Impact somewhat difficult to forecast given uncertain development within supply chains, incomes, and overall infrastructure.
	Disruption of infrastructure and labor	Temperature increases decrease overall labor production. The effects of heat are already impacting labor production, especially in communities dependent on agriculture. Decreases in labor production have a multitude of downstream impacts (e.g. increasing prices).		Adverse impact of increasing temperatures on labor productivity is well established. Disruption of physical infrastructure less researched, potentially because its impact is less significant.	H	H	L		West Africa could realize losses of ~5% or more of working hours. Agricultural workers are expected to be the worst affected, accounting for ~1/3 of working hours lost to heat stress.[3]
	Increased disease	Food safety becoming greater risk, especially related to food-borne mycotoxins. Pathogens increasingly prevalent in previously nonendemic areas.		Strong empirical evidence on expansion of range and increasing environmental conduciveness for pathogens caused by shifting and variable climate events. Scientific consensus on impact of many pathogens on nutrient uptake.	M	M	H		Advancements in pathogen control will have uncertain impact. Low resource settings in tropical and sub-tropical regions considered most vulnerable.

- Research has presented a clear view of the challenges to food systems that lead to increased rates of malnutrition, and **the direct effects of climate change on population health and nutrition have seen increasingly greater research focus.** Despite increased focus, **the complex relationships and intricacies involved in these interactional pathways are not yet sufficiently understood**
- Climate change's impact on malnutrition will **clearly and disproportionately affect those with low agency, purchasing power, resilience, and adaptability. Africa is particularly vulnerable given ~80% of Africans remain dependent on low-yielding, rain-fed agriculture**

1. Ringler et al. Climate Change Impact on Food Security in Sub-Saharan Africa
2. Beach et al. Combining the Effects of Increased Atmospheric Carbon dioxide on Protein, Iron, and Zinc Availability and Projected Climate Change on Global Diets: A Modelling Study
3. Kjellstrom, et al. Working on a Warmer Planet. The Impact of Heat Stress on Labor Productivity and Decent Work. International Labor Organization

APPENDIX C: EFFECT OF CLIMATE CHANGE ON MALNUTRITION | SOCIETAL IMPLICATIONS

**Camber analysis*

	H - High impact *M - Moderate impact* *L - Low impact* *? - Uncertain*	Key Takeaways for the African Context	Strength of Evidence (SoE)	Scarce / Moderate avail., or mixed conclusions / Well-supported	Impact on Nutrition Drivers*: Avail.	Access	Util.	Projected Impact*	Expected Impact on Malnutrition in 2050
Societal Implications	Strife, destabilization & migration	Climate-driven migration is increasing as food systems and livelihoods are stressed. Under certain conditions, stresses on food systems likely to exacerbate conflict.		Established link between climate change and migration. Lack of robust scientific evidence between climate change and conflict given nuance and broad range of potential non-climate causes (anecdotal evidence linking the two).	H	H	M	?	Climate-related migration will continue to increase but will have varying effects on malnutrition given certain variables (e.g. policy uncertainty). Low income migrants will face the greatest risk / burden.
	Disruption of global markets and supply chains	Markets are already burdened by the food system effects of acute disasters, particularly within the Sahel. Stressed markets will have a multitude of upstream and downstream effects, including significant societal consequences.		Scientific community agrees that climate change will affect markets - the extent is debated. Prices are predicted to increase. Globalization and long-term projected development variabilities makes predictions challenging.	H	H	L		Labor production and staple crop yield losses will increase prices and market uncertainty, disproportionately affecting smallholders. Impact will be felt greatest in regions with frequent acute disasters and those who rely heavily on imports.
	Governance limitations and systemic inequities	Climate change exacerbates socio-political shortcomings, especially lagging or poor policies and systemic biases. These shortcomings commonly target or impact marginalized populations, slowing inclusive growth and perpetuating vulnerabilities which have downstream links to malnutrition.		Research gap - superficial understanding of the pathways from climate change to systemic inequities and marginalized populations. High-level reviews of climate change policies in developed settings have been undertaken. Dearth of evidence on how non-climate focused policies are impacted by climate change.	H	H	L		Climate change will likely lead to an increase in societal inequities driven by deficient institutions. The impact on policy is unclear given increasing interest and resource allocation by states to combat climate change, but also overall development uncertainty.
	Increased demands for women / caretakers	Women are most vulnerable to direct effects of climate change in multiple ways and their health and overall workload directly impacts child and adolescent malnutrition.		Link not well established in academic literature, though connection assumed given consensus (although shallow) that climate change will adversely impact vulnerable populations. Caretakers' impact on child and adolescent nutrition is well established.	M	H	L		Women will likely bear disproportionate share of negative effects of climate change. Given agreement around impact on vulnerable, low-agency populations, children and adolescents of poor agriculture dependent women will be most at risk of malnourishment.

- Research increasingly recognizes the link between climate change and adverse societal implications as climate-related resource shortages and systemic disruptions are realized, yet **it is persistently challenging to identify climate change as the sole driver of societal crises given the complex nature of these crises** (e.g. migration)
- There is a need to better understand the **potentially disproportionate effect of climate change on women and caregivers**, which may exacerbate malnutrition in children

APPENDIX D: EFFECT OF FOOD SYSTEMS ON CLIMATE CHANGE IN AFRICA

**Camber analysis*

H - High impact *M - Moderate impact* *L - Low impact* *? - Uncertain*	Key Takeaways for the African Context	Strength of Evidence (SoE): Scarce / Moderate avail., or mixed conclusions / Well-supported	Current Impact on Climate Change*	Projected Impact*: *Expected Impact on Climate Change in 2050*
Societal Implications – Consumption Patterns	Animal-based foods, especially ruminant meats, are generally exponentially higher emitters of GHGs than plant-based alternatives. Development and urbanization drive demand for food with high GHG footprint, including animal-derived and highly processed foods. Enteric fermentation by animals is the largest agriculture GHG emitter in Africa (~50%).[1]	The supply chain for processed and meat-based diets are a heavy contributor to GHGs. At the moment the link between consumption patterns, urbanization, and purchasing power is clear. More research is needed to fully understand phenomenon in an African context.	L	Development projections which include increased urbanization and purchasing power will drive greatly increased demand for foods which carry high GHG footprint.
Land Use	Globally, deforestation and land use contribute to near 50% of all agriculture-related GHG emissions – livestock being a major driver. Deforestation decreases global CO_2 absorption capacity and soil disturbances increase atmospheric CO_2. Sub-Saharan Africa alone contributes ~1.4 Gt of indirect GHGs (land change and forestry), ~40% of global totals.[2,3] Soil management is the second largest direct source of GHG emissions from agriculture in Africa.[1]	Scientific research is clear that deforestation, land use, and cultivation techniques contribute significantly to atmospheric GHGs. Tracking of deforestation trends is robust, though future patterns are difficult to anticipate and often contingent on economic trends.	H	Increased population, high-footprint consumption patterns (e.g. meat), and the industrialization of supply chains will dramatically increase land used for agriculture unless policy changes and enforcement occur. Most rapid impact is forecast to occur in forested areas - DRC's primary forests could be completely razed by 2100.[5]
Food Production	On-farm fertilizers (manufacturing and use) are significant contributors to global N_2O – 3x more impactful on global warming then CO_2. On-farm energy use, diesel fuel and hot-houses, will become more significant as supply chains industrialize. In Africa, synthetic fertilizer emissions currently emit ~2.6% of total ag. emissions.[2]	The impact of on-farm fertilization, specifically manufacturing, is well researched. The GHG emission impact of manufacturing (e.g. fertilizer) is larger in certain regions (e.g. China). Impact of on-farm energy use (e.g. greenhouses and diesel) requires more research.	M/L	Demand will increase energy and fertilization need. Technological innovations may mitigate effect to an uncertain degree.
Post-production	Greatest contributor to global post-production emissions is air freight. Overall impact of post-production stage of supply chain is low compared to other stages. Impact will increase with globalization and industrialization in Africa and globally unless mitigated by technological advancements.	Least researched of all stages with transportation, specifically air freight, most measured. Post-production has measurable impact on nonorganic waste (e.g. plastics) that are negatively impacting planetary ecosystems and potentially human health - *not considered under climate change scope*.	L	? — Uncertain technological advancement in Africa make projections difficult. Low footprint and renewable energy will have major impact on this stage of the supply chain. Increased industrialization of food systems will drive evolution as well.
Food loss and waste	Food loss is a significant contributor to GHG emissions. Highest waste / loss occurs at early supply-chain stages in LMICs. Food loss in sub-Saharan Africa is ~23% of total food produced, ~39% of which comes during production and ~37% during handling and storage. Africa currently has a relatively low level of food waste / loss, accounting for ~11% of global waste emission totals.[2,3]	Food loss and waste globally is well researched – less in an African context, as well as GHG emission of decomposing food. Future patterns of waste and loss based on historical global and African development trends.	L	Food waste / loss on African continent may near highest levels on planet (20%). Majority of waste / loss will shift to post-production and consumption stages as supply chains industrialize and consumer purchasing power increases.[4]

- **Explosive population growth and rapid urbanization are expected to accelerate the impact of Africa's food systems on climate change** – a formidable challenge which requires early preventative action
- Given the variable nature of GHG emissions by elements of the supply chain, **the entire supply chain must be considered when evaluating impact of food on climate change**
- **Interventions for climate change mitigation can be at-odds with desire to accelerate economic development -** the impact and tradeoffs on livelihoods and development need consideration when contemplating interventions which aim to mitigate climate impact (e.g. ,reduced meat intake and its impact on livestock farmers)

1. Tongwane and Mokhele. A Review of Greenhouse Gas Emissions from the Agriculture Sector in Africa
2. Climate Watch & FAOStat
3. World Resources Report. Creating a Sustainable Food Future
4. Meybeck et al. Food Security and Nutrition in the Age of Climate Change
5. Tyukavina et al. Congo Basin Forest Loss Dominated by Increasing Smallholder Clearing

APPENDIX E: POTENTIAL PARTNERS FOR OPPORTUNITY AREAS

Opportunity 1, Coalition Building: International Climate, Food Systems, Nutrition Collaboration and Advocacy	
Potential Partners	Role / Description
EAT	Active thought- and organizing leader within nexus of climate and nutrition. Knowledge, credibility, and access may be critical to building knowledge base amongst members and advocacy efforts.
MERCY CORPS	Leading humanitarian and development organization. Climate Resilient Development (CRD) policy integrates climate considerations into all long-term objectives.
CAN	Climate Action Network- network of over 1300 NGOs in 100 countries fighting climate change. Forefront of discussions on projected impact of CC on African continent.
INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE IFPRI	Research agency at forefront of studies focusing on multiple climate and nutrition related topics, specifically the impact of climate change on equity.
THE WORLD BA IBRD • IDA	Increasingly more active in nexus of climate and nutrition. Important contributor globally to pushing topics to the policy forefront. Prospective financing source for coalition and corresponding programs.
ipcc	Leading UN body on climate change. Brings credibility, knowledge, and access to coalition. IPCC studies often comprise leading research on climate change-related matters.

Opportunity 2, Impact Investment: Convergence of Climate, Food Systems & Nutrition	
Potential Partners	Role / Description
GIIN	Leading network, thinker and forum for global impact investing. Large-scale impact financing will be needed for industrial food storage capital projects.
IFC	International financial institution that offers investment, advisory, and asset-management services to encourage private-sector development in less developed countries.
E	Climate and nutrition nexus thought leader and body of leading experts able to provide research and overall knowledge to support investment and divestment decisions.
EQUITY Bank	Large regional East African bank, active in large / capital project development space, specifically agriculture system development
	African Development Bank is a multilateral development finance institution. Potential to invest in public and private capital in projects and programs at heart of current and future African development challenges.

Opportunity 3, National Food Systems Support: Efficiency and Resilience	
Potential Partners	Role / Description
cirad	Agricultural research center specializing in ag. development in sub / tropical regions. Opportunity for them to provide diagnostic services, technical expertise, and training.

THE WORLD BANK IBRD · IDA	Increasingly more active in thinking about the nexus of climate change and nutrition with growth opportunity. Important contributor globally to financing and technical expertise at state level.
BILL & MELINDA GATES foundation	Strong focus in agriculture and (increasing) climate emphasis in Africa. Potential contributor to program financing.
African Union; CEDEAO	Regional bodies with decision-making authority, African standing, and regional expertise. Important stakeholders to support buy-in and program scale-up.
EAT	Active thought and organizing leader around nexus of climate change and nutrition. Most knowledgeable individuals and organizations could provide diagnostic and technical assistance.
unicef	Global leader in thinking about child and adolescent nutrition and the role of food systems in supporting population health. Strong international reputation and ability to convene global experts and partners and also work with governments.

Opportunity 4, Decreasing Impact of Reduced Nutrient Bioavailability

Potential Partners	Role / Description
FAO (FIAT PANIS)	FAO is a critical global actor in the agriculture space with a wide range of involvement in agriculture. Core strategic initiatives include, among other topics, elimination of food insecurity and malnutrition, improving sustainability of agriculture, and enabling inclusive and efficient
gain Global Alliance for Improved Nutrition	Thought leader on urban food systems, incentivizing consumption of nutritious foods, reducing food loss, and improving diets. Has co-led several global convenings on biofortification and has experience in policy change at country level for food fortification purposes.
HarvestPlus Better Crops · Better Nutrition	HarvestPlus develops and promotes new varieties of staple foods – expertise in biofortification. Member of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH). Current target countries include Rwanda, Uganda, Nigeria, Zambia, and DRC within Sub-Saharan
BILL & MELINDA GATES foundation	BMGF has put significant resources into its agriculture program, with emphasis on crop breeding to improve bioavailability of nutrients, resist lethal crop diseases, etc. Potential partnership opportunity.

Opportunity 5, Incentivizing Low Footprint, Resilient and Adaptive Agro-Practices for Smallholder Farmers

Potential Partners	Role / Description
FAO (FIAT PANIS)	UN agency active in developing programs to defeat hunger and improved nutrition. Source of overall knowledge and information on modernizing and improving agriculture, forestry and fisheries practices.
ACTION AGAINST HUNGER	Global humanitarian organization active in food security and malnutrition challenges and implementation of food security programs. Increasingly concerned with creating sustainable food system solutions.
ILRI International Livestock Research Institute Better lives through livestock	Livestock-focused research institute located in East Africa. Researches smallholder and pastoral productivity topics, specifically on enhancing development of new knowledge and livestock-related technology.

FCRN	Thought leader in food and food system sustainability. Increasingly detailed body of research on-farm GHG emissions.
William + Flora Hewlett Foundation	Large funder of climate change-related projects specifically on African continent. Interest in behavior change programming.
Opportunity 6, Urban-Focused Behavior Change: Sustainable Consumption Patterns	
Potential Partners	Role / Description
EAT	EAT-Lancet Commission is clear thought-leader on sustainable diets, with proposal of planetary health diet. Continued opportunity for thought leadership and collaboration around buy-in for planetary health diet approach.
unicef	Thought leader around children and adolescent nutrition and the role of food systems in supporting healthy populations. Strong reputation with country governments and effective convening power.
gain Global Alliance for Improved Nutrition	Thought leader on urban food systems, incentivizing consumption of nutritious foods, reducing food loss, and improving diets.
The World Bank IBRD • IDA	Major source of financing with strong understanding of food systems and the effect on malnutrition, with increasing focus around sustainable diets.
World Health Organization	Global leader in establishing recommendations around healthy diets and nutrition, with technical expertise on data and measurement as well as development of regulatory frameworks
Opportunity 7, Innovation: Sustainable, Scalable Storage and Transport Solutions	
Potential Partners	Role / Description
FAO Fiat Panis	UN body with technical expertise with that has focused resources on efforts on food storage, and food waste and loss issues in Sub-Saharan Africa.
Rabobank	Cooperative banking group that focuses sustainability, international business, and rural activities, specifically the food and agriculture sector. Previous investments in food storage.
IFC	Development funding mechanism for the World Bank. Previously invested in food security issues including food storage. Potential funder of large-scale financing needed for capital projects.
African Union	Regional body that has invested resources in food storage and infrastructure. Large scale and innovate technology would benefit from regional buy-in.
GIIN	Leading network and forum for global impact investing. Large-scale impact financing will be needed for industrial food storage capital projects.

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