



Adapting to climate change to sustain food security

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Climate change poses considerable challenges to food security. Adapting food systems both to enhance food security for the poor and vulnerable and to prevent future negative impacts from climate change will require attention to more than just agricultural production. This article surveys the multiple components of food security, particularly those relating to access and utilization, which are threatened by the complex responses of food systems to the impacts of climate change. Food security can only be ensured and enhanced with a suite of interventions across activities, ranging from production to distribution and allocation. Although many studies have demonstrated the importance of policy and institutional interventions for ensuring food security after a shock, the climate change impacts and adaptation community have been slow to pick up on these lessons. This article pulls together lessons from the literature on the type of institutional interventions that could be strengthened to enable adaptation in the food system to buffer against climate change at multiple levels, from the local to the global level. © 2010 John Wiley & Sons, Ltd. *WIREs Clim Change* 2010 1 525–540

The links between food security and climate change are complex, because food security involves food and its production, trade and nutrition as well as how people and nations maintain access to food over time in the face of multiple stresses. Although the likely significant impacts of climate change on food production have recently received a lot of attention, the links between climate change and the other components of food security including access, availability, stability, and utilization have not yet been well researched.^{1–3} This is likely to result in underestimating the impacts of climate change on food security, for example, through factors such as price increases⁴ and malnutrition.⁵ It also ignores a considerable body of research explaining vulnerability to climate change as embedded in social, economic, and political processes.^{6–8} In a similar vein, response or adaptation to climate change impacts in the food system has focused on adaptive actions related to agriculture, mainly adoption of improved technologies to accommodate the effects of changes in temperature, precipitation patterns, and length of

growing season.^{2,9,10} Although production impacts are critical, this article argues that the policies and institutions underpinning adaptation to climate change across the spectrum of food security issues need to be prioritized. A broad range of actions is necessary for adaptation responses to be stepped up to avoid increasing food insecurity, particularly for the most vulnerable.

The Food and Agriculture Organization (FAO) of the United Nations (UN) defined *food security* at the World Food Summit in 1996 as ‘when all people, at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life’.¹¹ The components of food security include adequate food production, but they also touch on larger socioeconomic issues surrounding food availability, or the ability to effectively translate hunger into an economic demand for food and to have access to nutritious, safe and culturally preferred foods. So too, the stability of food systems is important on both the supply side in terms of production and the demand side in terms of being able to trade for food.¹² Thirty years of research and interventions to protect or enhance food security (i.e., since Sen’s writings¹³) have demonstrated that the right to food embodied in the FAO food security definition rests in the performance of institutions such as markets,

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government programs, bilateral and international trade agreements, and donor obligations.^{14,15} Political processes and power relations among and within countries are a key determinant of the effectiveness of these institutions.¹⁶

The challenge of mitigating and adapting to climate change, as well as achieving food security, is embedded within a suite of issues related to development pathways and hence choices of decision makers at multiple levels. Meeting both the climate change and food security challenges requires progress in poverty eradication, reduced global inequality, assured resource rights, the promotion of stable livelihoods, and gender equity. These challenges need to be addressed at the same time as decoupling development from fossil fuel and energy intensive responses—i.e., moving to low carbon development pathways.^{17,18} The problems of global disparity and achieving food security in a highly variable climatic context are connected and cannot be solved separately. Currently, 20% of the population enjoys 85% of the world's wealth, and the poorest 20% live on 1% of global income.¹⁹ This meager percentage of global income has to contribute to the poorest's access to food, which is often compromised when resources are lacking (or income is chronically insecure) and complicated by economic and political histories.²⁰ Food insecurity is therefore concentrated more in sub-Saharan Africa, where 30% of the population is undernourished and in South Asia, where 23% is undernourished. It is also more prevalent at a local level in places with high poverty or conflicts, such as Haiti and Afghanistan.²¹

The challenges of achieving food security are closely intertwined with the challenges of human development and economic growth that include chronic poverty, poor health, inadequate distribution mechanisms, inadequate and distorted markets, lack of nutritious and culturally preferred foods, and production constraints. These challenges are most pronounced in developing countries and so this article focuses on food security in the Global South, paying particular attention to sub-Saharan Africa (while recognizing that this food security very much depends upon policies and markets in Europe and North America). Despite the challenges faced, there are numerous opportunities to adjust elements of the food system to cope better with current and future climate variability, although these opportunities often face political, cultural, technical, and institutional barriers with deep historical roots.

This article starts by defining food security and then addresses how it is and can be impacted by climate change. This sets the context for exploring the types of institutional support needed for sustainable

adaptation responses in food systems at multiple scales by exploring local, national, and international level options.²² The article ends by focusing on some of the challenges of strengthening institutional support for adaptation to climate change in the food system.

It is also becoming more apparent that the food system is a significant contributor to the problem of climate change and that reductions need to be made in emissions related to soil use, land clearing for agriculture, animal feed, and transport of food among others.^{23,24} This is a large area for discussion, particularly as consumers in developing countries change their food preferences, but the mitigation issues will not be addressed in this article. However, we do acknowledge that adaptation options to enhance food security should not exacerbate climate change.

DEFINING FOOD SYSTEMS AND FOOD SECURITY

The complexity of food systems and the link to food security are perhaps best described by Gregory et al.³ (p. 2139) as follows: 'Dynamic interactions between and within the bio-geophysical and human environments lead to the production, processing, preparation and consumption of food, resulting in food systems that underpin food security'. These food system activities contribute to four food security outcomes, namely availability, accessibility, stability, and utilization of food. These components are outlined below.

Food availability depends on the production, distribution, and exchange of food.^{3,12} Included here is the production of adequate crop, livestock, and fisheries as well as the collection of wild foods and resources for migratory and indigenous communities. While the components of food availability are contextual, current thinking suggests that domestic production, reliable import capacity, presence of food stocks, availability of social protection measures, decent transportation infrastructure and, when necessary, access to food aid are the major elements of securing food supply.²⁵

Food accessibility refers to the affordability, allocation mechanisms, and preferences that enable people to effectively translate their hunger into demand that is satisfied. Poverty and vulnerability play a central role in food accessibility, as this component is centrally concerned with the purchasing power of households and individuals and the social dynamics governing access.²⁶ Accompanying growth in urban areas has been a decline in the emphasis of production and greater emphasis on the incomes and social networks that are used in accessing food.²⁷ National economic security is also a factor, as it is reflected in

the presence of adequate food market infrastructure.²⁸ The food distribution and the location where food arrives for purchase also relate to food accessibility.²⁵

Food stability involves the presence of continuous food supply and access to food. This recognizes that certain shocks, especially climatic or conflict related, can contribute to transitory food insecurity or exacerbate chronic food insecurity.²⁹ Factors affecting food stability include seasonal variation in food supply or income that can be impacted by climate variability, price fluctuations, and political and economic factors. Health factors, such as HIV and AIDS, also affect the stability of the labor force and therefore food security outcomes.

Finally, *food utilization* refers to how a person is able to utilize food and nutrients (depending on age, health, and disease) as well as the quality of food intake.^{30,31} In countries plagued by poor health, sanitation, and inadequate safety standards, chronic illness may compromise a person’s digestion and undermine nutrient intake. Prevalence of diseases such as malaria and cholera compound food insecurity via nutritional impacts,^{32,33} and chronic diarrhea is well-known to undermine nutritional status and is a major contributor to malnutrition in children under 5 years of age. For example, HIV and AIDS research has shown that HIV positive people require more calories and protein to sustain them and infections can worsen with poor nutrition.³⁴ Food utilization also relates to the ‘social value’ of food in terms of kinship, traditions such as Sunday dinners, Sabbath meals, or the breaking of fast during Ramadan.²⁵

In addition to recognizing the different outcomes of food security, it is important to recognize that food security can be viewed at different levels. Table 1 illustrates the type of processes that can impact food

security outcomes at the local level, where people take their food production and consumption decisions; at the provincial and national level, where many policies are set; and at the international level, where many commodities are traded, global agreements are disputed and multinational actors wield influence, highlighting the need to tackle food insecurity at multiple levels. It is clear that there are linkages between these processes that need to be understood as well. The examples presented here are not exhaustive, but illustrate the mixture of processes affecting food security, which can be disaggregated by institutional or spatial level for closer analysis. Some of these processes might lead to greater food security for some people, while the same process might undermine food security for others.

Although food security is most acutely experienced at the local level, it is a policy concern in almost every country, linked to national economic goals, social welfare, and poverty alleviation. However, many analysts argue that alleviating food security requires an ‘anti-hunger’ social contract that is ultimately a government obligation, embedded in legislation.³⁶ This is the logic behind the ‘Right to Food’ initiatives, which are spearheaded by a UN special rapporteur on the right to food, who works under the auspices of the UN Human Rights Council (<http://www.srfood.org/>).

IMPACTS OF CLIMATE CHANGE ON FOOD SECURITY

In order to understand the impacts of climate change on food security it is necessary to understand the linkages between climate change, food security, and its drivers as shown in Figure 1. The drivers, that

TABLE 1 | Examples of the Type of Processes at Different Levels that Can Impact Food Security

Local e.g., household	National/Provincial	International
Loss of customary rights and change to modern ‘tenure’ systems	Urbanization	Globalization leading to ‘teleconnected’ commodity markets
Loss of access to communal resources	Changing legislation and tenure systems	Trade policy reform (or failure)
Increasing need for cash	Population growth	Demand for reduced GHG emissions
Monetization of resources and services/increasing health and education costs	Increasing penetration of global markets/ reorientation of production away from local circulation and reciprocity	Global disease epidemics
Deagrarianization (diversification out of agricultural-based livelihoods)	Declining biodiversity and forests and expansion of agriculture	Environmental change processes (including deteriorating water quality, soil degradation, changes in climate variability, etc.)
Privatization of land and resources	Increasing HIV and AIDS prevalence	

Source: Adapted from Ref 35.



FIGURE 1 | Linkages between climate change and food security.

can all be impacted by a change in climate variables in some way, can include the biophysical system, its cycles and its management as well as socio-economic, demographic, cultural and political variables that can be directly or indirectly impacted by climate. Changes in climate variables might also impact on science and technology demands and outcomes that in turn may impact on food security outcomes. These drivers impact the four components of food security. But there are also feedbacks from the outcomes of food security to the drivers. For example, if there is reduced precipitation and this is not addressed by agricultural management strategies, crop yields will decline and reduce food availability. This might then impact on the price of the crop. This economic driver might then effect accessibility of food.

To date, the focus on the impacts of climate change on food security has been on availability and production in particular. This is the area where the impacts of climate change are likely to be felt the most and the soonest. A chapter of the IPCC, devoted to food, fibre, and forest products makes a number of important points linking climate change and food production² (p. 8). This has since been updated with a number of other studies^{10,37} that increase the level of concern, particularly as the likelihood of global warming beyond 2° by the latter part of this century is much greater than previously thought.^{38,39} The spatial heterogeneity of impacts on productivity is important, with concerns that at low latitudes, crop productivity is projected to decrease for even small local temperature increases (1–2°C),⁴⁰ and increases in the frequency of droughts and floods are projected to affect local production negatively, especially in subsistence sectors at low latitudes. Although increases in CO₂ can increase crop yields, this response decreases after the optimal temperature is exceeded and is less in open air than in chamber experiments, resulting in questions about the long-term benefit of CO₂ fertilization, given expected temperature increases and reduced soil moisture availability.^{41–43} Regional changes in the distribution and production of particular fish species are expected due to continued warming, with adverse effects projected for aquaculture and fisheries.⁴⁴ Climate change impacts on food production will increase

regional disparities and require significant livelihood shifts.⁴⁵ These climatic impacts will increase the current stress production systems already faced due to degradation of key ecosystem services such as nutrient balance, water quality, and biodiversity.⁴⁶

An important argument of this article, however, is that limited attention has been paid to the impacts on the other critical dimensions of food security: food accessibility, utilization, and the stability of food systems.³⁷ By not exploring the range of primary and secondary impacts, adaptation and mitigation options might overlook important opportunities for changes in food systems on the one side and unintended consequences of food security responses on the other side. Such a narrow consideration of food security ignores many years of research documenting the multi-faceted nature of food security, in particular its links to poverty, inequality, gender, and demographic trends including health.

Accessibility to food can be impacted by extreme events including droughts and floods.⁴⁷ If infrastructure is damaged or destroyed, either through heat stress on roads or through increased frequency of flood events that destroy infrastructure, distribution of food could be impacted. These factors could also impact people's access to markets to sell or purchase food.

Access is particularly important in urban areas experiencing rapid urbanization.²⁷ Some urban settlements may have access to urban food production, though stress on water resources and land could reduce yields and price. However, the majority of food needs to be transported in from rural areas. Allocation of food to different areas can therefore impact its availability and hence accessibility.²⁵ Most frequently, food needs to be purchased in urban areas and often in rural areas as well. Food prices are therefore a direct determinant of affordability and hence access. If climate variability impacts on job opportunities, such as reduced seasonal work during droughts, it can also impact on the ability to purchase food.

Food stability can be affected if food prices are not constant. The Niger food security crisis of 2005 saw the impact of local level production failures from drought exacerbated by high demand from Nigeria coupled with long-term poverty.⁴⁸ The

change in seasonality attributed to climate change can lead to certain food products being more scarce at certain times of the year, a phenomenon that FewNet, the USAID-funded early warning system, regularly monitors (e.g., West Africa Food Security Alert November 25, 2009). These seasonal variations in food supply, in addition to vulnerabilities to flooding and fire, can overlay to make livelihoods more vulnerable at certain times of the year.

The food price crisis of 2008 illustrated how climatic shocks in one location combined with other types of food system shocks trigger a widespread and prolonged commodity price rise and food instability. Protracted drought in Australia affected global rice and wheat supply combined with stagnant production in China, the EU, India, and the United States. Subsidies for ethanol in the US spiked prices of maize. Global food reserves were very low.⁴⁹ National reactions to these high prices were often constrained to domestic price controls and export bans, which prolonged the high prices.⁵⁰ At household and community levels, poor consumers lacked the money to afford staple foods, leading to protests in a number of places and a sharp increase in the number of undernourished; the subsequent economic crisis did nothing to alleviate the situation. The poorer a household is, the larger the percentage of its income it spends on food.

The utilization of food can be impacted by climate changes. As the type of seed cultivars and varieties that can be grown change to be more appropriately suited to the climate, so people may change what they eat. For example, in southern Africa maize is a staple crop. However, sorghum fares better if there is less rainfall. Yet, many people prefer to eat maize than sorghum and so continue to plant maize in years of low rainfall despite poor yields. Jones and Thornton⁵¹ suggest that maize production is likely to be reduced overall by 10% by 2055, in Latin America and Africa, equivalent to losses of \$2 billion per year, having significant implications for food security. If other produce that is easier to grow in a different climate is more widely available and/or cheaper, people may change their food basket or it could result in people spending a greater percentage of their income on food if prices increase. On top of this, people with certain diseases require improved nutrients to help fight disease, such as in the case of HIV/AIDS. Changing food security linked to climate and environmental change can therefore impact nutrition security of ill household members.^{34,52}

Wild foods, that many poor households rely on, particularly when there are few other food sources, are expected to change in their distribution. Levin and Pershing⁵³ undertook a study in sub-Saharan Africa

of 5000 plants species, of which they predicted that 81–97% of the plant species' suitable habitats will decrease in size or shift due to climate change and by 2085, between 25 and 42% of the species' habitats are expected to be lost altogether. The implications of these changes are particularly great among communities that use plants as food sources or for plant-based medicines. This example also illustrates the importance of maintaining multiple ecosystem services such as biodiversity, in the face of a changing climate.

Utilization of food, dependent on the type and quantity of food available, will have significant consequences for nutrition. The IPCC Fourth Assessment Report Chapter on Health concluded that increased malnutrition was a highly likely and significant outcome of climate change for human health.⁵⁴ Compounding this are the impacts of climate change on other determinants of health, particularly disease distribution and the availability of safe, clean water for drinking and preparing food. As a recent survey of the health consequences of climate change demonstrates, vector-borne diseases such as malaria are likely to spread to new areas as the world warms and water-borne diseases like cholera or dengue may increase as flood events become more frequent. Both increased floods and more frequent droughts increase the risk of contaminated water, a key factor affecting food safety.³³

In addition to climate change impacts on different outcomes of food security, women and children are likely to be disproportionately impacted by climate change as they are already vulnerable to food insecurity within households. Children are vulnerable because of their susceptibility to disease and poor nutrition. Women, who play a key role in ensuring household nutrition, may be at a greater risk of undernutrition often because of intra-household allocation patterns and social norms.^{55,56} An emerging area of research is the gendered nature of vulnerability to climate change⁵⁷; as climate change affects labor and income opportunities, and availability of natural resources such as land and water, the outcomes for men and women will differ.

RESPONDING TO THE IMPACTS OF CLIMATE CHANGE ON FOOD SECURITY

The impacts of climate change on the food system are emerging at a range of scales and across sectors. Food security will continue to be affected at an increasing rate in the future. It is therefore necessary to understand how best the food system can adapt to climate change.

It should not be assumed that we can predict the local impacts of future climates on all aspects of the food system. Rather, we have scenarios that climate scientists have provided that are downscaled to the local level and give an indication of future changes from 2046 to 2100.⁵⁸ Although there is uncertainty associated with these scenarios, there is enough information to understand expected long-term trends, although the information needs to be presented in a way the users can understand and apply in their evaluation of adaptation options.⁵⁹ When developing adaptation strategies to respond either to current climate variability or to long-term change, there should be a focus on ensuring robustness against a wide variety of future climate conditions, with successful adaptations remaining useful despite uncertainties in the climate projections.^{60–62}

Climate change adaptation is more than a set of projects that help to deal with climate variability, change, and potential impacts. Rather, adaptation to climate change is a process of socio-institutional learning that recognizes often competing stakeholder goals and processes and uses information at various levels and in many ways. The importance of this has been clearly shown through adaptive management approaches researched in the water sector.^{63,64} Given this, it is necessary to explore the conditions for enabling learning and support for processes that increase robustness against a range of climate futures rather than discrete activities. Although this encompasses many elements, this article focuses on policies and institutions that might enable processes of adaptation at the local, national, and international levels.

In order to suggest policy and institutional responses to supporting adaptation, it is important to reflect on lessons from 30 years of food security interventions and analysis that highlight the importance of access and utilization as well as availability. Many of these lessons stress the importance of institutional and policy responses. Key lessons about responding to food insecurity and managing transitions or innovations in cropping systems include:

- Chronic poverty and lack of government funds undermine coping and adaptive capacity to reduce food insecurity²⁶; one or two good years are often not enough for farming households to recover from repeated crop losses or other shocks to their income and assets. Social protection programs hold considerable promise but require national and international policy support.^{65,66}
- Functioning markets are critical for food security and agricultural growth; often poverty and food insecurity arise because prices for inputs or food are too high, while prices for local production are too low. However, it is extremely difficult to get domestic market interventions ‘right’,²⁸ and sometimes such interventions can exacerbate food insecurity.⁶⁷
- Farmer attitudes toward managing risks are varied and context specific⁶⁸; however, they need support (e.g., from extension and credit services) if risks are too big or unknown.⁶⁹
- Reforming or improving the institutions responsible for managing food and agricultural systems is both critical and extremely challenging. In addition to the market, extension, credit, and social policy issues, basic food security planning, and relief mechanisms are also important.
 - a. Food security and vulnerability assessments rely upon holistic, integrated frameworks and reliable, up to date monitoring information.⁷⁰
 - b. International donors wield considerable influence over food relief operations; however, in recent years they have faced difficulty meeting annual appeals for food aid to ‘chronically’ food-insecure countries and regions as highlighted in IRIN and WFP bulletins.

Another lesson pertains to the highly contested nature of many of the ‘solutions’ proposed to enhance food security and upon which adaptation measures will build. In particular, the move toward liberalized commodity markets in many developing countries since the 1980s is viewed by many as a key step toward enhancing food security,^{28,71} yet others criticize this as opening up smallholders in particular to greater risk and more food insecurity.^{7,72} Food aid continues in spite of 50 years of lessons about its inefficiencies and poor governance.⁷³ Food is a ‘human right’ protected in formal language by the UN; the growing food sovereignty movement would expand this to trade and choice over agricultural production.^{74,75} Thus adaptation in food systems is fundamentally a political issue.

Policy and institutional responses to supporting adaptation can be viewed at different levels of governance, from local to international. Although there is much in the literature related to various aspects of food security and related policy, we have focused on those that have linked this to climate change, as few authors writing about food security have specifically thought about how climate change will increase the need for certain types of interventions, albeit with some modifications. A selection of these responses (at each level) is discussed, and gaps in the literature identified.

TABLE 2 | Institutions that Could Support Adaptation to Enhance Food Security Under Climate Change at the Local Level

Local
Food Availability <p>Production</p> <ul style="list-style-type: none"> • Improve storage facilities and ability to change annual crop selection in response to El Nino projections⁷⁶ • Improve access to climate information relevant to farming^{77,78} • Access to formal credit for farmers⁷⁷ • Explore potential evaluation and readoption of traditional land management systems where appropriate⁶⁰ • Secure land rights and tenure⁷⁷ • Reduce production risk through index-based crop insurance^{79–81} <p>Distribution</p> <ul style="list-style-type: none"> • Improve market access for small-scale farmers⁷⁷
Food Access <ul style="list-style-type: none"> • Support for transitioning from food production based livelihood to alternative livelihood⁸² • Ensuring people's ability to pay for food is necessary when their role in the food system shifts from producing to purchasing food⁸²
Food Utilization <ul style="list-style-type: none"> • Support for dietary diversity related to changing food consumption patterns⁸⁴ • Support for health and viability of some rural communities who have suffered from transition from local foods to commercial foods⁸³ • Ensure food options remain relevant to local cultural, psychological, and biomedical needs⁸³
Cross-cutting <ul style="list-style-type: none"> • Prioritize adaptation responses that are useful regardless of the uncertainties linked to climate change projections⁶⁰ • Support education, public awareness and environmental advocacy responses that can help people recognize links among social, environmental and economic components of the system⁶⁰

Local Institutional Support for Adaptation to Food Security

Table 2 summarizes the literature relating to institutions and policies that could support adaptation to enhance food security under climate change at the local level. It is clear from this table that although research is starting to explore the institutions necessary for adaptation across the food system, there are a number of areas that have not been well explored.

There is growing understanding of opportunities for adaptation related to production and much of this is relevant at the local level, often related to smallholder agriculture within developing countries. Although, Morton⁸⁵ cautions that it is often hard to model the impact of climate change on smallholder production because of a lack of standardized data and the complexity of diverse livelihoods. However, suggestions for the necessary policy and institutions to support adaptation to climate change range from helping to ensure that farmers have access to climate information about the season⁷⁷ to supporting farmers who might want to change their annual crops in relation to expected changes in the climate.⁷⁶ There has been growing support for microinsurance to manage risks, particularly using index-based crop

insurance for smallholder farmers, where the payout is based on timing and quality of rainfall rather than on actual yields.^{79–81} There has also been a call for security of assets including better access to formal credit for farmers and secure land rights and tenure to encourage agricultural investment.⁷⁷

Lioubimtseva and Henebry⁶⁰ focus on arid Central Asia, providing examples of food production responses to climate change that can lead to negative impacts on humans and ecosystems. They suggest that adaptation responses should be prioritized if they are useful regardless of the uncertainties linked to climate change projections.⁶⁰ An example they propose is that if climate-appropriate fruits and vegetables are grown, including legumes, while practising conservation tillage, food security is likely to be improved as well as improving soil through nitrogen fixation, decreasing water use, and reducing net carbon flux to the atmosphere. They suggest that this requires education, public awareness, and environmental advocacy in order to help people recognize these positive links among social, environmental, and economic components of the system.

There has been a limited discussion on how to support dissemination and exchange of food, although Bryan et al.⁷⁷ suggest that improved market access

will support small-scale farmers' adaptation to climate change in Ethiopia and South Africa.

Utilization of food under climate change is explored by Loring and Gerlach⁸³ through the nexus of food, culture, and human health in Alaska. They suggest that it is necessary to assess the health implications related to a change in diet from locally produced food to commercially available foods, because of stresses on local food due to global environmental change. They suggest that food options should remain relevant to local cultural, psychological, and biomedical needs.⁸³

Barnett's⁸⁶ assessment of food security under climate change for Pacific Islanders suggests that although Islanders have diverse livelihoods that assure a degree of food security, fisheries and food production in the region are likely to be negatively impacted by climate change, compromising local food availability, access, and utilization. Ford⁸⁷ illustrates how the Inuit's food security is vulnerable to climate change and suggests that long-term monitoring of how the food system responds to climatic and non-climatic stresses is necessary. This research suggests that different communities around the world are likely to be impacted by shifts in the climate in different ways but it appears that support for local communities needs to focus on changes in diet and health and support those shifting from production to purchase in many cases, while recognizing the range of challenges associated with this.⁸⁴

Although livelihood diversification often needs to be supported through national policies, it is clear that these decisions are taken at the local level. A strategy on which poor rural households already rely to smooth both income and food consumption in the face of shocks is off-farm or non-farm livelihood diversification.^{65,88–90} This includes seasonal or longer term migration, petty trade in charcoal or local crafts or small business opportunities all of which provide cash to purchase food in the lean seasons or after a drought. With climate change increasing the seasonal variability and hence volatility of food prices as well as production shortfalls, households can be expected to diversify sources of income, as well as adjust some of their current livelihood strategies.⁴⁵ For this, they will need support from district, state and national bodies to help with market access, to provide safety nets, and to support educational and training opportunities.

Research is limited in exploring the links between food security, climate change, and urban dwellers. Given that more than half the world's population lives (and eats) in urban areas, this should be a priority. It is likely that this focus would help to

understand how access to food at the local level might be better supported under climate change.

National Institutional Support for Adaptation to Food Security

National governments have various policy instruments available to assist populations to be food secure, including distributing food aid, controlling domestic prices, implementing safety nets, and promoting active market participation within country but also regionally,^{65,71,91,92} as summarized in Table 3. Most economic analyses favor market solutions, particularly better regional trade and promotion of private sector participation in food importing. These necessarily will require improved transportation infrastructure. Again the experiences of 2008 illustrated how many countries reverted to price controls and export barriers in the face of political pressure.⁵⁰ Although such interventions are widely viewed as constraining production incentives, it is unclear what other options governments have. The role of national governments in ensuring food security is a hugely contentious issue.^{50,67}

Although food security is not a 'rural' issue, it is often associated with rural development because of the role of agriculture. It is important that the interconnectedness of rural and urban areas is recognized when responding to food security. Many policies have been built on 'presumptions of separateness or on traditional notions of urban and rural livelihoods'⁹⁸ (p. 2). This limits the type of integrated response that is likely to have the most impact, and could indeed increase tensions between the needs of urban and rural communities. Responses including information technology, better infrastructure, and good education can help to strengthen connections between more urban and rural complements. It is also important to recognize that even with high migration from rural to urban areas, many people remain in rural areas and may not be involved in agriculture. It is imperative to support food security for rural populations beyond promoting agriculture. This could be supported by policies that focus on 'systems' rather than 'sectors'.⁹⁹

Safety nets, such as food or cash-based transfers,³⁰ are intended to protect households from experiencing food insecurity in situations of price volatility, chronic poverty, or repeated production failures. They have become popular with donors and food security analysts as they are less market distorting than price controls, and they ideally can be targeted at the most vulnerable or poorest households. Countries including South Africa, Malawi, Bangladesh, India, and Ethiopia have implemented

TABLE 3 | Institutions and Policies that Could Support Adaptation to Enhance Food Security Under Climate Change at the National Level

National/Provincial
Food Availability
Production
• Policies for marine resource management agencies with explicit decision rules that specify the actions to be taken as soon as there are indications that a regime shift has occurred ⁹³
• Improved coverage of extension services ^{60,77}
• Support for agronomists to work across sectors of the food industry to develop new research approaches to better link research on food production to food security issues likely to be policy relevant ⁹⁴
• Support agricultural research that goes beyond plot scale to larger temporal and spatial scales ⁹⁴
Distribution
• Prepare for potential shortages of strategic staple grain reserve based on seasonal projections ⁷⁶
Food Access
• Access to food aid removes consumption pressure and so enables poor farmers to engage in adaptation ^{77,95}
• Policies for reducing price variability and volatility ⁹⁶
• Understand the role of biofuels within countries to ensure they do not negatively impact staple food markets and required nutrients ⁹⁷
• Support for those without skills or capacity needed to migrate, yet can no longer engage in their previous livelihoods because of environmental change ⁶⁰
Food Utilization
• Integration of food as a matter of human health with regionally nuanced outcomes ⁸³
Cross-cutting
• Expand food security policies beyond agronomic perspectives ⁹⁴

government safety net programs, for over a decade in some cases, and are gaining emphasis in relation to the growing social protection agenda.

The more ambitious programs in India and Ethiopia are trying to build household and community assets. However these programs are expensive to maintain and difficult to design such that they target the right households and have long-term impacts on poverty and vulnerability reduction.^{100,101} In terms of the challenges that climate change will exacerbate, current social protection programs are not designed to manage increased seasonal shocks.¹⁰²

An important consideration in supporting adaptation in developing country contexts is the duality of the food sector that includes both strong formal components and many informal components including small manufacturing enterprises, small traders, and service providers as well as legal and illegal activities related to food.¹⁰³ The informal components are characterized by very low capital investment and strong inter-linkages between production and consumption, as the informal food trade can be both producer and consumer of food products and services. Innovation is often more social than technical. Because of the relations it often maintains with the rural sector, urban informal food trade can provide raw materials at lower cost. The social networks can also provide low

cost or 'free' labor in the form of apprentice help or family members who are fed but receive no or little pay. Many of these characteristics show the adaptive nature of how a large section of the population has responded to the challenges they experience with the formal sector. It is important to explore the possibility of dovetailing the informal food sector with the formal food sector to satisfy a differing demand and customer base that tends to meet the needs of households and micro-enterprises with varying and limited purchasing power. Policies and institutions are needed to protect and support the informal sector as a key component of adaptive capacity.

Providing the opportunity for different national stakeholders with different aims to build an integrated vision and response aimed at ensuring food security in the face of climate change is critical. Platforms or communal learning spaces enable communication between climate scientists, adaptation experts, and those impacted by climate change.¹⁰⁴ The importance of multi-stakeholder platforms lies in going beyond a focus on activities that need to change and toward social and institutional processes that reduce vulnerability.¹⁰⁵ This requires more than technical projects that are 'delivered' at the local scale, and which tend to be based on a 'predict and provide' approach to adaptation, to processes that

support institutional change and learning and reduce vulnerability to a wide range of difficult to predict climate change impacts.

International Institutional Support for Adaptation to Food Security

Managing the consequences of climate change for food security at the international level of governance and policy is perhaps the most challenging part, although research on this is limited (see Table 4). Both national and household level food security are strongly influenced by international trade and markets, donor aid agreements, and global grain stocks. Post 2008, we have seen unprecedented attention to international action and efforts at coordination, beginning with the formation of high-level task force led by FAO in the summer of 2008 and culminating in the World Food Summit in 2009. Not surprisingly, the first and most often repeated policy recommendation is for increased investment in agriculture, from research to technological development.^{30,49} In addition, the inability of the World Food Programme to meet all its food aid needs in 2008, largely due to the high prices of staple grains, has called attention to the need for regulation to prevent price spikes, in particular those due to speculation, and to prevent global grain reserves from declining to the low levels of 2007. IFPRI has spearheaded a proposal to make the World Food Programme a regulatory body in charge of both physical grain reserves and a virtual reserve that would prevent speculation from driving up international prices.^{106,107} They argue that such measures are needed to convince national governments to retain their trust in international markets, rather than revert to domestic price controls and self-sufficient policies.¹⁰⁸ Disappointingly, there

has been little action on resolving the Doha Round of negotiations for the WTO or revising EU and US subsidies and targets for biofuel production.

International cooperation is critical to many of the options for supporting adaptation. This includes improved international action beyond increased investment in agricultural research and extension services in order to deliver on the promise of technological advances. Improved monitoring of human health impacts of environmental change and food security requires better research coordination among the health and agriculture communities.¹⁰⁹ Monitoring marine ecosystems and recognizing their importance for food security involves increased attention to fishing livelihoods and international agreements to protect fish stocks.¹¹⁰ Improving systems of cooperation for conservation of genetic resources is a governance challenge recognized by many UN and CGIAR organizations, but also a highly contested area. Again, research at this level is limited.

CHALLENGES FOR ADAPTING TO CLIMATE CHANGE

Each of the levels of potential adaptation options described above comes with a relevant set of very real policy and institutional constraints, as illustrated in the discussion. However, it is important to consider the connections among these levels of decision making and policy implementation. The challenges of adapting food systems to ensure food security in the face of climate change must be addressed with an eye to integrating responses across these levels. Often international and national level policies will support local change. For example, water stress may be amplified

TABLE 4 | Institutions and Policies that Could Support Adaptation to Enhance Food Security Under Climate Change at the Local Level

International
Food Availability
<ul style="list-style-type: none"> • Support for research and monitoring of marine ecosystems⁹³ • International cooperation on conservation and use of crop genetic diversity¹¹¹ • Accelerate investment in innovations for rain-fed agriculture likely to have a high probability of economic success and adoption¹¹² • Set up an internationally governed set of physical and virtual food reserves to support food affordability^{106,107}
Food Utilization
<ul style="list-style-type: none"> • Understand linkages between increased vector control measures and direct and indirect impact on food system and human health¹⁰⁹
Cross-cutting
<ul style="list-style-type: none"> • Focus on meeting development goals that also reduce vulnerability to climate change as well as increase capability to address them¹¹³ • Support scenario development to explore the wider issues that underpin food security and the environmental consequences of different adaptation options⁹⁶ • Explore and support improved governance of food systems⁹⁶

by climate change in some places. The increased use of rainwater harvesting could make a small impact on livelihoods of those living in areas without good access to piped water, by impacting on people's health and increasing the ability to grow vegetables and to have water available for household activities including cooking and cleaning. National policies subsidizing rainwater tanks would encourage households directly and could reduce demand on water sources used by multiple users, thereby supporting adaptation.

Improved short- and long-term climate information can give greater choice on how to manage climate-related risks. Improvements in early warning systems can help reduce the impacts of extreme events if people are able to prepare. For example, information about oncoming drought might provide agricultural responses where crop types are changed or livestock sold as well as food storage responses. On a longer timescale, climate change scenarios can be used to assess the timing and level of adaptation needed. For example, scenarios could inform a water department's plan for future water supply. Unfortunately users often battle to access and interpret climate change information, and downscaled scenarios have been limited in their distribution.⁵⁹ It is also challenging to integrate climate change scenarios on the timescale of 2045 to 2046, when assessing responses that need to be implemented this year.

As seen in the aftermath of 2008 and the limited outcomes of the World Food Summit in November 2009, it is immensely difficult to get international responses coordinated, whether it is food aid or policy reform. The mistrust between countries which constrains the reform of the WTO and the completion of the Doha Round of trade talks is another issue with deep historical roots and power issues.¹¹⁴ Without the resolution of this, it will be very hard to persuade developing countries to trust their food security to global markets, rather than relying on increased self-sufficiency. This is complicated by the rise of multinational actors who have tremendous control over food supply chains, from inputs to outputs. The lack of public-private partnerships has limited the integrated response to supporting food security, in spite of the fact that the private sector has such a dominant role in distribution and retail of food. The private sector has engaged with climate change where there are business opportunities. There are multiple options for partnering on food security related opportunities, including working with designers for better packaging that reduces greenhouse gas emissions or marketing local products most suited to the local climate. Other sources of information such as improved technologies and seeds similarly need to

be made publicly available, but in a context of institutional and policy support, with sufficient attention to disempowered voices regarding their own sovereignty.

CONCLUSION

Projections of a world that is at a minimum 2° warmer than current global average temperatures will increase regional disparities in food production, enhancing existing inequities in food availability. This, coupled with poor access to food in many developing countries, is a pressing concern, especially as climate change impacts are likely to further constrain access. Current international trade regimes and regional and national markets are insufficient in dealing with these inequities and challenges. There is therefore a need to focus on how to address these emerging challenges. Many adaptation options exist but often it is the lack of institutional flexibility and support that reduces the possibility for these being implemented. One important area that is emerging is the need for policy, regulatory and other types of institutional reform to support sustainable responses to enable appropriate adaptation responses to be implemented. Because most of the debate on food security and climate change has focused solely on agricultural production, insufficient attention has been given to policy and institutional reform.

The widespread commodity price increases of 2008 were a wake-up call to the international community about future risks that will increasingly be faced due to climate and other global changes because of connections world wide between disparate shocks such as drought in one part of the world, biofuel subsidies in another part, protectionist responses by national governments combined with chronic national and local issues of poverty and poor production, that combined to produce world-wide food price increases. Among the debates are questions around ways in which policy makers can make sense of the complex war on hunger when climate change emerges as a new front. This needs to be sensitively handled as the nature of solutions to food insecurity is contested, and declining agricultural productivity complicates policy making.

It is a challenge for policy makers to integrate future climate predictions into their policymaking now, particularly when they are already faced with imminent and certain threats to food security in the present. Challenges include how to integrate responses to poverty and hunger with international calls for actions to improve climate change adaptation in developing country communities, while assessing which populations are most at risk and where they are. At the

same time, there may be responses to climate change, in terms of both mitigation and adaptation, which may actually compound food security problems. It is important, therefore, that climate change adaptation policies support integration across scales and sectors as well as exploring new avenues of cooperation and

strengthening institutional capacity to analyze and monitor all climate change impacts. Fundamentally adapting food systems to climate change will require much better governance from local to international levels, to ensure that adaptation does not result in increased vulnerability and food insecurity.

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