Food and Agriculture Organization of the United Nations

Climate change impacts and adaptation options in the agrifood system

A summary of the recent Intergovernmental Panel on Climate Change sixth Assessment Report

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BRIDGING SCIENCE AND POLICY FOR CLIMATE AND FOOD

Climate change impacts and adaptation options in the agrifood system

A summary of the recent Intergovernmental Panel on Climate Change sixth Assesment Report

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Highlights

- The Working Group II contribution to the sixth cycle of Assessments (AR6) "Impacts, Adaptation and Vulnerability" focuses on some new themes or gives more attention to: health, nutrition, and migration; indigenous knowledge; gender and other social inequalities; ecosystem-based adaptation; maladaptation; and, non-crop systems and mixed systems (food and livelihoods of many rural people depend on combinations of crops, livestock, forestry, and fisheries).

- The assessment confirms the significant impacts of climate change on agrifood systems. This applies to crop, livestock, fisheries, and aquaculture systems. The authors state that 10 percent of the currently suitable area for major crops and livestock are projected to be climatically unsuitable by mid-century under high emission scenarios. Increased, potentially concurrent climate extremes will periodically increase simultaneous losses in major food-producing regions.

- Observed impacts are throughout the supply chain, from agricultural yields to supply chain disruptions, and climate impacts interact with other drivers to generate conflicts and migration. The higher temperatures and humidity will generally raise storage costs and lower the quantity and quality of stored product, reducing producer incomes and raising consumer prices. For example, in Michigan, climate change will shorten the period of reliable cold local storage of potato by 11–17 days by mid-century.

- Extreme events are increasing, causing substantial direct economic damage, and reducing economic growth, up to 15 years after the event. For example, in western Africa, warming has increased heat and rainfall extremes, and reduced yields by 10–20 percent for millet.

- Climate change increases the risk of hunger, malnutrition, and diet-related mortality, and is particularly problematic in Africa and South Asia. Climate change disproportionately hits vulnerable groups.

- There are countless adaptation technologies and practices, many of them ecosystem-based. However, the assessment notes that on-farm options are insufficient to meet Sustainable Development Goal 2 (SDG2) on zero hunger, with climate change impacts interacting with other non-climatic drivers of food and nutritional insecurity. Current adaptation options will be unable to deal with 2 °C+ global temperatures. For many options there is lack of information on economic and institutional feasibility. Maladaptation is a problem that needs to be dealt with.

- It is crucial to deal with the enabling environment if adaptation actions are going to reach the scale that is needed. This involves dealing with structural vulnerabilities (related to poverty and gender) as well as creating enabling policies and institutions, making markets work for smallholders, and driving more investment in adaptation. Maladaptation can be avoided by flexible, multisectoral, inclusive and long-term planning and implementation.

Introduction

The Assessment Reports of the International Panel on Climate Change (IPCC) are important as they provide policymakers with state of knowledge assessments on climate change, its implications and potential future risks. These assessments also put forward adaptation and mitigation options. With the release of its latest Assessment Reports, the IPCC has nearly completed its sixth cycle of Assessments (AR6). Working Group II (WGII) of the IPCC, involving hundreds of scientists, focuses on "Impacts, Adaptation and Vulnerability", and many of its findings are relevant to the agrifood system.[1]

The WGII contribution to AR6 was released in February 2022. Several chapters are relevant to the agrifood system, especially the chapters on "Food, Fibre, and other Ecosystem Products", "Water", "Poverty, Livelihoods and Sustainable Development", "Health, Wellbeing, and the Changing Structure of Communities", "Key Risks Across Sectors and Regions", "Climate Resilient Development Pathways", as well as the many regional chapters (such as "Africa", "Asia"), "Summary for Policymakers", and "Technical summary".

This paper summarizes the findings of WGII AR6 which runs over 3000 pages, focusing on the assessment's conclusions and their effect on agrifood systems.

[1] Working Group III is also important as that focuses on emissions of greenhouse gasses and their mitigation, including from agriculture.

WGII AR6 stands out from previous Assessment Reports by giving more attention to:

- Health, nutrition, migration
- Indigenous knowledge
- Gender and other social inequalities
- Ecosystem-based adaptation
- Maladaptation
- Non-crop systems and mixed systems

What are the new directions or themes for AR6?

The coverage of agrifood issues has changed significantly over the course of the Assessment Reports. This is important as it indicates the unfolding scientific understanding of the link between agrifood systems and climate change. The fifth Assessment Report (AR5) was important as it shifted the focus away from purely agricultural production to the whole food system. Building on this, AR6 expands on this in the following ways:

Health, nutrition, migration

While previous assessments have focused on food security, this assessment dives deeper into other outcomes of the impact of climate change on agrifood systems. For example, it states: *"Climate-related illnesses, premature deaths, malnutrition in all its forms, and threats to mental health and wellbeing are increasing (very high confidence). Climate hazards are a growing driver of involuntary migration and displacement (high confidence) and are a contributing factor to violent conflict."*

Indigenous knowledge

WGII AR6 has a much greater focus on indigenous and local knowledge than earlier IPCC assessments. It recognizes the important role of indigenous knowledge in adapting to climate change, though also points to the need to bring in new knowledge: *"Evidence shows that climate resilient development processes link scientific, indigenous, local, practitioner and other forms of knowledge, and are more effective and sustainable because they are locally appropriate and lead to more legitimate, relevant and effective actions (high confidence)."*

Gender and other social inequalities

WGII AR6 integrates knowledge more strongly across the natural, ecological, social and economic sciences than previous assessments. The greater focus on the social sciences can be seen in the considerable attention given to policies, institutions, social justice, rights-based approaches, and governance.

The assessment includes many references to governance and social processes, and pays more attention to gender and other social inequalities. For example, in the food chapter: *"Addressing gender and other social inequalities (e.g., racial, ethnicity, age, income, geographic location) in markets, governance and control over resources is a key enabling condition for climate resilient transitions in land and aquatic ecosystems (high confidence)."*

Ecosystem-based adaptation[2]

The assessment gives more attention to ecosystem-based adaptation, variously termed and sometimes encompassing concepts such as nature-based solutions,

[2] Chapter 5 commonly uses "nature-based solutions" while the Summary for Policy Makers uses "ecosystem-based adaptation".

agroecological approaches, among others. A broad set of approaches are included under this category, for example *"agroecological practices include agroforestry, intercropping, increasing biodiversity, crop and pasture rotation, adding organic amendments, integration of livestock into mixed systems, cover crops and minimizing toxic and synthetic inputs with adverse health and environmental impacts".* The executive summary of the food chapter includes highlights as follows: *"Ecosystem-based approaches such as diversification, land restoration, agroecology, and agroforestry have the potential to strengthen resilience to climate change with multiple co-benefits but trade-offs and benefits vary with socioecological context (high confidence)."*

Maladaptation

Another key topic throughout the assessment is maladaptation. Maladaptation refers to actions that may lead to increased risk of adverse climate-related outcomes, now or in the future. Most often, maladaptation is an unintended consequence. Maladaptation is highlighted as one of the focus points in the Summary for Policy Makers: *"There is increased evidence of maladaptation across many sectors and regions since the AR5. Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change and exacerbate existing inequalities."*

Greater focus on non-crop systems and on mixed systems

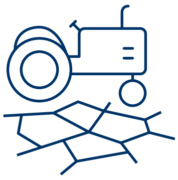
In the past, Assessment Reports have been criticized for their focus on crop production. In AR6, for the first time there is a "mixed system" section that cover, for example, crop-livestock systems. Furthermore, there is a much greater attention to livestock, fisheries and aquaculture. *"Rural households in low and middle-income countries earn almost 70 percent of their income through mixed production systems…..(mixed production systems) can help in adapting to climatic risks and reducing greenhouse gas (GHG) emissions."*

There is hardly any good news for observed and projected impacts of climate change for crops, livestock, fisheries, and aquaculture. These include yield declines; a rise in pests and diseases; supply chain disruptions; economic damage; increasing food and nutritional insecurity; and conflicts and migration.

Observed and projected impacts

There is hardly any good news on observed and projected impacts. There is widespread evidence that impacts are already severe across all sub-sectors of food systems, and there is now much more evidence of impacts on diverse livelihood outcomes. For example:

- *"The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt (high confidence)."*
- *"Climate change impacts are stressing agriculture, forestry, fisheries, and aquaculture, increasingly hindering efforts to meet human needs (high confidence)."*
- *"Extreme weather events not only cause substantial direct economic damage (high confidence), but also reduce economic growth in the*



Around 10 percent of current areas of production will be climatically unsuitable by mid-century under high emission scenarios.

Increased climate extremes will periodically increase simultaneous losses in major food-producing regions.

short-term (year of, and year after event) (high confidence) as well as in the long-term (up to 15 years after the event) (medium confidence), with more severe impacts in developing than in industrialized economies (high confidence).”

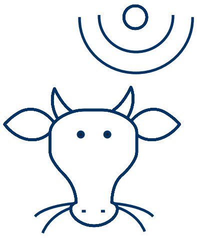
- *“There is increasing evidence of observed changes in hydrological cycle on people and ecosystems. A significant share of those impacts is negative and felt disproportionately by already vulnerable communities (high confidence).”*

The projected impacts also make for sober reading. For example, the assessment states: *“Globally, 10 percent of the currently suitable area for major crops and livestock are projected to be climatically unsuitable in mid-century and 31–34 percent by the end of the century under (high emission scenarios)”.*

Crops

Observed climate impacts differ by crops and regions (see Figure 5.3 in AR6). There are some positive effects in high latitudes, but mostly negative effects in sub-Saharan Africa, south America and Caribbean, southern Asia, and western and southern Europe. For example, in western Africa, warming has increased heat and rainfall extremes, and reduced yields by 10–20 percent for millet, and 5–15 percent for sorghum. In Australia, yield potential of wheat has decreased by 27 percent over a 15-year period due to declined rainfall and increased temperatures. Since AR5, more evidence has emerged on simultaneous crop failures due to climate change. Increased, potentially concurrent climate extremes will periodically increase simultaneous losses in major food-producing regions.

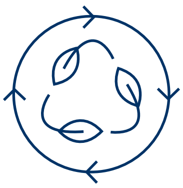
The observed impacts on other crops such as vegetables, fruit, nut, and fibre are under-researched and uncertain, but overall observed impacts are negative across all crop categories.



Heat stress because of climate change will have a negative effect on livestock.

Livestock and mixed systems

Climate change impacts livestock systems in many ways, including negative effects on animal heat stress, changes in rangeland quality and water access, and increased incidence of vector borne diseases and parasites. For example, there has been an observed range expansion of economically important tick disease vectors in north America and Africa posing new public health threats to humans and livestock. Rangeland quality is expected to decline through the expansion of woody cover at the expense of grassland (for example, in tropical and subtropical drylands), and through reduced forage quality. Woody encroachment is projected to occur on 51 percent of global rangeland area.



Mixed systems can reduce vulnerability to climate change but may come with trade-offs.

There is some evidence that mixed systems (including crop-livestock and aquaculture-agriculture systems) can reduce vulnerability to climate change. For example, in Ethiopia, crop-livestock households were more resilient than livestock-only households to climate-induced shock. In the face of climate change, shifts have also been recorded in the farming system, for example towards more livestock keeping in the face of crop losses. These mixed systems, however, may also come with trade-offs, such as the high levels of management skill and extra labour required, and increasing burdens on women. Integrated crop-livestock systems can help control weeds, pests, and diseases, but can also come with environmental benefits, such as increased soil carbon and a reduced need for inorganic fertilizers.

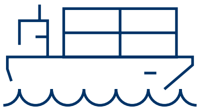
Pests, diseases, weeds

Pests, weeds, and diseases, including zoonoses, are expected to change in occurrence and distribution, while control will become costlier. Risks will increase for climate-driven emerging zoonoses. Significant poleward expansions of many important groups of crop pests and pathogens; climate change and rising carbon dioxide levels favouring the growth and development of weeds over crops and reducing herbicide efficacy; and a warmer climate increasing the need for pesticides were amongst the many findings cited in the assessment.

Fishery and aquaculture systems

Ocean and inland systems and their fisheries, both wild capture and aquaculture, are already facing significant impacts of climate change. In the northeast Pacific, for example, over five years of warmer than average water temperatures have affected the migration, distribution, and abundance of several fisheries resources. Increased ocean acidity, declined dissolved oxygen, the redistribution of salt content, and increased vertical stratification all have negative consequences for marine organisms and the associated fisheries and mariculture. Major threats to inland fisheries include water stress, sedimentation, weed proliferation, sea-level rise, and loss of wetland connectivity. Observed impacts in some inland systems indicate substantial productivity reductions. For example, changes in temperature, precipitation, droughts, floods, and erosion have caused significant production losses for aquatic farmers in multiple countries.

There is medium confidence that climate change will reduce global fisheries' productivity. Figure 5.15 in the AR6 gives an example of the diverse negative impacts of climate change on inland fisheries.



Supply chains will be hit by food safety concerns, impacts on storage and disruptions to transport and trade networks.

Supply chain and post-harvest

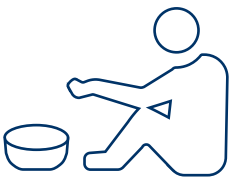
WGII AR6 discusses three aspects of the post-harvest system: food safety, storage, and domestic and international transactions.

Food safety is impacted by climate change through multiple pathways: toxigenic fungi, plant and marine based bacterial pathogens, harmful algal blooms, and increased use of chemicals for plant protection and veterinary drugs. For example, climate change can affect the growth and geographical expansion of toxigenic fungi which are found on many crops. The resulting mycotoxins can contaminate food and feed, and cause diverse impacts on human and animal health.

Extreme weather events can impact storage, through for example electricity failures and loss of cold storage. This is a particular problem for nutrition -dense foods, which tend to be more perishable than other foods. Thus, storage failures will also have negative nutritional outcomes. Warming can also impact the cost of storage, given an increased need for cooling facilities, and reducing producer incomes and raising consumer prices. For example, in the state of Michigan, climate change will shorten the period of reliable cold local storage of potato by 11–17 days by mid-century and by 15–29 days by late century.

Post-harvest losses are expected to increase, given the number of mice, rats, insects, and microorganisms such as toxigenic fungi are expected to increase in warmer and more humid conditions.

Climate change is also expected to disrupt the transportation of food. Domestic and international trade flows can be significantly hit by climate change impacts, especially by floods.



Climate change increases the risk of hunger, malnutrition, and diet-related mortality.

Outcomes on nutrition, food security, health, and migration

Impacts of climate change on food availability and nutritional quality will increase the risk of hunger, malnutrition, and diet-related mortality. Increased carbon dioxide concentrations are expected to decrease the nutritional density in some crops. In sub-Saharan Africa, climate change is an emerging risk factor for undernutrition, especially in countries relying on subsistence agriculture. Women and children are particularly at risk. Due to rising temperatures in 51 countries affected by El Niño Southern Oscillation intensity in 2015–2016, it is estimated that 5.9 million children became underweight. Geographically, nearly 80 percent of the population at risk of hunger are projected to occur in Africa and Asia. Threats to farming livelihoods and risks of undernutrition increase significantly with higher levels of global warming, but even for global warming of 1.5 °C or less, impacts of climate change on livelihoods are significant. For example, in the Sahel, the area suitable for maize production will decline by about 40 percent.

There is high confidence that risks to water scarcity have the potential to become severe due to climate change. Consequences of water scarcity include malnutrition resulting from inadequate water supplies, leading to long-term health impacts such as child stunting.

Climate interacts with other drivers to influence migration and conflict.

Agricultural labour will be increasingly exposed to heat stress. One study estimated that the heat stress from projected 3 °C warming above baseline (1986–2005) would reduce labour capacity by 30–50 percent in sub-Saharan Africa and southeast Asia. This, in turn, would lead to increases in crop prices, thereby undermining livelihoods, as well as food availability and access.

Weather events can act as indirect drivers of migration and displacement (for example, rural income losses and/or food insecurity due to heat- or drought-related crop failures). Rising food prices can affect conflict, political instability, and migration, but often interact with other non-climatic drivers.

Climate change disproportionately affects vulnerable groups (women, children, low-income households, indigenous or other minority groups and small-scale producers).

Vulnerabilities and inequalities

Climate change disproportionately effects vulnerable groups, such as women, children, low-income households, indigenous or other minority groups and small-scale producers. It can lead to malnutrition, livelihood loss, rising costs, competition over resources, and most importantly, further amplify vulnerabilities and inequalities and undermine sustainable development. Globally, smallholders are more vulnerable than large-scale producers to climate change due to, amongst other things: limited policy, infrastructure and institutional support; low credit access; lack of viable markets; limited political voice in policy debates; and heavy reliance on one crop for income.

Adaptation actions

On-farm adaptations are insufficient to meet SDG2 (zero hunger).

The overall situation is that, while many adaptation options have been implemented, on-farm adaptations are insufficient to meet SDG2 on zero hunger, with climate impacts interacting with non-climatic drivers of food and nutritional insecurity. In addition, it is noted that there are cases of maladaptation. The most frequently reported adaptation-related responses are autonomous adaptation: behavioural changes made by individuals and households in response to drought, flooding, and rainfall variability in Africa and Asia. There are, however, increasing numbers of government-led planned adaptation initiatives, including for example coordination mechanisms; disaster and emergency planning (that relate to agricultural livelihoods); and extension services to support farmer uptake of, for example, drought tolerant crops.

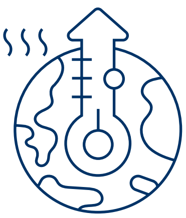
Insufficient adaptation is especially a problem in Africa, Small Island States and south Asia.

Autonomous and planned adaptation

There is a lot of research on autonomous adaptation, that is, farmers, fishers and pastoralists making changes to cope with weather extremes and changes, and with water availability. This includes livestock and farm management; switching varieties or species (for example to less water -intensive crops); diversifying farming systems and livelihoods; altered timing of key farm activities such as planting, stocking, and harvesting; and making fish harvesting gear modifications to access new target species.

However, individuals and households often have insufficient adaptive capacities and non-climatic factors further drive food insecurity. Hence, overall, these autonomous adaptations in combination with non-climatic factors will not result in the global community achieving SDG2. This is especially the case for Africa, Small Island States and South Asia.

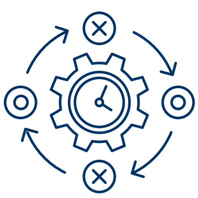
Planned adaptation practices include social safety net interventions for vulnerable populations; managing weather risks through insurance products; providing the right mix of training and capacity building; implementing climate information services for farmers (including through digital means) related to extreme events, the timing of farm operations, dealing with salinity intrusion, amongst others; enhancing extension services; and rolling out sustainable intensification initiatives, for example based on drought-adapted varieties. These adaptation practices can be implemented by civil society, governments, and the private sector. Enhanced support for autonomous adaptation can also fall under planned adaptation.



Many options may be effective in a 1.5 °C or 2 °C world, but the negative impacts will grow with greater warming levels.

Overall, AR6 makes sober reading on adaptation in agrifood systems. The authors state that currently available management options have the potential to compensate global crop production losses due to climate change up to ~2 °C warming, but the negative impacts even with adaptation will grow substantially from the mid-century under high temperature change scenarios. Under this high temperature scenario, the costs of adaptation will be substantial. The impacts will be greatest in the currently warmer regions in the low latitudes. A regional study in west Africa found that currently promising management would no longer be effective under the future climate. In the water chapter it is stated that water and soil management related measures show high potential efficacy in reducing impacts in a 1.5 °C world, with declining effectiveness at higher levels of warming.

Some countries will have the resources to support people at risk with planned adaptation actions, as illustrated by the compensation payments for drought exposed farmers in Australia. However, the literature shows that the poorest groups in society, especially those in poorer countries, often lose out due to climate change and require greater planned adaptation support. Unfortunately, this support is often lacking due to disenabling policies and the difficulty of mobilising the needed finance.



There is increased evidence that maladaptation can apply to many commonly implemented agricultural development options.

Maladaptation

Maladaptation emerged as a major topic in AR6 across all sectors, but with increasing reporting of maladaptation especially in the context of agricultural, forestry, and fisheries practices. Many examples of maladaptation are drawn from activities common to agricultural development (and not primarily a climate change response), indicating that strategies and action for agricultural development and climate adaptation should be carefully selected and implemented. Three categories of maladaptation, not necessarily mutually exclusive, can be recognized:

1. Short-term adaptations that decrease adaptive capacity and hinder future choices

While efficient irrigation technologies like drip and sprinkler irrigation can reduce water application rates per unit output, their broad application can increase overall water extraction by increasing the total land under irrigation.

A frequently cited example of this is groundwater over-use because of irrigation intensification. Another example is shifting from agroforestry coffee and cocoa systems to high-input monoculture systems, which can raise incomes in the short term, but in the longer term there is reduced resilience and reduced carbon storage. Intensification based approaches increase costs of cultivation and can lead to more use of fertilizers and herbicides. Intensification of pasture use as a coping response to drought has been observed to increase risks due to overgrazing. Investment in improved cultivars or shifts to different crops may displace local varieties and reduce diversity; increase risks from pests, diseases and drought; and cause a loss of indigenous knowledge. Diversification away from food crops can also negatively impact food and nutritional security.

2. Shifting vulnerability from one group to another, or one area to another

Some autonomous adaptation by individuals and households shifts risks to others, with net increases in vulnerability. Water-related and other technologies can have negative outcomes on certain groups; for example, when only rich and male farmers can adopt high-cost technologies like solar irrigation pumps. Climate services can reinforce existing inequalities if they are more directed to the powerful stakeholders.

The adoption of more labour-intensive crops, and livelihood diversification through male out-migration can increase women's burdens. There are examples of large-scale irrigation projects in which only richer farmers could participate, resulting in poorer and small-scale farmers having to sell or rent their land to those who joined the irrigation project, in the process losing access to what was communal water rights. Some larger-scale adaptation actions produce spill-over effects in other locations, for example irrigation schemes upstream increasing climate risk to those downstream. Digital agriculture for more efficient input use could lead to net job losses, particularly for those with lower levels of education.

3. Eroding sustainable development: adaptation strategies which increase emissions, deteriorate environmental conditions and/or social and economic values

Large-scale irrigation schemes can reduce the long-term potential of hydropower and groundwater availability, and increase salinization and the cost of water. Coastal infrastructure and riverbed draining and dikes to reduce flood risk can degrade mangroves, deplete freshwater fisheries, reduce fish diversity, and may divert funds from other more sustainable measures. Government policies to manage coastal fisheries which overcapitalize fisheries and offer index insurance may promote over-fishing and may worsen the livelihoods of the small-scale fishers. Social safety nets may provide funds which increase consumption of processed, purchased food and erode indigenous knowledge. Intensification approaches could result in higher GHG emissions. In Burkina Faso, a region highly impacted by severe droughts, local communities have become less able to cope with droughts given a decline in cultural pastoralism and increased dependence on crops.

Adaptation technologies and practices

There are many technical adaptation options but these need to go hand in hand with creating an enabling environment.

For many adaptation options there is a lack of information on their economic or institutional feasibility, as well as on the limits to adaptation.

Adaptation options are highly context specific in relation to socioeconomic and agro-ecological situations.

There are many adaptation technologies and practices available. Several of these adaptation options are discussed below. However, the previous section has already indicated that these are unlikely to be sufficient on their own, and a much more transformational agenda needs to be pursued. The subsequent section, "Creating an enabling environment" explores options to address this adaptation gap.

As the AR6 food chapter notes, various adaptation options are feasible and effective but some lack adequate information on their economic or institutional feasibility. For some, we also have insufficient insights on the limits to adaptation; for example, the degree to which they can reduce risks, and the degree to which they are effective under different warming scenarios. The water chapter echoes this, calling for better evidence on the costs and benefits of low-regret solutions, such as water pricing and increasing water use efficiency through technology and service improvements. This presents a major drawback to adaptation efforts.

Effective adaptation options for specific localities, farming systems and farmer socioeconomic situations (related to gender and income levels) are obviously highly context specific. This is most clearly seen in the maladaptation examples, where commonly used adaptation options have also been shown to be maladaptive when applied in particular ways or in certain contexts.

Many of the options involve ecosystem-based adaptation, such as diversification, agroecology, and agroforestry. These have the potential to strengthen resilience to climate change, but co-benefits and trade-offs vary with socioecological context.

Table 1. Summary of possible adaptation options

Cultivars and breed improvements (crops, livestock, aquaculture)	Genetic improvements are an effective option for adapting to climate change, drawing on modern biotechnology and conventional breeding. Genome sequencing significantly assists in identifying genes relevant to adaptation to, for example, stress from pests and disease, temperature, and water extremes. For livestock, a key need is breeding for heat resistance. Genetic resources are available for many important aquaculture species. However, to date, these have been mostly used for disease and growth selections rather than climate resistance, but shellfish selections for ocean acidification and warming are underway. At the same time, a variety of socioeconomic and political variables limit uptake of climate-resilient crops and breeds, especially for the most vulnerable farmers. Participatory breeding can be an effective adaptation strategy in generating varieties and breeds well adapted to the socio-ecological context and climate hazards.
Changing management practices for crops, livestock and aquaculture	Many management adaptation options are available, including changing the timing of key farm operations (like planting, stocking, and harvesting), implementing different tillage practices, and changing water management (see "Managing water" below). For livestock, options include matching of stocking rates with pasture/feed production; adjusting herd and watering point management; managing diet quality; more effective use of silage, rotational grazing or other forms of pasture management; and fire management to control woody thickening. Managing heat stress, for example through introducing shading, fanning, and bathing, is important. Shading could be done by introducing trees into pastures, thus also contributing to diversifying the system (see "Diversifying agricultural systems" below). Land-based aquaculture systems, including hatcheries, may reduce exposure to climatic extremes, due to a better control of the environment, and buffer climate effects using optimal diets. However, some trade-offs could include large capital and operational costs, and increased conflicts between land and water use. Careful selection of marine farm sites may prevent the decline of productivity. Adaptation options for such sites in relation to extreme events would include: building coastal protection, and using stronger cages, mooring systems, deeper ponds, and sheltered bays.
Switching crops, breeds and farming systems	Farming system transitions are already occurring in a variety of settings. For example, in low-lying areas prone to sea-level salinity intrusion in the Mekong delta, rice paddies have been converted to mixed plant-animal systems, while freshwater ponds have been converted to brackish or saline aquaculture. There is some confidence in the effectiveness of changing the nature of the integration between crops and livestock as an adaptation, including: moving from crops to livestock, moving from livestock to crops, and moving from one species of livestock to others. Given that there are many different crop species, there is great potential for crop switching to match changing climates, but cultural and economic barriers will make implementation difficult. Similar considerations apply to livestock and fish switching. For livestock, switching from large ruminants to more heat-resilient species will be an option. For example, switching from cattle to more heat- and drought-resilient camels and small stock in pastoral systems of southern Ethiopia is already occurring. In general, many of these switching options come with trade-offs.
Managing water	Irrigation is one of the most common adaptation responses in agriculture. Hence, expansion of irrigation in the coming decades is expected, leading to shifts from rain-fed to irrigated systems. Rainwater storage and deficit irrigation techniques are frequently mentioned as adaptation options. Many nutrient-dense crops are water demanding, and thus water management and access to irrigation water are important adaptation requirements. Many techniques can be used to make irrigation more efficient: laser levelling, micro-irrigation, efficient water distribution systems and pumps; improved agronomic practices; and economic instruments like water trading. However, irrigation is also associated with adverse environmental and socioeconomic outcomes, including groundwater over-use, and the concentration of benefits in richer households, among others. Water and soil conservation measures such as reduced tillage, contour ridges, or mulching are common adaptation responses to reduce water-related climate impacts. The use of non-conventional water sources, like desalinated and treated wastewater, is emerging as an important component of increasing water availability for agriculture. Techniques are also available to deal with saline intrusions.

Diversifying agricultural systems through crop, legume, and soil organism's diversification, as well as through livestock integration and mixed agroforestry systems	Various types of diversification can strengthen resilience to climate change, with socioeconomic and environmental co-benefits. However, tradeoffs and benefits vary by socioecological context. Multiple diversification options are feasible, including mixed planting, intercrops, crop rotation, diversified management of field margins, agroforestry, and integrated crop livestock systems. Inclusion of legumes can be effective for both mitigation and adaptation, and has positive impacts on nutrition. At the same time, legume production can be constrained by many factors, like extension support, access to genetic material, market access, and food preferences. Organic amendments, crop residue retention, and low tillage may increase diversity in soil biological organisms, which might be important in resilience to stresses such as drought and pest pressure. Agroforestry increases resilience against climate risks through a range of biophysical and economic effects. Furthermore, diversification can improve ecosystem services such as pest control, soil fertility, pollination, water regulation and buffering of temperature extremes. Further progress is needed via breeding and/or agronomy to adapt underutilized as well as major food crops to diversified systems. In aquaculture systems, diversification is seen through co-culture, integrated aquaculture-agriculture (for example by combining rice and fish) and integrated multi-trophic culture (for example by cultivating shrimp-tilapia-seaweed or finfish-bivalve-seaweed combinations). However, single-species systems still dominate. Barriers such as land availability, freshwater resources and lack of credit access may limit the uptake and success of integrated adaptation approaches.
Managing fisheries	For coastal and inland fisheries, there are relatively few well-documented examples of effective adaptation responses to climate change. Over-fishing is a critical non-climatic driver in the fisheries sector, and reducing over-fishing is an important adaptation measure. With fish migrations and changes in species composition, adaptation responses include changes in fishing grounds and changes in target species. Other adaptation options include increasing ecosystem resilience by rebuilding coastal mangroves and harvesting gear modifications to access new target species.
Supply chain options	There are also a range of supply chain adaptation options. These are captured in Figure 5.17 in AR6.
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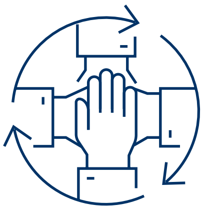
Source: Bruce Campbell



Enabling conditions are key for implementing, accelerating and sustaining adaptation:

- Dealing with structural vulnerabilities
- Political commitment and follow through
- Institutional frameworks
- Policies and market and other instruments with clear goals and priorities
- Mobilization of and access to adequate financial resources
- Insurance
- Expanded climate and extension services, and early warning systems
- Social protection

Creating an enabling environment

The WGII AR6 states that worldwide climate resilient development is more urgent than previously assessed in AR5. We need to shift away from the current situation of small, fragmented, sector-specific actions. Given current rates of adaptation planning and implementation, the adaptation gap will only grow.

The assessment distinguishes between soft limits to adaptation and hard limits and suggests that soft limits have been reached for many smallholder farming households in central and south America, Africa, Europe and Asia. These soft limits can be overcome by realizing an enabling environment for adaptation action. In many cases, overcoming these soft limits will promote transformation. In Chapter 5, transformation is defined as “a redistribution of at least a third in the primary factors of production (land, labour, capital) and/or the outputs and outcomes of production (the types and amounts of production and consumption of goods and services arising from multifunctional agricultural systems)”. These enabling conditions are key for transformation by facilitating the implementation, acceleration, and sustaining of adaptation actions.

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Addressing social inequalities will involve, amongst others:

- Capacity development
- Improved access to resources
- Empowerment
- Structural approaches to gender inequalities
- Harnessing youth innovation
- Attention to indigenous and local knowledge
- Community-based approaches

Dealing with structural vulnerabilities

Impacts of climate change in combination with non-climatic drivers can create poverty-environment traps that increase the probability of chronic poverty (Figure 8.4 in AR6). In addition, responses to climate change – both autonomous and planned – can exacerbate poverty. Many adaptations aim to reduce exposure to climate-related hazards or help households cope with climate change, rather than addressing the root causes of structural vulnerability. Addressing structural vulnerability means that responses to climate change should consider institutional root causes, be intersectoral, and require higher levels of vertical (across levels from communities to nations) and horizontal (across sectors) coordination and integration.

Inequality and poverty constrain adaptation, leading to soft limits and resulting in disproportionate impacts for the most vulnerable groups. Addressing gender and other social inequalities (like racial, ethnicity, age, income, and geographic location) in markets, governance and control over resources is a key enabling condition for climate resilient transitions. If not addressed, adaptation strategies and technical approaches can worsen socioeconomic inequalities.

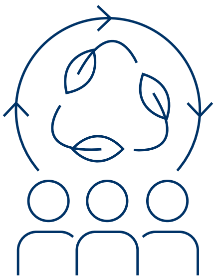
Key to an enabling environment for tackling inequalities involve inclusive decision-making; **capacity-building;** shifts in social rules, norms and behaviours; **access to resources** for marginalized groups for climate change adaptation (like land, water, and seeds); **empowerment;** and **structural approaches to tackling gender inequalities.** Approaches that emphasize social justice concerns, including gender inequalities, are considered crucial for climate change adaptations. Supporting the active involvement of women helps address gender inequity.

Furthermore, it is important to understand the role **youth** play in all aspects of the agrifood system. This is especially the case in youthful regions such as sub-Saharan Africa, south Asia, and central America, which are also regions that are especially vulnerable to climate change. Youth from these regions are particularly vulnerable to climate risks, often with less access to resources like land, water, and capital. Young low-income rural women may be most marginalized. Harnessing youth innovation and vision will support effective climate change adaptation, foster systemic change, as well as address youth marginalisation.

Indigenous and local knowledge facilitate adaptation strategies, especially when combined with scientific knowledge using participatory and community-based approaches. While indigenous and local knowledge is an important component of many local adaptation strategies, it continues to be marginalized in food system actions. Elements to consider include indigenous access and control, and recognition of indigenous rights, governance systems and laws. Many examples of successful local systems exist. For instance, indigenous knowledge and community-based management of fisheries and aquaculture in the Arctic and Asia provide important adaptive strategies. There are examples of integrating indigenous and local knowledge into resource management systems and school curricula. However, there are limitations to such knowledge and thus the need for science-based knowledge and other knowledge to coalesce to produce solutions.

Community-based adaptation approaches allow for locally driven, place-based adaptation approaches. However, these require attention to power dynamics; respect for local and Indigenous knowledge systems; adequate resources; and coordination at multiple levels of governance to be effective. Since the publication of AR5, there is strong evidence that participation of local stakeholders improves communities' capacity to monitor and respond to climate change. Participatory monitoring of climate change impacts, and participatory scenario development to formulate adaptation action plans are examples of strategies that help strengthen community adaptive capacity. Other examples are community seed banks and networks to strengthen local seed systems, which complement participatory breeding programs. There is evidence that early participation of stakeholders in adaptive planning has promoted action and ownership, in aquaculture in India and United States of America.

High performing community-based initiatives in the Pacific Islands had the following six key entry points: 1) effective methods to improve adaptive capacity, 2) appropriateness to the local context, 3) methods which considered differentiated impact within the community, 4) ecosystem-based approaches, 5) approaches that addressed climatic and non-livelihood pressures, and 6) consideration of future climatic trends. Community-based approaches may lack local knowledge of potential strategies to address future climatic scenarios.



Rising public awareness, building business cases for adaptation, monitoring and evaluation of adaptation progress, and social movements will be critical to accelerate commitment and follow-through.

Political commitment and follow-through

The WGII AR6 concludes that political commitment and follow-through across all levels of government accelerate the implementation of adaptation actions. Political commitment and follow through is needed because implementing actions can require large upfront investments of human, financial and technological resources, whilst benefits may only come much later (in the next decade or beyond). As a result, many initiatives prioritize near-term climate risk reduction which may reduce the opportunity for transformational adaptation. Accelerating commitment and follow-through is promoted by rising public awareness; building business cases for adaptation; accountability and transparency mechanisms; mainstreaming adaptation into institutional budget and policy planning cycles; monitoring and evaluation of adaptation progress; social movements; and fostering enhanced knowledge on impacts and solutions.

Developing climate-resilient development pathways offers a way forward to guide climate action in food system transitions. To do so, robust analyses are needed that detail plausible pathways, and implementation needs to apply appropriate monitoring and feedback to food system actors.

Institutional frameworks

Successful adaptation action will require effective coordination within government, for example in dealing with growing demands for food, water and energy under a changing climate. Single-sector policies can create strong trade-offs with other policy targets and Sustainable Development Goals (SDGs).

Successful adaptation action will require effective coordination across government, amongst stakeholders, across jurisdictional boundaries and across multiple levels.

Hence, multi-sector approaches are important for several areas in the agrifood system. One example is solar-based irrigation, where the energy, water and agriculture sectors overlap and are interconnected. Another example is bio-based products as part of a circular bioeconomy which has the potential to support adaptation and mitigation, but requires sectoral integration on energy, water, waste management, agriculture and industry.

The agrifood sector is not the only sector looking to other sectors to achieve its SDG and climate outcomes. Other sectors also see the agrifood sector as a crucial component of reaching their sectoral outcomes. For example, for health outcomes, the health sector envisions actions in, and collaboration with, multiple sectors including that of agriculture (Figure 7.14 in AR6). Hence, increased horizontal coordination will be critical to reach adaptation outcomes in all sectors. Maladaptation can also be avoided by flexible, multisectoral, inclusive and long-term planning and implementation of adaptation actions with benefits to many sectors and systems.

Adaptation actions will also need effective and greater coordination across multilateral institutions, and amongst the multiple stakeholders involved initiatives. Institutional innovations are also needed for cross-jurisdictional management of natural resources, particularly related to trans-boundary management of water resources and marine fisheries.

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Hence, institutional mechanisms need to be in place to foster negotiation amongst many stakeholders at multiple government scales (from local community level to a national level). These need inclusive mechanisms to address power inequalities in governance structures and communities. These mechanisms, in turn, are enabling conditions for effective community-based approaches.

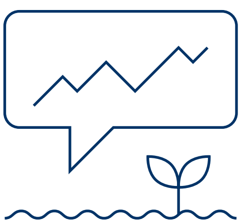
Multiple policy dimensions need to be tackled, from shifting subsidies to public procurement, to support to capacity building and empowerment, amongst others.

Policies and instruments with clear goals and priorities

Policies and instruments that support adaptation actions and system transitions include shifting subsidies (for example to diverse systems rather than monocultures); removing perverse incentives, regulation and certification; green public procurement; investment in sustainable value chains; support for capacity-building; empowering farmers; improved access to insurance premiums and credit; payments for ecosystem services social protection; and more secure land, property and grazing rights, among others. For many adaptation technologies and practices, a lack of market access is mentioned as a bottleneck through limited storage and transport infrastructure; subsidies that promote monocultures and do not support more resilient and/or nutrient-dense crops; and market instability.

Policy support is also needed to incentivize local and national markets, shorter food chains, and food sovereignty, for example through public procurement policies, and innovative institutional mechanisms such as collective trademarks and participatory guarantee systems. Urban and peri-urban agriculture, including controlled environment agriculture (like vertical agriculture) are promoted as effective strategies to adapt to climate change in specific contexts. However, trade-offs remain a challenge, for example the high energy use in controlled environment agriculture. Multi-level policies and programs that support urban and peri-urban networks, including farmers' markets, public procurement, incentives for short food value chains are possible areas to support transitions.

However, international trade may also play an important role in adaptation, for example when a national food system fails due to extreme events or other related climate shocks. Climate change impacts can be much reduced by reducing tariffs and dealing with institutional and infrastructural barriers. Trade-offs especially occur in hunger-affected and export-oriented regions, where exports may be at the expense of domestic food availability.



Lack of financial resources is a severe constraint to adaptation action and will increase the adaptation gap. Currently, there are still many barriers to increase private sector investment in agrifood systems.

Policy decisions that ignore or worsen risks of adverse climate effects for different groups and ecosystems increase vulnerability. This has included sedentarisation policies, large-scale irrigation projects and large-scale land acquisitions, amongst others.

Mobilization of and access to adequate financial resources

While large public and private investment are required, many barriers to private sector investment remain. Public sector investment has grown four-fold since 2010, but to meet future needs adaptation costs will far exceed current public commitments. As an example, the needed investments in agricultural research and development to offset the effects of climate change on hunger must rise from USD 1.62 billion to USD 2.77 billion per year between 2015 and 2050. Furthermore, significant investment increases in water are required, a considerable portion of which is relevant to the food system (USD 12.7 billion per annum).

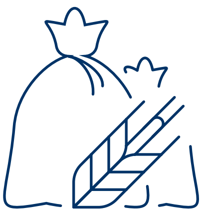
The level of private sector finance going into adaptation is unknown as it is difficult to track, but WGII AR6 records the increased presence of financial actors in the agrifood system. New types of investment vehicles such as commodity index funds have emerged, and the use of older vehicles such as forward and futures markets has increased. These trends are linked to climate change and the resulting commodity and farmland price variability.

Despite increased presence of financial actors, flow of adaptation finance is impeded by weak measurement and benchmarking of financial and resilience outcomes; challenges in assessing repayment capacity of investee producers and companies; and immature information systems (weak analytics and fragmented standards). This inhibits effective due diligence and impact assessment, contributing to low investor confidence. There are also high upfront costs to private investment, including high transaction and intermediation costs, and relatively long pay-off time. Market development has been shown to be a critical factor for successful adaptation at scale in sub-Saharan Africa, illustrating the need to lift these finance barriers to accelerate adaptation.

Index-based insurance is a promising adaptation enabling condition but must be carefully implemented to prevent growing inequality and maladaptation.

Insurance

Insurance is one type of financial adaptation strategy that is increasingly used in agriculture and aquaculture. In fisheries, insurance can cover natural disasters and disease, enabling faster livelihood recoveries and preventing poverty. For example, small-scale shrimp farmers were willing to pay higher premiums to manage risk, after participation in government pilot insurance schemes. Index-based agricultural insurance is particularly common and helps farmers deal with weather-related production risks. It can provide coverage at a fraction of the costs of loss-based polices, and thus makes it more affordable to insure small plots of land. Some insurance products are bundled with other services, such as fertilizer use or seeds, with the result that insurance can incentivize technology uptake. However, extensive data is needed to derive appropriate indices. Furthermore, as with many other adaptation options, insurance may often benefit wealthier farmers, and maladaptive cases have been identified (for example cases where insurance promotes over-fishing). In addition, insurance products often need to be subsidized by government.



Climate services can improve agricultural practices but must be carefully employed as not to worsen existing inequalities.

Expanded climate and information services, and early warning systems

Limited availability of information and data pose constraints to adaptation, especially for poorer and more marginalized farmers. Thus, improving extension services is a priority, including extension for diversification practices, agroecological approaches, and nutrient-rich crops, among others.

Climate services that are inclusive can improve agricultural practices and inform better water use and efficiency. Bundling them with non-climatic services, like market information, may be effective at improving farmer decision making. Access to, and value of, climate services can be enhanced by the development of digital tools, including radio and text messages, targeted to different vulnerable groups, as well as by participatory processes in the development of the tools. Digital technologies can support agrifood adaptation, but digital divides must not worsen inequalities. In some cases, community-based approaches to climate services may be appropriate. For example, community-based climate services in the Andes built capacity around climate change as well as trust in local climate institutions. These were managed through a collaboration of smallholders and an international partnership, resulting in information for regional responses to climate change.

Early-warning systems provide valuable regional or farm risk information. Examples include drought and flood warnings that can trigger farmer responses but also national-level response to early warnings for harmful algal blooms that impact fisheries, and systems for pests and diseases. Novel surveillance systems for food quality are needed to speed up detection and improve intervention in foodborne outbreaks.

Social protection

Integrated multisectoral strategies that incorporate social protection are effective adaptation responses. These include: cash transfers; weather index insurance; farmer-managed regional storehouses; and asset-building activities such as well construction. The strategies can support short-term response to acute food security but can also build assets for increased resilience. For example, an adaptive social protection scheme in the Sahel combined early warning systems, capacity building and dialogue amongst forecasters, community groups and humanitarian agencies. Forecast-based financing, which automatically disperses funds when threshold forecasts were reached allowed flood-prone households in Bangladesh to access food without going into debt. As with other options, they can come with both co-benefits and trade-offs. In many cases social protection approaches can be usefully combined with introducing standard agricultural adaptation technologies and practices, like drought adapted seeds and diversified production.

Conclusions

The WGII AR6 makes for sober reading. Climate change impacts are severe and will intensify in the decades ahead. These impacts will have direct and indirect consequences for agrifood systems around the world. At the same time, many on-farm adaptation options will be insufficient to achieve SDG2, and ineffective in a more than 2-degree warmer world. Ecosystem-based adaptation does provide some optimism but will require much attention to the enabling conditions for adaptation action and to the social-ecological context.

Hence, while it is crucial to implement and scale up diverse on-farm options, it is at least as important to foster an enabling environment. This requires policy and institutional change; intersectoral action; coordination across levels; dealing with structural vulnerabilities related to poverty and gender; mobilising youth; empowering stakeholders through community-based approaches and capacity building; advancing climate information and extension services; and implementing social protection schemes. Only coordinated and ambitious action on many fronts will bring the needed transformation that has to happen in agrifood systems.

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