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AGRICULTURE GLOBAL PRACTICE
DISCUSSION PAPER 09

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AGRICULTURAL RISK MANAGEMENT IN THE FACE OF CLIMATE CHANGE

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LIST OF ABBREVIATIONS

ARM	agriculture risk management
ARMT	agriculture risk management team
CSA	climate-smart agriculture
FAO	Food and Agriculture Organization
GHG	greenhouse gas emissions
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
PDSI	Palmer Drought Severity Index
RVF	Rift Valley Fever
UNFCCC	United Nations Framework Convention on Climate Change
WB	World Bank
WMO	World Meteorological Organization

All dollar amounts are U.S. dollars unless otherwise indicated.

GLOSSARY

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Agricultural risk: The possibility of an event or events that can create an unexpected, unplanned outcome, usually resulting in losses. There are three main attributes of risk: event hazard, uncertainty, and losses (World Bank 2015).

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change: Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. In its Article 1, the Framework Convention on Climate Change (UNFCCC) defines climate change as: a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which, in addition to natural climate variability, is observed over comparable time periods.

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce a most likely description or estimate of the actual evolution of the climate in the future, for example at seasonal, inter-annual, or long-term time scales.

Climate projection: A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions, concerning, for example, future socio-economic and technological developments, that may or may not be realized, and are therefore subject to substantial uncertainty.

Climate variability: Refers to variations in the mean state and other climate statistics (standard deviations, the occurrence of extremes, and so on) on all temporal and spatial scales beyond those of individual weather events. Variability may result from natural internal processes within the climate system (internal variability) or from variations in natural or anthropogenic external forces (external variability).

Extreme climate event: See **Extreme weather event.**

Extreme weather event: An extreme weather event is an event that is rare within its statistical reference distribution at a particular place. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place. An **extreme climate event is an average of a number of weather events** over a certain period of time, an average which is itself extreme (for example, rainfall over a season).

Mitigation: Mitigation has different definitions in the climate change and risk management communities respectively. In the former, the mitigation *of climate change* is defined as anthropogenic interventions to reduce the sources or enhance the sinks of greenhouse gases. In the area of risk management and for the purposes of this report, *risk* mitigation is defined as activities designed to reduce the likelihood of an adverse event or reduce the severity of actual losses.

Rapid climate change: The non-linearity of the climate system may lead to rapid climate change, sometimes called abrupt events or even surprises. Some such abrupt events may be imaginable, such as a dramatic reorganization of the thermohaline circulation, rapid deglaciation, or massive melting of permafrost leading to fast changes in the carbon cycle. Others may be truly unexpected, as a consequence of a strong, rapidly changing forcing of a non-linear system.

Resilience: The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.

Uncertainty: An expression of the degree to which a value (for example, the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable.

It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (for example, a range of values calculated by various models) or by qualitative statements (for example, reflecting the judgment of a team of experts).

United Nations Framework Convention on Climate Change (UNFCCC): In its Article 1, the UNFCCC defines climate change as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Weather: is the state of the atmosphere with respect to wind, temperature, cloudiness, moisture, pressure, and so on. Weather refers to these conditions at a given point in time (for example, today's high temperature), whereas Climate refers to the "average" weather conditions for an area over a long period of time (for example, the average high temperature for today's date). (NOAA 2015).

All definitions unless otherwise stated are from the Intergovernmental Panel on Climate Change (IPCC) (2014).

EXECUTIVE SUMMARY

While all sectors of economic activity experience hazards and unexpected events arising from the "damaging whims of nature," agriculture is one of the riskiest: Weather events and climate patterns directly cause significant production volatility, can often have indirect ripple effects in markets for agricultural inputs and outputs as well as ultimately lead to reactionary shifts in legal and policy frameworks. Few other sectors and their stakeholders are so immediately dependent on weather and climate.

Climate change is becoming a source of significant additional risks for agriculture and food systems. Climate projections suggest that impacts will include shifting average growing conditions, increased climate and weather variability, and more uncertainty in predicting tomorrow's climate and weather conditions. More concretely, these impacts will translate into an overall warming trend, an increasingly erratic distribution of precipitation, more frequent as well as far more devastating extreme events and spatial shifts in the occurrence of pests and diseases.

Far from being a distant future reality, impacts are already being felt today. Research shows that many agricultural regions have already experienced declines in crop and livestock production due to climate change-induced stress (Lobell and Field 2007). Climate disruptions to agricultural production have increased over the past 40 years and are projected to further increase over the next 25 years (Hartfield et al. 2014).

While climate change is expected to produce both winners and losers overall, losses will far outweigh the gains (Jarvis et al. 2011) and the poor will be disproportionally affected because of their dependence on agriculture and a lower capacity to adapt (World Bank 2008).

The scale of projected impacts is alarming. For instance, each degree Celsius of global warming is projected to lead to an overall yield loss of about 5 percent (National Research Council 2011). As climate change progresses, it is increasingly likely that current cropping systems will no longer be viable in many locations. In Africa, for instance, under a range of scenarios progressing to 2050, 35 million farmers across 3 percent of the continent's land area are anticipated to switch from mixed crop-livestock systems to livestock only (Jones and Thornton 2008).

Agricultural risk management (ARM) is ideally placed to support stakeholders in building resilience to these increased risks in short and medium term. While climate change may introduce new types of extreme events in some locations, it most frequently will translate into "more (frequent and intense) of the same" hazards. ARM frameworks and approaches can point the way to identify optimal risk mitigation, transfer, and coping strategies—and help identify appropriate actions for strengthening resilience and climate change adaptation. Please refer to appendix A for a description of the ARM approach.

ARM can also play an important role in the transition to a climate-smarter agriculture system by offering a useful entry point for dialogue. The clear initial focus on the management of shorter term risks and their economic impact can help create a sense of urgency and attract stakeholder involvement that then paves the way for broader discussions around climate-smart agriculture.

To understand the potential role of ARM in the global response to climate change, two considerations are important.

First, agricultural risks faced by hundreds of millions of farmers, traders, processors, retailers, and other stakeholders engaged in agricultural supply chains around the world can be usefully classified into production, market, and enabling environment risks (World Bank 2013a). This threefold categorization can help avoid the common fallacy of exclusively situating climate change impacts in agriculture at producer level. Production losses due to climate and weather events, in concurrence with other factors, can have far wider reaching implications for entire supply chains and the food system as a whole. They can ultimately trigger government reactions such as export controls that can alter the enabling environment of the industry.

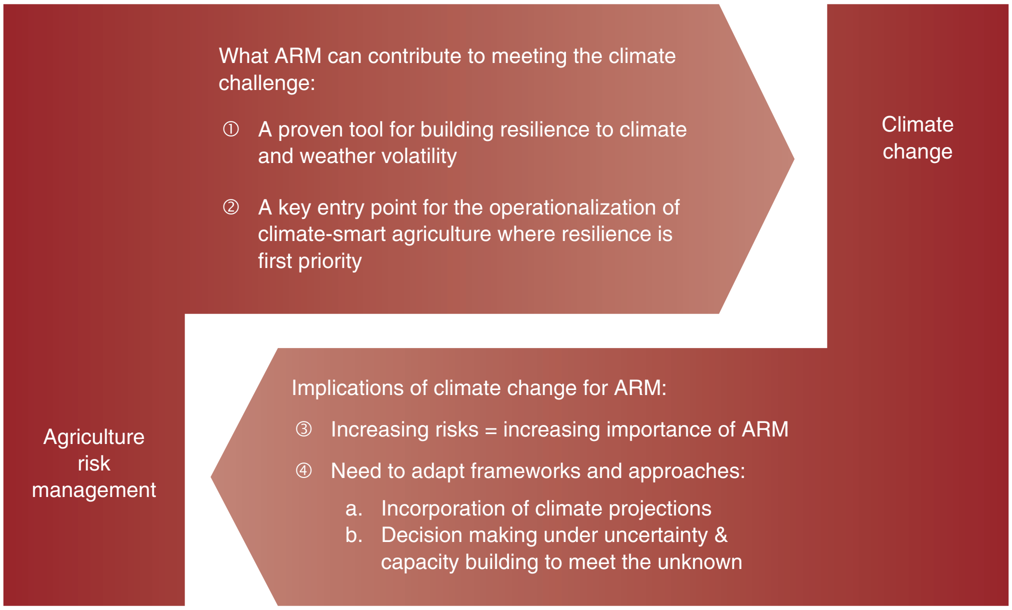
Second, climate change impacts that lead to short-term risk events—highly relevant to agriculture risk management—need to be differentiated from slow-onset changes in average climatic conditions, which are most relevant to agriculture policy planning more broadly. ARM can however play a key role in enabling longer term adaptation planning by increasing the awareness of the importance of climatic and weather risks for agricultural production and by highlighting trends as they emerge in the data.

Impacts from climate change on agriculture may be broken into three categories: changes in average climate conditions, climate variability, and climate uncertainty:

- **Average climate conditions** may be defined as the expected temperature and precipitation in a given location at a given time. Shifts in these averages and expected seasonal structural changes associated with them are largely gradual in nature and will require responses that may involve adjustments in crop rotations, planting times, genetic selection, fertilizer management, pest management, water management, and shifts in areas of production (Hartfield et al. 2014). Such change in long-term average growing conditions do not imply risk in the sense of exposure to sudden harmful impacts.
- **Climate variability** refers to variations in the mean state and other climate statistics (standard deviations, the occurrence of extremes, and so on) on all temporal and spatial scales beyond those of individual weather events. Increased climate variability will bring increasingly frequent incidence of extreme weather events such as heat waves, droughts, and heavy precipitation. In addition, risk of pest and disease events may increase indirectly due to increases in climate variability. Since variability and extreme events are a key subject of risk management, these impacts are the most relevant in the context of this study.
- **Climate uncertainty** is the degree to which we are currently unable to predict future climate. While remaining challenging, projections of yearly averages under climate change are currently significantly more precise than projections of the implied risk from extreme events and incidences of pest and disease. In projecting the latter, significant error margins persist, particularly at local scales. In addition, because climate change is anthropogenic or man-made, uncertainty over future emissions translates into uncertainty over future climate. For several reasons, uncertainty over both weather and climate is hence increasing with climate change.

Under a changing climate, the past will often no longer be the best guide to the (climatic) future—and climate change

FIGURE ES.1. ILLUSTRATION OF KEY MUTUAL POINTS OF RELEVANCE BETWEEN CLIMATE CHANGE AND AGRICULTURE RISK MANAGEMENT


What ARM can contribute to meeting the climate challenge:

① A proven tool for building resilience to climate and weather volatility

② A key entry point for the operationalization of climate-smart agriculture where resilience is first priority

Climate change

Agriculture risk management

Implications of climate change for ARM:

③ Increasing risks = increasing importance of ARM

④ Need to adapt frameworks and approaches:

a. Incorporation of climate projections
b. Decision making under uncertainty & capacity building to meet the unknown

will therefore also require a paradigm shift in ARM. As climate change creates new and often uncertain risks, increasingly sophisticated tools will be needed to understand and manage them. Future projections will need to be incorporated in risk models and methodologies for decision making under deep uncertainty will need to be deployed.

This study seeks to understand the climate change impacts on agricultural risk—*how do risks change?*—and on agricultural risk management—*how can agricultural risk managers respond?* This response has two elements: First, *what role can ARM play in meeting the climate change challenge?* Second, *how will ARM need to adapt its methodology to the "New Normal" of climate change?*

The study limits itself to a discussion of crops and livestock. The principle audience for this report comprises practitioners working on agriculture risk management and other interested stakeholders.

Chapter 2 of this report sketches a conceptualization of climate change impacts on agricultural risk. It introduces the more important concepts and definitions needed to frame the content. This includes a brief discussion on concepts of weather, climate, and climate change; of the ways in which climate change will impact agriculture; and of the relevancy of these impacts to ARM.

Chapter 3 assesses the impact of climate change on agriculture, including the following:

- **Production risks:** Including temperature fluctuations, drought events, heavy rainfall (including floods), and other direct weather events, such as cyclones and storms, as well as indirect implications of climate change, such as pests and diseases.
- **Risk repercussions at the market level:** For instance, increasingly averse growing conditions will impact food price volatility and increased extreme events will impact increasingly complex global supply chains.
- **Risks on the enabling environment:** Extreme weather events and associated price changes can indirectly contribute to reactive trade and domestic support policies; natural resource constraints may further exacerbate underlying tensions and lead to instability or even violence and conflict.

Chapter 4 assesses the implications of climate change impacts for agricultural risk management. It asks what ARM can contribute to climate change adaptation and resilience building and enquires how ARM needs to adjust its methodologies to reflect the "new normal" of climate change, offering four key recommendations summarized in figure ES.1.

FIGURE ES.2. OVERVIEW OF THE ELEMENTS OF THE *NEW NORMAL* OF CLIMATE CHANGE AND IMPLICATIONS FOR AGRICULTURAL RISK MANAGEMENT

ELEMENTS OF THE NEW NORMAL		TYPE	IMPLICATIONS	DEMANDS ON ARM
1. Distribution on the move	**1.a) Mean/ Average**	*APPROXIMATE KNOWNS*	Average/expected conditions change	▪ Supporting trend identification and change awareness building *Limited, subject of medium- to longer-term agricultural development/adaptation planning*
	1.b) Tails		Redefinition of 'extreme events', in many locations likely: ▪ More extreme heat ▪ More extreme precipitation events (more/less volume, intensity change, type change) ▪ More pests & diseases ▪ Advent of types of climate and weather events without precedent in a given location (e.g., wildfires, floods)	▪ Managing deteriorating conditions often with increased risks even under full adaptation ▪ Providing sensitivity analysis to identify threats without precedent in a given location *Important to avoid mal-adapting an existing system to fundamentally different conditions.*
2. Change in variability and volatility (most frequently: increase)		*KNOWN UNKNOWNS*	In the most frequent case of increasing variability: ▪ More extreme events ▪ Less predictability ▪ More pests & diseases	▪ Managing increased risks ▪ Strengthening overall system resilience
3. Increase in uncertainty (Projection confidence uncertainty over future emissions)		*UNKNOWN UNKNOWNS*	▪ Climate projections have limited precision, particularly at local scales ▪ Reduced predictability of future climate & weather conditions	▪ Strengthening overall risk management capacity to prepare for the unknown/ unexpected ▪ Uncertainty-proofing decision-making processes

CHAPTER ONE

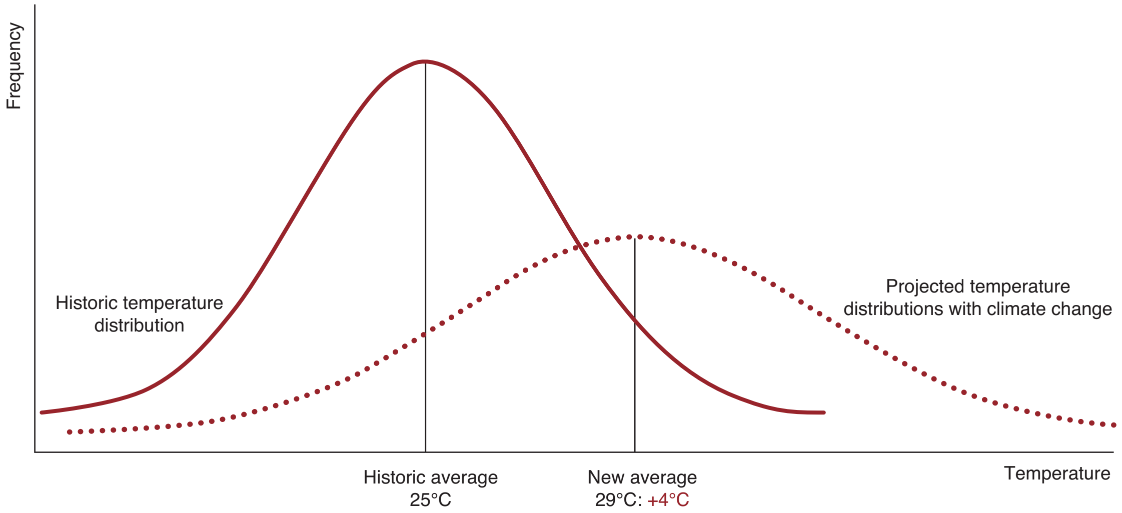
CONCEPTUALIZING CLIMATE CHANGE IMPLICATIONS FOR ARM

As a starting point in conceptualizing the implications of climate change for ARM, consider the below illustrations of the different effects climate change will entail.

Figure 1.1 shows two probabilistic distributions of average maximum temperatures in a given location on a given day of the year. The solid green line shows that on average and before climate change, the weather on that day was most likely to exhibit a maximum of 25°C or fall into the range just around it (23–27°C). (See box 1.1.) With climate change of +4°C, this average would move to 29°C (dotted green line).

Note that the distribution shows the different probabilities of a particular temperature maximum occurring. As temperatures move away from the mean and toward the flatter parts of the distribution (the tails) manifestations become much less likely. If such a very unlikely event occurs (for example, a temperature above 30°C in the original distribution), scientists speak of an "extreme event."

FIGURE 1.1. ILLUSTRATION OF THE EVOLUTION OF A TEMPERATURE DISTRIBUTION WITH A +4°C CHANGE IN AVERAGE TEMPERATURE



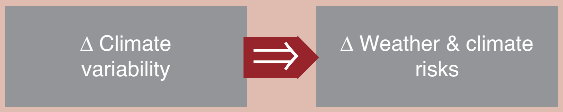
BOX 1.1. KEY CLARIFICATIONS

Weather describes the atmospheric conditions at a specific place and time. *Climate*, in a narrow sense, is often defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. Thus climate change typically refers to any change in the climate conditions over time that can be identified by changes in the mean or the variability of its properties (IPCC 2014).

Weather and climate as well as their derivative terms such as "climate variability" or "weather risk" are not always used consistently and may carry different meanings across the climate change and agriculture risk management communities.

Climate variability refers to variations in the mean state and other climate statistics (standard deviations, the occurrence of extremes, and so on) on all temporal and spatial scales beyond those of individual weather events. While this definition for instance includes natural inter-decadal climate variability or long-term climate change, the term climate variability most commonly refers to shorter term variation in climate conditions, such as extremes occurring within a season or varying rainfall quantities across seasons.

FIGURE B1.1.1. CHANGES IN CLIMATE VARIABILITY TRIGGER CHANGES IN WEATHER AND CLIMATE RISKS



A change in climate variability entails a change in the incidence of weather and climate risks. For instance, higher rainfall variability can increase the risks of flooding and drought. Based on the IPCC's distinction between extreme weather and climate events (2012), climate risks can be defined as risks arising from events happening over a longer time scale, for instance low rainfall over a season. Weather risk on the other hand would be risks associated with a single weather event such as a heavy precipitation event. The distinction between the two terms is not precise (IPCC 2012) and they are used almost interchangeably in the ARM literature.

Shift in Climatic Means

In the ARM literature, changes in climate averages are often referred to as "trends" and are described to have limited implications for ARM. Such "climate trends" may give rise to complex questions of adaptation planning but answers will mostly need to come from broader agriculture development planning.

To simplify, ARM is concerned with risks arising in the short run, treating the agricultural system as a given. Adjustments to shifts in average growing conditions, however, involve the development of policy responses to medium- to long-term challenges. ARM can help inform these choices but does not take a primary role.

It is important to note that when ARM is misguidedly deployed to protect farmers from the results of a change in average growing conditions, maladaptation may result. Maladaptation in this case would describe a process where ARM helps to maintain a status quo that will eventually become non-viable. The longer ARM prolongs the situation, the more time and resources are lost that could have been used to support the sector in the transition to a new adapted system.

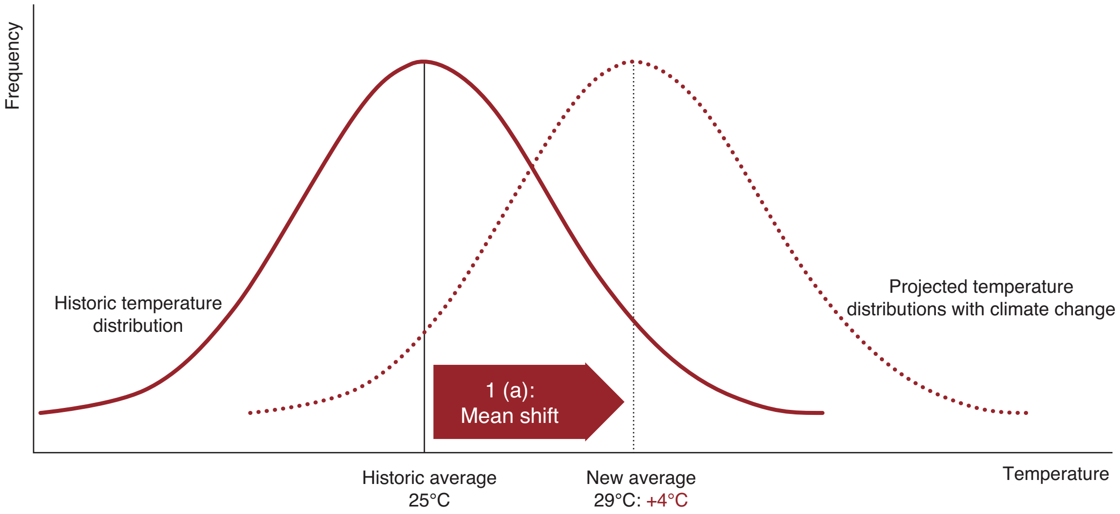
To illustrate, figure 1.2 depicts a 4°C increase in the average temperature maximum for a given location on a given day of the year. Such a change would gradually, yet profoundly, alter the climatic context of the agriculture sector in the region in question. For instance, a 4°C shift corresponds to the difference in yearly average temperature maximums between New York (17°C) and San Diego (21°C).[1] ARM's role would be to manage the risks arising from corresponding shifts of the distribution's tails (part of what the ARM literature refers to as "risks"), not so much to plan for and design the new agricultural production system fit for the new climatic average. By inference, ARM's role would not be to enable ultimately futile attempts to practice "New York agriculture" in a "San Diego climate."[2]

---

[1] Comparison for illustrative purposes only, every local climate context is complex and many variables are needed to describe and compare contexts.

[2] This illustration uses temperature because temperature distributions are well approximated using simple normal distributions. Other climate variables such as precipitation tend to follow more complex statistical patterns, please refer to box 2.2. Moreover, different locations are best approximated by different distributions. However, the basic concepts of mean, variability, and tails are also applicable here.

FIGURE 1.2. ILLUSTRATION OF CLIMATE CHANGE SHIFTING THE MEAN OF A TEMPERATURE DISTRIBUTION



The implications of a change in climatic means for ARM are limited, as gradual slow-onset temperature or precipitation shifts at or around the mean are unlikely to affect agricultural risks in the short or medium terms (in difference to the moving tails described in the next section).

Shifting Tails

As temperature means can shift, so can the tails of distributions. Since tails of temperature or precipitation distributions house climate and weather extremes, they are of more immediate importance to ARM.

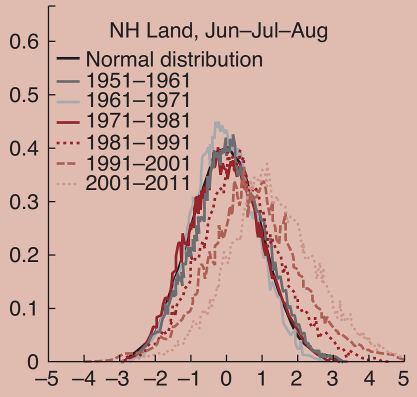
Extreme events are commonly defined by the likelihood of their occurrence. Even if a climatic condition is "extreme" compared to global averages (say the dryness of a desert), it may not be classified as an extreme event if it is a common occurrence in the given context (such as a drought in the desert).

Shifting tails imply that the definitions of "extreme" events will change. What used to be an extreme event before the shift may become a common occurrence while more extreme or altogether new events will be classified as "extreme events." Take the example in figure 1.3. Originally, a day above 30°C only occurs with a probability of 5 percent. With 4°C climate change however, temperatures 30°C and above lay only 1°C above the average and will occur much more frequently. 30°C is no longer an extreme. The new extreme events, occurring only with a probability of 5 percent, would be temperatures of 34°C and above.

BOX 1.2. SHIFTING TEMPERATURE DISTRIBUTION

Figure B1.2.1 illustrates such a shift in temperature distribution in the case of the shift in average temperatures on the landmass of earth's northern hemisphere over the past 50 years (Hansen et al. 2012).

FIGURE B1.2.1. SHIFT IN THE SUMMER TEMPERATURES ON THE LANDMASS OF THE NORTHERN HEMISPHERE

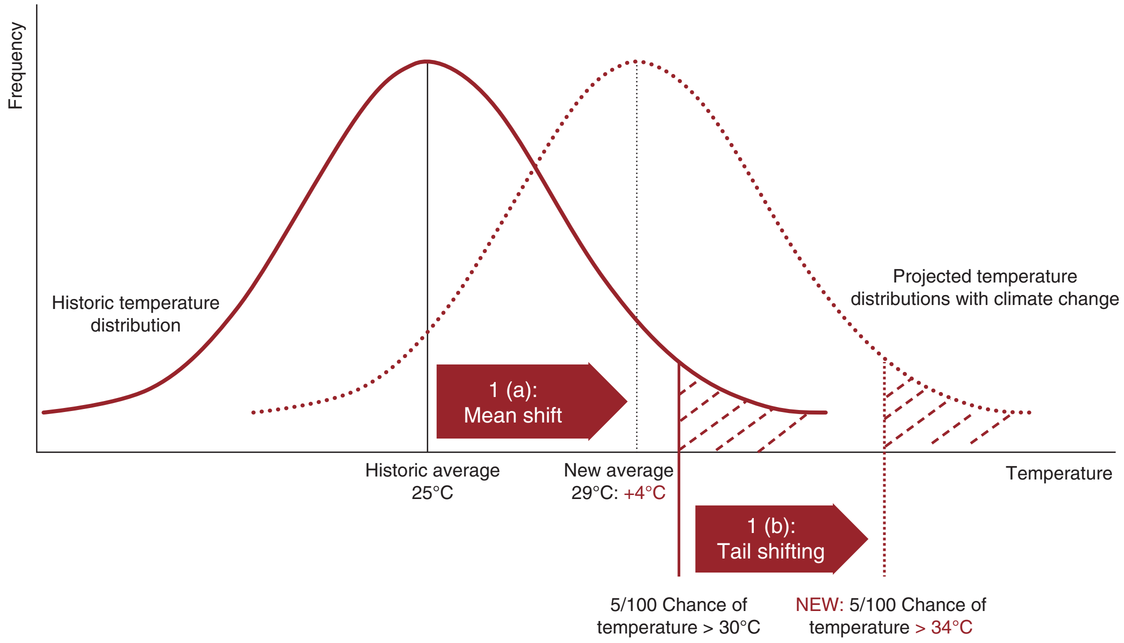


Source: Hansen et al. 2012.

Strictly speaking, even a shift of the tails and the altered frequencies of extreme events that come with it result directly from the overall climate change trend, akin to the shift in averages.

If complete adaptation of production systems to new sets of climatic conditions (including mean and tails) could be

FIGURE 1.3. ILLUSTRATION OF THE EFFECT OF CLIMATE CHANGE ON THE TAILS OF A TEMPERATURE DISTRIBUTION



assumed, there would be no unambiguous effect of climate change on agricultural risks within a given system. To illustrate, take a semi-arid region with a production system centered around maize as an example. Say the climate change trend were to bring fully arid conditions with diminished average rain and a strong increase in the risk of drought. Assuming full adaptation, the production system might switch entirely to, as an example, the production of dates and pastoralist livestock. In this case, agricultural risks may even have diminished as a result of the adaptation to the climate change trend.

However, there are several reasons why shifting tails will, in many cases of climate variables and contexts, increase agricultural risks and hence the need for ARM.

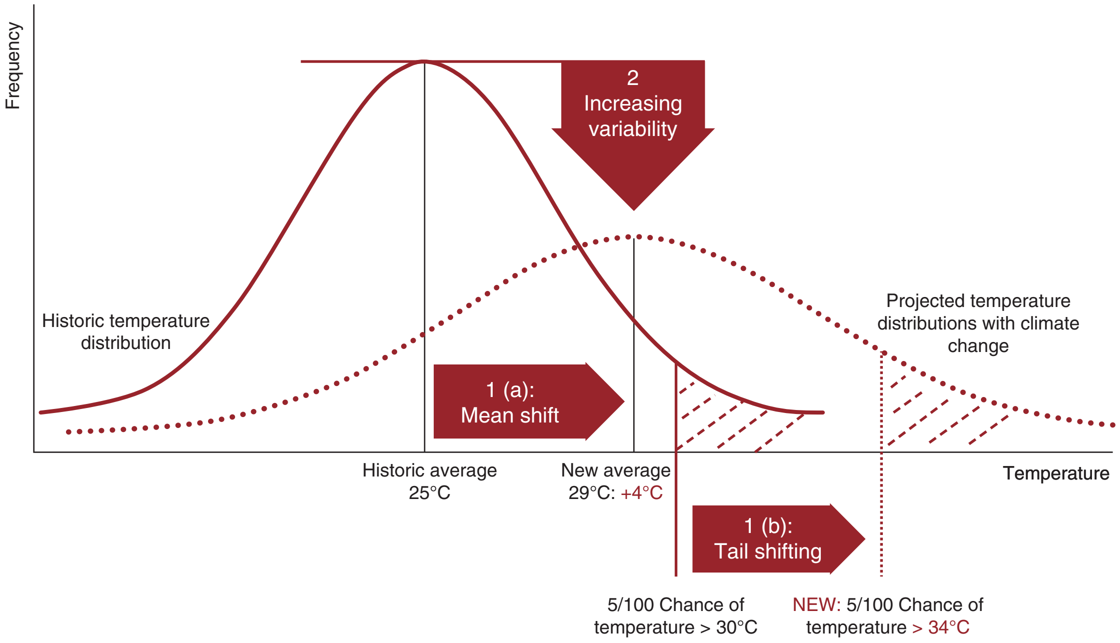
First, adaptation will take time. It will often require structural changes and involve transitional phases. For instance, new types of physical and human capital will need to be accumulated and access to new markets developed. During transition periods, parts of the production system may be maladapted to prevailing climatic conditions and hence require increased ARM capacity.

Second, full adaptation may often remain elusive. Especially in many tropical contexts, the direction of the climate change trend will lead to a deterioration of agricultural conditions overall (Jarvis et al. 2011). One very important case in point are the critical temperature thresholds that all members of the "big four"—corn, rice, soybeans, and wheat—exhibit. When temperatures during certain stages of plant growth exceed these thresholds, severe yield losses occur (see the section on Increasing Climate Variability). These crops are of systemic importance for food security. Equally calorie-productive substitutes are often not available. Farmers may therefore often have no choice but to continue to grow the same crop as conditions deteriorate, particularly those practicing subsistence farming. In such contexts and all others where growing conditions worsen overall, agricultural risks will increase significantly—and so will the need for ARM.

Finally, new kinds of extreme events, may also be part of this "new normal." New types of climatic hazards may affect regions without previous experience in managing the risks associated with them. For instance, this dynamic is particularly relevant for pests and diseases, where relatively minor deviations from average weather patterns can lead to non-linear changes in disease and pest prevalence.

The possibility of the appearance of new types of extreme events will pose a new challenge to ARM. ARM will be required to develop

FIGURE 1.4. ILLUSTRATION OF THE EFFECT OF CLIMATE CHANGE ON THE VARIABILITY OF A TEMPERATURE DISTRIBUTION



the capacity to identify thresholds triggering potential new hazards and anticipate which novel extreme events may arise to help prepare farmers and national, as well as regional, systems in dealing with the risks associated. This will be particularly critical as it can help avoid the often drastic losses associated with the first appearance of a locally as yet unknown risk.

Increasing Climate Variability

Science predicts that climate change will alter climate variability, with increases expected for most locations. More variability translates into less predictability of climate and weather. Increased variability can be observed in figure 1.4: As the temperature curve flattens, variability increases. The expected temperature at the mean is still the most likely outcome, but it is less dominant than it previously was. That is, other temperatures have become more likely and the tails have “fattened,” showing the increased likelihood of extreme events. This flattening implies overall less predictable and therefore more “variable” climate.

The resulting demands on ARM of increased climate variability are as straightforward as they are critical. As it has been to date, ARM’s job will be to protect such weather fluctuations from impacting production and farmer incomes. More variability will entail more frequent risk events and an increase in the degree of difficulty and importance of managing risk.

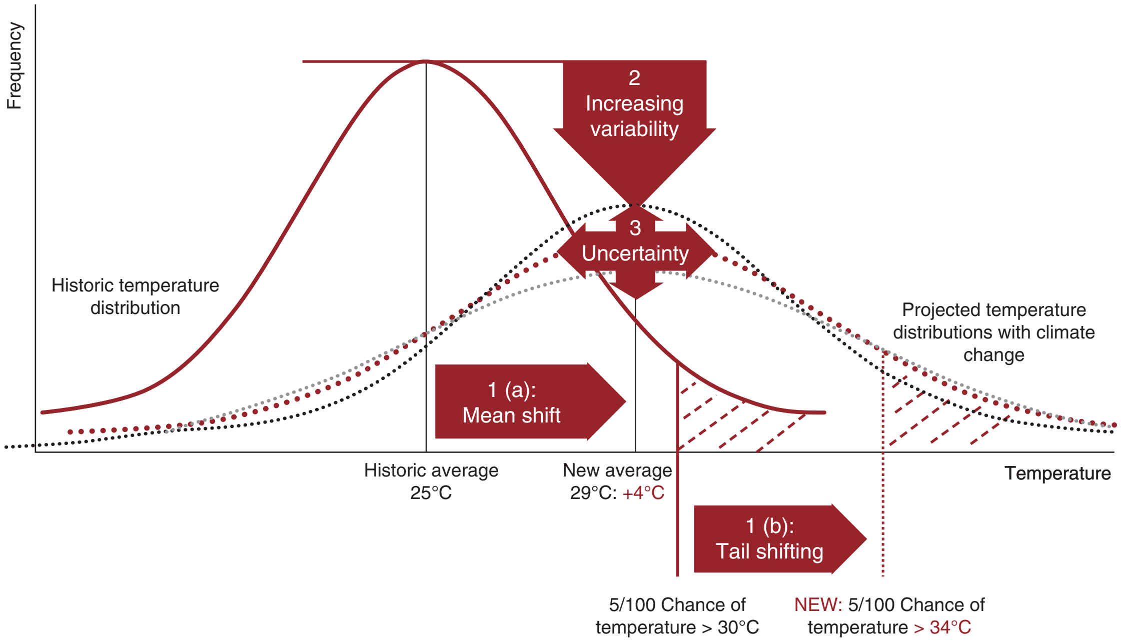
Increased Climate Uncertainty

Finally, climate change means that we know less about what the climate will be like in future times than we used to (see dotted lines in figure 1.5). Natural variation (internal variability) has always created uncertainty over future climate conditions and only parts of it could be explained by science.

Today, the additional layer of man-made climate change (a type of external variability) introduces additional uncertainty from two sources. First the phenomenon is not fully understood and projections include errors of varying importance depending on scale and nature of the phenomenon projected. For instance, projections of highly relevant climate extremes tend to contain larger errors than projections of average climatic conditions. A second source of uncertainty stems from our limited ability to predict the human behavior that drives man-made climate change. Projections hinge on emissions scenarios, particularly for longer time scales.

ARM will need to take account of uncertainty over future climate, for instance by developing strategies to take robust decisions under uncertainty and further emphasizing institutional capacity that enables successful risk management under many scenarios.

FIGURE 1.5. ILLUSTRATION OF THE EFFECT OF CLIMATE CHANGE ON CLIMATIC UNCERTAINTY



Conclusion

In summary, climate change requires adjusting both to new average climatic conditions and preparing for more volatile weather with more frequent and intense extreme events in most locations (see figure 1.2). This is because changes in average conditions also impact the frequency of what today are considered extreme events (see figure 1.3) and because climate change will alter the inherent climate variability (see figure 1.4). Finally the remaining uncertainty over future climate change will lead to more climatic uncertainty overall (see figure 1.5). Together, these effects combine to form the "new normal," to which all stakeholders will need to adapt.

CHAPTER TWO

CLIMATE CHANGE RISKS IN AGRICULTURE

Weather and climate risks are pervasive in the agriculture sector.[3] Agricultural risks driven by the vagaries of weather are a daily reality for hundreds of millions of farmers, traders, processors, retailers, and other stakeholders engaged in agricultural supply chains around the world. Since the beginning of time, actors have been exposed and have found ways to mitigate, transfer, and cope with risks both before (ex-ante) and after (ex-post) they occurred (Hess et al. 2004).

These risks can be classified primarily into production risks, market risks, and enabling environment risks. Climate change will have impacts at all three levels.

This threefold categorization of agricultural risks has previously been shown to be useful (World Bank 2013a) and can help avoid the common fallacy of exclusively situating climate change impacts in agriculture at producer level. Production losses due to climate and weather events, in concurrence with other factors, can have far reaching implications for entire supply chains and the food system as a whole. They can ultimately trigger government reactions such as export controls or subsidies that can alter the enabling environment of the industry. It is therefore necessary to examine climate change impacts on agricultural risk beyond the production level.

Among the many implications of climate change for agriculture, the following chapters will focus exclusively on the domain of agricultural risk management: changes directly affecting short- to medium-term agricultural risks. That is, the changes that entail additional variability of weather and climate, more frequent and intense extreme events and higher uncertainty overall. For a brief summary of the impacts of changing average conditions on the global agriculture system, see appendix A. For a more detailed discussion, refer to the IPCC (2014) chapter on the impacts of climate change on food security and food production systems.[4]

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[3] In this report, agriculture consists of crops and livestock.

[4] http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap7_FGDall.pdf

BOX 2.1. AGRICULTURE IS PART OF THE PROBLEM AND THE SOLUTION TO CLIMATE CHANGE

Agriculture is a very significant part of the climate change problem. Agriculture and associated land use change account for up to one quarter of greenhouse gas (GHG) emissions globally. It is the largest single contributing sector after energy. For many developing countries, agriculture is the largest source of emissions.

At the same time, agriculture has the potential to become part of the solution. A number of agriculture practices are known to reduce emissions or enable the sequestration of carbon in soils and biomass. Moreover, by increasing productivity, agriculture can help to reduce deforestation pressures.

One key strategy to achieve this directional shift of the sector, is climate-smart agriculture (CSA). CSA is an approach for transforming and reorienting agricultural systems to support food security under the new realities of climate change (Lipper et al. 2014). It aims to achieve three simultaneous outcomes: Increased productivity, enhanced resilience, and reduced emissions. Examples of tools that can increase the climate-smartness of production include a wide range of practices and approaches from agroforestry to rangeland management to climate and weather information services.

PRODUCTION RISKS

This chapter assesses production risks amplified by increased frequency and intensity of extreme events as well as higher climatic variability overall. Building on the information provided by publications such as the World Bank's "Turn Down the Heat" Series (2014a), temperature fluctuations, drought events, heavy rainfall (including floods), and other direct weather events—such as cyclones and storms—as well as indirect implications of climate change—such as pests and diseases are discussed. Understanding how these will occur and what the overall risk landscape will look like will be critical in developing measures to manage risks and adapt agriculture to climate change.[5]

TEMPERATURE FLUCTUATIONS

Change in the occurrence of temperature extremes has been observed since the mid-20th century, some of which can be attributed to anthropogenic or man-made climate change (IPCC 2013). Both heat- and cold-day extremes have a detrimental impact on crops, but climate change will have different impacts on the probability of the occurrence of these events in a given season. According to the IPCC (2013), the number of cold days and nights has decreased over the past several decades, while globally the number of warm days and nights has increased. Fewer frost days over time have been found for every country in which they have been studied (Easterling 2000). Further, extreme minimum temperatures have had a strong increasing trend in each season over the last several decades. Significantly, the frequency of heat waves over a large part of Europe, Asia, and Australia has increased, with the probability of heat wave occurrence more than doubling in some locations (IPCC 2013). Daily temperature extremes in Africa and South America have less certainly been affected by climate change, but in most regions of the globe that have enough indicative data available, there is at least medium confidence that the duration or frequency of heat waves or warm spells has increased (IPCC 2011).

EXTREME HEAT DAYS AND NIGHTS; HEAT WAVES

Short-term temperature extremes can be critical for plant growth, especially when coinciding with key stages of plant development. Plant physiology can be significantly altered beyond key temperature thresholds, leading to the potential for severe crop yield impacts from projected climate change (Gornall et al. 2010).

For many crops, when a plant enters its flowering stage (including right before and after), just a few days of extreme temperatures (greater than 32°C) can drastically reduce yield (Wheeler et al. 2000). For rice, if temperatures at flowering exceed 35°C for more than just one hour, high percentages of the grains become sterile (Luo 2009). In one experiment, soybeans produced nearly a third less in seed yields after experiencing a 10°C temperature increase for 8 days during the late flowering stage and early pod filling (Luo 2009).

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[5] For a discussion of the impacts on climate change on average growing conditions rather than short- to medium-term agriculture risks, please refer to appendix A.

Short-durations of high temperatures can also impact crops in other ways. Despite being typically produced in high temperatures, groundnuts for instance see severely reduced yields when temperatures exceed 42°C even for short periods of time during post-flowering (Prasad et al. 2003). For maize, short periods above 36°C reduce its pollen's viability. Plants that require seasonal cold temperatures to flower, such as winter wheat, are also impacted by periods of high temperatures, impeding the flowering process. Furthermore, in the United States, crop yields are negatively impacted by temperatures above 29°C for corn, 30°C for soybean and 32°C for cotton (Gornall et al. 2010).

Without adaptation, even mid-latitude crops could suffer at very high temperatures during critical growth stages. Recent increases in climate variability may have affected crop yields in countries across Europe since around the mid-1980s causing higher inter-annual variability in wheat yields (Porter and Semenov 2005). Changes in annual yield variability would make wheat a high-risk crop in some locations, such as Spain. In 1972, an extremely high average summer temperature in the former Soviet Union (USSR) contributed to widespread disruptions in world cereal markets and food security (Battisti and Naylor 2009). Similarly high temperatures and drought have had an impact in Russia in recent years, including 2010 and 2012, impacting global wheat prices and policies, further discussed in the following sections on market and enabling environment risks.

The sensitivity of production systems to extreme temperatures is partly the result of biophysical relationships but also depends strongly on their individual characteristics and context. For instance, while irrigated systems also face stress under extreme temperatures, it is typically expected that rain-fed systems will experience more harm, since transpiration cools canopies and prevents direct temperature damage (Lobell and Gourdji 2012). Crops that are more frequently irrigated such as rice and sugarcane may therefore be less sensitive to extreme temperatures.

In some instances, rice may even benefit from moderately higher maximum temperatures, until direct heat damage occurs (Welch et al. 2010). Similarly, irrigated maize in the western United States is much less sensitive to extreme heat than rain-fed maize elsewhere (Schlenker and Roberts 2009). In very wet areas, rain-fed crops have a similar level of resilience to heat stress as irrigated crops.

While the impact of extreme heat on livestock has not been well studied, it is known to cause physiological harm. The thermal comfort zone of temperate-region cattle is 5–15°C, although tropical breeds have higher heat tolerance (Sirohi and Michaelowa 2007). Temperatures above this range affect livestock in four significant ways: (1) causing mortality through heat-stress, (2) reducing feed intake, (3) reducing dairy yields, and (4) affecting reproduction (Thornton et al. 2009). In general, most livestock species have comfort zones between 10 and 30°C, and at temperatures above this, animals reduce their feed intake 3–5 percent per additional degree of temperature, so temperature extremes may have a large impact.

Finally, extreme heat poses significant risks for farmers and rural labor directly. Several recent studies have shown that many rural areas of the world will likely be exposed to prolonged heat waves that impact rural populations' health disproportionately severely (see for instance Burgess et al. 2015).

FEWER COLD DAYS AND NIGHTS, DECREASE IN FROST OCCURRENCE

Decreased incidences of cold days and nights are, independently, likely to have a positive impact on crop production. Frost occurrences typically have a negative impact on crop production, so a decrease in the incidence of frost and similar cold stresses will improve crop production globally. One of the crops likely to benefit from this is wheat, as less occurrences of frost will reduce the potential for chilling and freezing injuries (Government of Western Australia 2013). However, the positive impact of less frost days is not expected to outweigh the negative impacts of more frequent high temperature extremes.

Crops experience different risks from frost. Although cold extremes are typically harmful, cold temperatures are often important for pre-flowering plant stages, so a decrease in cold temperatures can also have negative impacts in certain cases. For non-grain crops such as fruits, production risks may result from variability, as seen in reduced low-temperature nights and earlier start of the warm season. If the temperature drops shortly after a brief warm period, fruits such as cherries, apples, and pears may flower too early, harming yields if temperatures drop.

DROUGHT EVENTS

Drought is a climatic occurrence characterized by temporary moisture availability significantly below average over a specified period. It can thus occur even in wet and humid regions. Arid areas are prone to drought because the amount of rainfall often critically depends on a small number of rainfall events (Dai 2011).

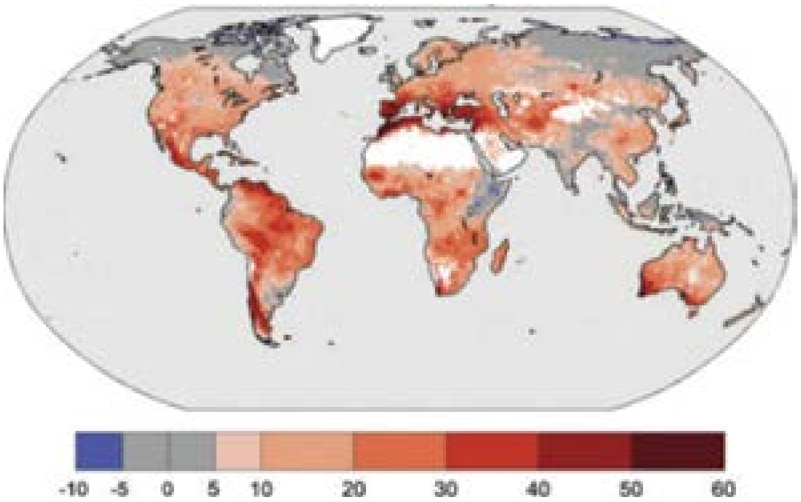
Droughts arise from combinations of five factors: (1) Delays in the onset of rain or rainy seasons; (2) early cessation of rain or the rainy season; (3) prolonged periods without rainfall resulting in an unusual rainfall distribution; (4) a lack in the volume of cumulative rainfall over the growing season; and (5) water and soil moisture deficits during critical stages of crop growth (for example, flowering).

All of these factors are likely to be impacted by climate change. Some areas have already experienced more intense and longer droughts due to climate change, in particular southern Europe and West Africa (IPCC 2011). Figure 2.1 shows the relative increase in the occurrence of drought conditions for a 4°C world relative to the 1976–2005 baseline (Prudhomme et al. 2013).

Many of the largest reductions in crop productivity historically have been attributed to anomalously low precipitation events (Kumar et al. 2004; Sivakumar et al. 2005). Since the 1960s, major growing areas of barley, maize, rice, sorghum, soybean, and wheat globally have seen an increase in the percentage of area affected by drought, from approximately 5–10 percent to approximately 15–25 percent as defined in terms of the PDSI (Gornall et al. 2010). Anthropogenic increases in greenhouse gas and aerosol concentrations have made a measurable contribution to the observed drying trend in PDSI (Burke et al. 2006; IPCC 2007).

Droughts are expected to intensify with medium confidence in the 21st century in regions including southern Europe and the Mediterranean region, central Europe, central North America, Central America and

FIGURE 2.1. PERCENTILE CHANGE IN THE NUMBER OF DAYS UNDER DROUGHT CONDITIONS BY THE END OF THE 21ST CENTURY (2070–2099)



Source: Prudhomme et al. 2013.
Note: White regions: Hyper-arid regions for which runoff is equal to zero more than 90 percent of the time in the reference and future periods.

Mexico, northeast Brazil, and southern Africa (IPCC 2011; figure ES.2). Monsoon failures in South Asia are a possibility of non-negligible likelihood (Nelson et al. 2010). Other areas have overall low confidence for drought intensification as a result of inconsistent drought change projections, dependent both on model and dryness index.

At mid to high latitudes, drought impacts may complicate the potential benefits the regions may experience due to average increased temperature and season length. In Russia, for instance, while some losses may be offset by gains in other areas, many of the main crop growing areas may experience crop production shortfalls twice as often in the 2020s, and triple in the 2070s (Alcamo et al. 2007).

Droughts also affect livestock significantly either through reduced length of the growing period (Kristjanson et al. 2004), reduced feed and fodder availability, or through lack of water. In India for instance, reduced feed and water availability due to a drought in 1987 affected 168 million cattle. The state of Gujarat alone, lost more than half of its cattle (Sirohi and Michaelowa 2007). In Mongolia, summer droughts have been observed to cause delayed rather than immediate fatalities. There, a summer drought prevents cattle from obtaining enough calories to subsequently weather the harsh winters and spring windstorms, causing delayed fatalities during these periods (Batima 2006). Finally, when droughts are followed by high rainfall, there has been some observance of increased outbreaks of diseases (Thornton et al. 2009).

INCREASED PRECIPITATION EVENTS

Rising temperatures generally lead to heavier precipitation events for two reasons. First more evapotranspiration under higher temperatures results in more water vapor present in the atmosphere. Second, simultaneously, a warmer atmosphere can hold a greater amount of moisture (UCSUSA 2011). Extreme and heavy precipitation has had multiple definitions in the literature due to the diversity of climates to which the descriptions apply. The most common four definitions include: precipitation from very wet days, simple daily intensity index, wettest day, and wettest consecutive day (IPCC 2013).

More regions have likely seen increases in the number of heavy precipitation events than decreases (IPCC 2011). In North America and Europe, the frequency and intensity of heavy precipitation events has likely increased. Most countries that experienced a significant increase or decrease in monthly or seasonal precipitation also experienced a disproportionate change in the amount of precipitation falling during the heavy and extreme precipitation events. In some areas the frequency of 1-day heavy precipitation events increased but the seasonal total did not; this can indicate a deficiency in available water for some of the month, followed by a harmful heavy precipitation event (Easterling 2000). Increases in extreme precipitation events, including major storms, are responsible for a disproportionate share of the observed 5 to 10 percent increase in total annual precipitation that the United States has experienced since the early 20th century.

TABLE 2.1. DEFINITIONS AND INDICES MOST COMMONLY USED IN CLIMATE LITERATURE TO DESCRIBE EXTREME PRECIPITATION

Name	Description
Precipitation from very wet days	Amount of precipitation from days greater than the 95th percentile (mm)
Simple daily intensity index	Ratio of annual total precipitation to the number of wet days, which are those with 1 mm of rain or more (mm day)
Wettest day	Maximum 1-day precipitation (mm)
Wettest consecutive 5 days	Maximum of consecutive five days of precipitation (mm)

Source: IPCC 2013.

As mean surface temperature increases, extreme precipitation events are very likely to become more intense and more frequent by the end of the 21st century over most of the mid-latitude areas, especially in winter, and over wet tropical regions (IPCC 2013).

Heavy rainfalls associated with tropical cyclones are likely to increase with continued warming. In some regions, increases in heavy precipitation will occur despite projected decreases in total precipitation in those regions. Multiple emissions scenarios suggest that in many regions, a current once-in-20-year annual maximum daily precipitation amount is likely to become a once-in-5 to once-in-15-year event by the end of the 21st century. The proportion of total rain falling in heavy rainfall events appears to be increasing, and this trend is expected to continue as the climate continues to warm. For instance, a doubling of carbon dioxide is projected to lead to an increase in intense rainfall over much of Europe (Gornall et al. 2010).

Heavy rainfall can severely impact crop production. Overabundant water can result in reduced plant growth due to poor seed distribution, germination and emergence, soil and nutrient erosion, soil water logging, siltation of water storage areas, and floods. For rice, it is especially harmful when heavy rain falls on freshly seeded fields, and is worse if the field has been wet direct seeded. Heavy textured soils tend to have a worse result (IRRI 2009). Heavy rainfall at the crop maturity stage may be linked to crop lodging, delayed harvest, higher grain moisture content, potentially lower grain quality and increased frequency of fungal disease infections of the grain (Kettlewell et al. 1999). In one case, due to the poor quality of the product, the amount of milling wheat exported from the UK decreased significantly (Kettlewell et al. 1999). If agricultural machinery is not appropriately adapted to wetter soil conditions, planting may also be delayed, leading to huge potential crop losses.

FLOODS

Changes in the magnitude and frequency of floods associated with climate change are somewhat difficult to ascertain due to limited instrumental records taken by gauge stations and complicating factors such as the simultaneous impact of land use change and engineering, both of which have a significant effect on flood occurrence. Therefore there is low confidence in flood changes resulting from climate change (IPCC 2011). Despite low overall confidence in flood predictions, the expectation of heavy rains and temperature changes in some regions can imply, through physical reasoning, possible increases in flood risk in those locations (IPCC 2011).

Flooding can have significant negative impacts on crop production. Heavy rainfall events that result in flooding can wipe out entire crops over wide areas. For instance in Jamaica, flooding causes large-scale damage to sugarcane, for which a high water table, about one foot below the surface is detrimental (IDB 2013). In addition to high water tables, in coastal communities flooding can cause damage by increasing salinity, through saline water intrusion (IDB 2013). Flooding can also have duplicitous harmful effects in countries with winters if it occurs prior to winter freezes. In 2011, the areas along the largest rivers in the United States—Missouri, Ohio, and Mississippi—experienced $3.4 billion of direct damage, including significant crop loss, due to flash flooding. The flash flooding occurred after heavy spring snowmelt was induced by heavy precipitation in the Northern Plains in the summer and fall of the year prior (NOAA 2011).

Flooding also harms livestock through multiple channels. Significant flooding, particularly in the form of flash floods, can lead to significant livestock losses. In India alone, flooding has caused average losses of nearly 94 thousand cattle annually (Sirohi and Michaelowa 2007). In the year 2000, one state alone lost 84 of a total of 93 thousand cattle during Southwest monsoon floods (Sirohi and Michaelowa 2007). Furthermore flooding can increase the spread of pests and diseases (see subsequent section). Finally flooding also affects feedstocks with possible negative effects on availability and price.

EXTREME PRECIPITATION AND DROUGHT RISK FOR IRRIGATED CROPLAND

Water requirements for irrigation imply that deviations in climate patterns even in areas far from agricultural fields can affect irrigated agricultural production. Agriculture along the Nile in Egypt, for instance, depends on rainfall in the upriver areas of the Nile such as the Ethiopian Highlands (Döll and Siebert 2002).

Climate change may increase river flow for a number of years due to a higher rate of glacier melt. However, this may not always be beneficial. In central Asia for instance, the increased flow in Amu Daria comes in early spring when crops do not require water and often causes harmful floods.

Heavy and low precipitation events in areas besides primary agricultural land may therefore have a significant impact. Despite overall increases in annual water availability, insufficient storage of peak season flow may lead to water scarcity that could affect irrigated crop production, while overabundant rainfall could lead to flooding, indicating the critical importance of extreme or low precipitation events outside river-irrigated croplands for agricultural productivity.

OTHER DIRECT WEATHER EVENTS

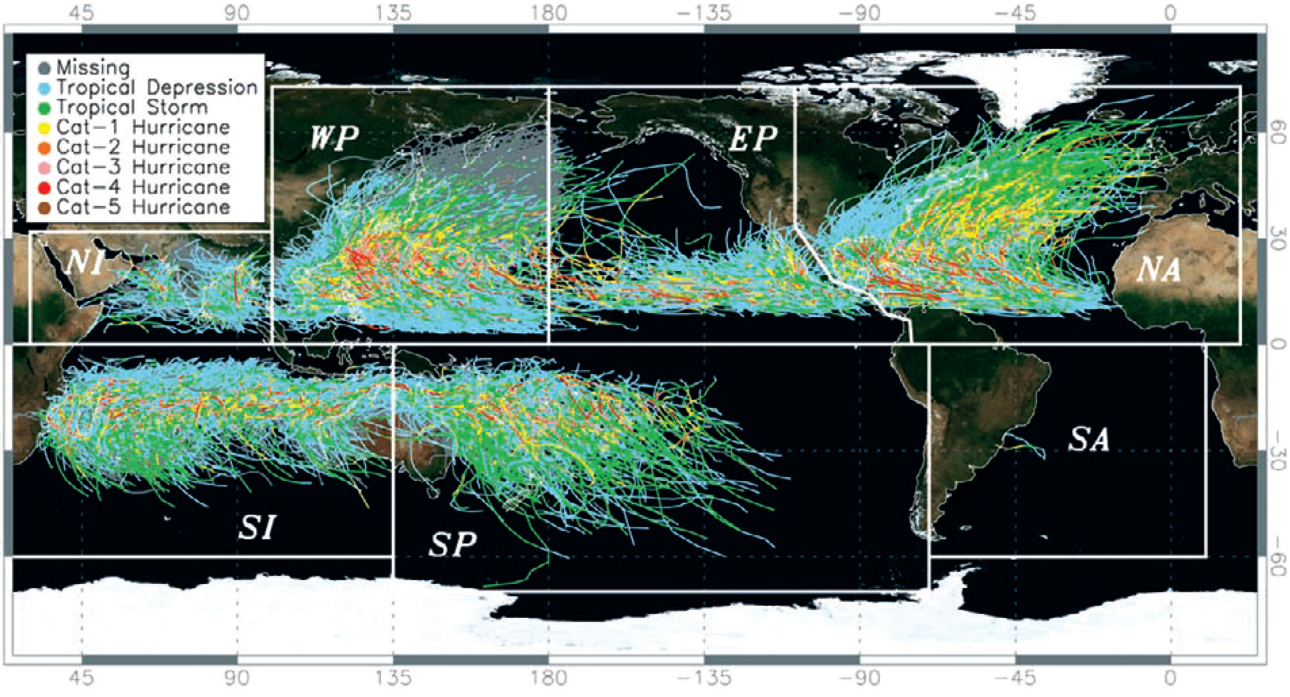
Increase in Heavy Tropical Cyclone Activity

The degree and direction of global change in tropical cyclone frequency and intensity under a warming climate is uncertain. Tropical cyclones may become more intense in the future with stronger winds and heavier precipitation (IPCC 2007). High-resolution models indicate a possible decrease in the frequency of future global tropical cyclones (McDonald et al. 2005; Bengtsson et al. 2007; Gualdi et al. 2008). The models do not all agree on projections of the regional variations in tropical cyclone frequency.

The implications of tropical cyclones for agriculture can be important, particularly in developing countries with high population growth rates in vulnerable tropical and subtropical regions. Tropical cyclone tracks for all known storms over the period 1945–2008 are shown in figure 2.2.

The agricultural regions found most vulnerable to tropical cyclones include the United States, China, Vietnam, India, Bangladesh, Myanmar, and Madagascar. The river deltas of countries along the North Indian Ocean are especially vulnerable because farming in coastal regions most at risk from flooding has increased due to high population growth (Webster 2008). In October 2010 typhoon Megi damaged $44 million of agricultural products and facilities in the Philippines, while typhoon Ketsana caused

FIGURE 2.2. OBSERVED TROPICAL CYCLONE TRACKS AND INTENSITY FOR ALL KNOWN STORMS OVER THE PERIOD 1947–2008



Tracks are produced from the IBTrACS dataset of NOAA/NCDC.
Source: Knapp et al. 2010.

$130 million damage in the agriculture sector in 2009 (CGIAR 2013). Tropical cyclones may result in mixed benefits to agriculture in some cases, including providing relief from droughts and abating water shortage, wildfires, and saltwater intrusion. For instance, in February 2000 cyclone Eline devastated agriculture in Madagascar, but later contributed significantly to beneficial rainfall in southern Namibia (Gornall et al. 2010).

Storm surge events can cause great devastation, even if land is not permanently lost. Relatively little work has been done to assess the impacts of either mean sea-level rise or storm surges on agriculture.

Hail, Bushfire, Windstorm

Hailstorms are an extreme event very frequently associated with risk for agriculture. Hail has been known to prevent wheat flowering in Eastern European and Scandinavian countries, and has a great impact in some parts of the Middle East. It is typically considered a localized event, so most climate models' resolutions are too coarse to simulate hailstorms explicitly. Therefore it has been unclear whether such events will become more likely through intensified thunderstorms or less likely as a result of overall warmer conditions. Recent simulations of hail generation and maintenance during extreme precipitation events in one area have indicated a near-elimination of hail at the surface in the future, despite more intense future storms and significantly larger amounts of in-cloud hail (Mahoney et al. 2012). The main reason for the disappearance of surface hail appears to be an increase in the height of the environmental melting level due to higher temperatures increasing the melting of frozen precipitation. A decrease in future surface hail at high-elevation locations may imply potential changes in both hail damage and flood risk (Mahoney et al. 2012).

Predicted changes in the climate are expected to increase the frequency of fires, as a combination of earlier snowmelts, droughts, and long heat waves that create the conditions for their spread. One such example occurred in 2009 in Victoria, Australia, where drought, record heat, and a 35-day period without rain, created a high-risk fire location from an area normally considered low to medium risk (IPCC SREX 2011). This combination of conditions is not limited to Australia. In 2003, for instance, during a long summer heat wave Italy saw a prolonged period of very high temperatures which caused large fires and a 36 percent drop in maize production (IPCC, SREX 2011). Other conditions leading to fires include droughts following rainy seasons which can turn vegetation into fuel for wildfires (IPCC, SREX 2011). Additionally, in the western U.S. rangelands, droughts can promote the growth of invasive fire-fueling grasses (Walthall et al. 2012)

Windstorms, storms with winds typically exceeding 34 miles per hour, but classified separately from cyclones and tornadoes, are expected to increase in intensity and frequency with climate change (IPCC 2013). Livestock can be severely damaged by windstorms, as has been the case during a dzud in 2009–10 in Mongolia. A dzud is an unusual weather condition combining heavy windstorms with heavy snowfalls. It affected 50 percent of the livestock from the households of the country's herders and by April, 75 thousand herder families had lost more than half or all of their livestock.

INDIRECT EFFECTS OF CLIMATE AND WEATHER EVENTS—PESTS AND DISEASES

Climate change will have significant impacts on the occurrence of pests and diseases because weather exerts an influence on all stages of host and pathogen life cycles and the development of disease. Increasing climate variability, higher average temperatures, warmer winter minimum temperatures, changes in precipitation patterns, and water shortages are all climate factors that may favor pest and disease invasions.

Active debate is ongoing and significant uncertainty remains regarding the likely effects of climate change on pests and diseases. Some argue that while the distribution of diseases may be affected by some climate-related shifts in the areas suitable for vector-borne diseases—such as malaria and bluetongue—impacts in the shorter term are not expected to be significant (Woolhouse 2006).

Other studies indicate that increases in climate variability and average conditions may extend the geographic range of some insect pests. For instance, with a 1°C increase in temperature a northward shift in distribution of between 165 and 500 km is indicated for the European corn borer, a major pest of grain maize. La Roya coffee rust has attacked coffee plants in Central and South America at higher altitudes as the climate warms (Oxfam 2013). Over the next 10–20 years, oilseed rape disease could both become more severe in its current area and spread to more northern regions (Evans et al. 2008). Temperature increases may also advance invasions in the growing season, when the crop is at early development and susceptible. Precipitation increases are also likely to favor the development of fungal and bacterial pathogens (Parry 1990). Similar developments are already ongoing, for instance with the coffee berry borer (*Hypothenemus hampei*) having become more prevalent in East Africa due to existing warming (Jaramillo et al. 2011). Some pests, including aphids and weevil larvae, respond positively to higher levels of atmospheric CO_2 (Staley and Johnson 2008; Newman 2004). Aphids may also benefit from increased temperatures, which prevent them from dying in large numbers during the winter and may allow the species to disperse earlier and more widely (Zhou et al. 1995). As a result of rainfall-based migration patterns, precipitation variability due to climate change may affect locust occurrences in sub-Saharan Africa (Cheke and Tratalos 2007).

Climate change impacts have had profound effects on the distribution of animal diseases, and will further transform the ecology of numerous pathogens. The current trend regarding the ever-increasing globalization of the trade of animals and animal products ensures that agricultural diseases will continue to follow legal and illegal trade patterns with increasing rapidity. In recent years, many agricultural diseases have given cause for concern regarding changes in distribution or severity. Foot-and-mouth disease, avian influenza, and African swine fever continue to cause serious problems (Arzt 2010).

Risk of water-associated diseases may be further exacerbated by the increased potential for flooding in some areas and complicated by inadequate water access. For instance, the Rift Valley Fever's (RVF) vectors are mosquitos whose population grows with period of desiccation and flooding, even if the flooding period is short. The disease is highly detrimental to livestock, as well as humans—in 1997/98 over 100,000 animals died and 90,000 humans were infected (World Bank 2014b).

Higher infection can result from more malnourished animals, which may be an indirect result of lowered precipitation, and could exacerbate potential spread of these diseases. Increased movements of people and livestock resulting from drought impacts could expose them to environments with new or increased health risks.

Overall, it is clear that the potential impacts of climate change on pest and disease could be of major significance. While the debate on the immediacy of some of the effects continues, significant knowledge gaps concerning many existing diseases of livestock and their relation to climate remain, and it is crucial to continue pursuing the topic (King et al. 2006).

Conclusion

Climate change brings predominantly negative impacts on agricultural production of both crops and livestock. Increased climate variability, more frequent and intense extreme events of different types and more uncertainty overall will lead to increased production risks.

As discussed in the following chapter, these risks will often transmit into markets for agricultural commodities, creating additional risks at the market level.

MARKET RISK

Markets are directly affected by agricultural production risks from climate and weather events. As a result of this transmission, climate change will indirectly amplify price volatility of agricultural commodities and increase supply disruptions. This section examines challenges posed by climate change beyond the farm, as agricultural products travel from farms to consumers through markets utilizing a variety of infrastructure.

Interactions between climate change and other trends are likely to have particularly significant implications for risks at the market level. From one side, population growth, shifting diets, and competing demands on biological raw materials all contribute to increasing demand pressure while climate change will negatively impact the supply side both through production and supply chain disruptions.

The challenges arising from these interactions could well result in significant additional market volatility and risk beyond even what the impacts of climate change seen in isolation would already suggest. Indeed, in some cases these factors may be a bigger constraint on availability and driver of rising food prices than direct impacts of climate change on food production (Oxfam 2013).

FOOD PRICE VOLATILITY

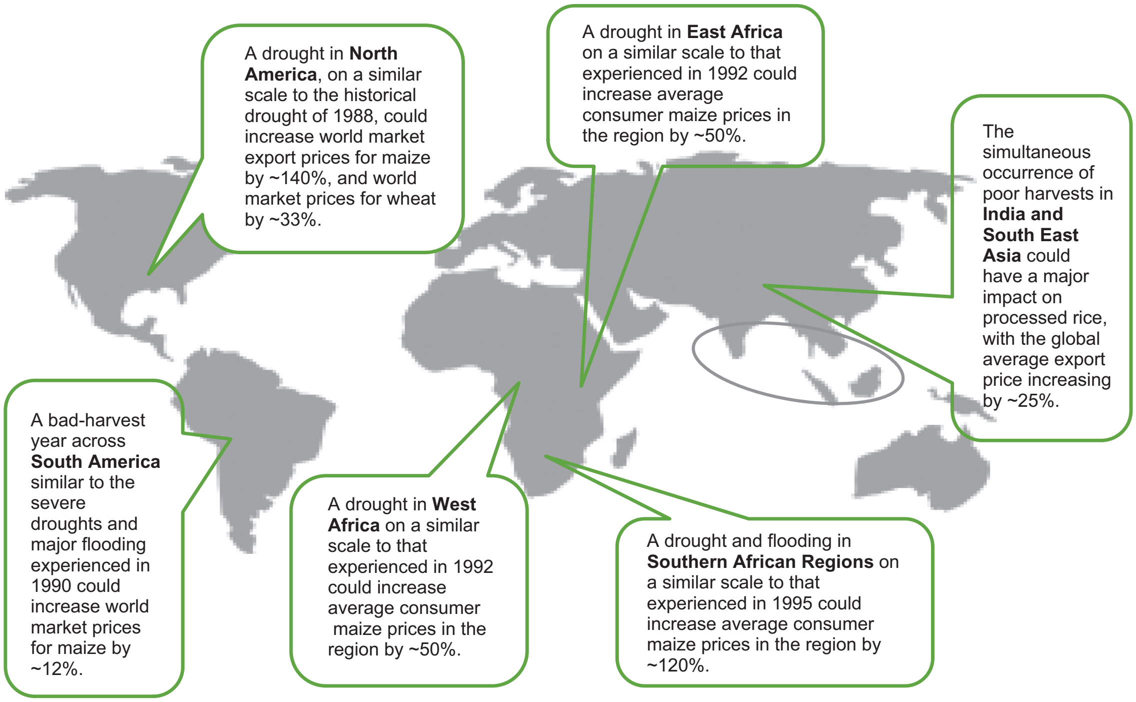
Variations in food (and more broadly agricultural) prices over time are problematic when they are large, unexpected, and when they create uncertainty that increases risks for players along the supply chain including producers, traders, consumers, and governments (FAO et al. 2011).

Both low and high price levels are sources of concern. Low prices benefit consumers, but reduce incentives for production and investment for producers. High prices hurt consumers, but benefit producers who can respond to this signal. The majority of producers in developing countries, however, does not have the capacity to do so, and moreover, few smallholder households are net producers of food. The net effect of high prices therefore depends on a number of factors (FAO et al. 2011).

Global food price volatility has sharply increased over the past decade. World food prices have spiked thrice. After a long secular decline from 1974 onward, the World Bank Food Price Index rose by 62 percent over the course of just a few months in 2008. International prices of maize, rice, and wheat increased in nominal terms by 70 percent, 180 percent, and 120 percent respectively, compared to mid-2007. After declining by 30 percent from mid-2008 to mid-2010, it rose sharply again and in February 2011 regained its 2008 peak. Throughout 2012 food prices remained high and in July 2012 they spiked again, especially for maize and wheat, with world food prices being 65 percent higher than their mid-2007 levels (53 percent in real terms) (World Bank 2013b). Future food prices are expected to remain higher than pre-2007 levels (World Bank 2012).

Climate change has already acted as a significant driver of supply pressure and resulting price spikes of recent years and will do so even more going forward. See box 3.2 for an indicative collection of partly climate change driven extreme events that contributed to food price volatility to date. Figure 2.3 shows the projected effects of a number of possible climate change driven extreme climate and weather events on global commodity markets.

FIGURE 2.3. MODELED PRICE IMPACTS OF EXTREME WEATHER EVENT SCENARIOS IN 2030



Source: Willenbockel 2012.

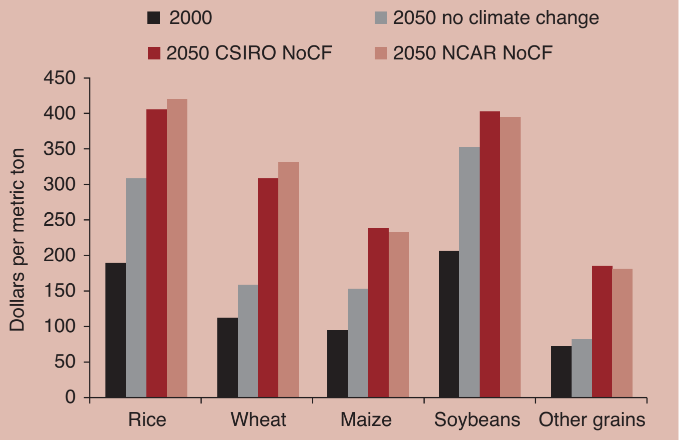
BOX 2.2. IMPACTS OF CLIMATE CHANGE ON AVERAGE GROWING CONDITIONS AND THE SUPPLY OF FOOD

In the longer run, changes in average growing conditions resulting from climate change are expected to lead to considerable price increases under all models. Figure 2.4 illustrates that climate change impacts could cause 2050 prices to rise by 94–111 percent for wheat, 32–37 percent for rice, and 52–55 percent for maize, based on models from two modeling groups—CSIRO (Commonwealth Scientific and Industrial Research Organisation) and NCAR (National Center for Atmospheric Research) both using the A2-SRES scenario from the IPCC[a] incorporating assumptions of lower and higher land precipitation, respectively (World Bank 2010).

Another analysis projects price rises of 54 percent for both rice and wheat and 101 percent for maize by 2050 under climate change (PwC 2013). The exception is soybeans, where most estimates predict minimal impacts. Grain price increases resulting from climate change also indirectly result in higher meat prices due to higher feed prices for livestock. Beef prices are estimated to be 33 percent higher by 2050 with no climate change and 60 percent higher with climate change, with similar numbers for pork and poultry (World Bank 2010). As a general average, the expected effect of climate change on crop prices is a 20 percent increase—an average that masks significant variation across crops and regions.

[a] *Roughly corresponding to a path where emission growth continues and results in an increase of average temperature of more than +4°C by 2100.*

FIGURE B2.2.1. WORLD PRICE EFFECTS FOR THE MAJOR GRAINS (IN U.S. DOLLARS 2000), ASSUMING NO CARBON DIOXIDE FERTILIZATION EFFECT UNDER TWO DIFFERENT MODELS (CSIRO AND NCAR)



Source: World Bank 2008.

In addition to extreme climate and weather-event-driven disruptions, climate change will put pressure on the global food supply overall. Since its impacts on average growing conditions are negative overall, supply will come under significant pressure to achieve the yield gains required to feed 9 billion increasingly wealthy customers in 2050 even in the absence of extreme events. See appendix A for more details.

Together, continued rising demand, slow-onset impacts of gradually rising temperatures or reduced precipitation combined with increased frequency and intensity of extreme events will cause food price volatility to persist and amplify it into the future.

Importantly, these estimates do not incorporate the impact of increased or intensified extreme events resulting from climate change, discussed in the preceding chapter.

SUPPLY CHAIN DISRUPTION RISK

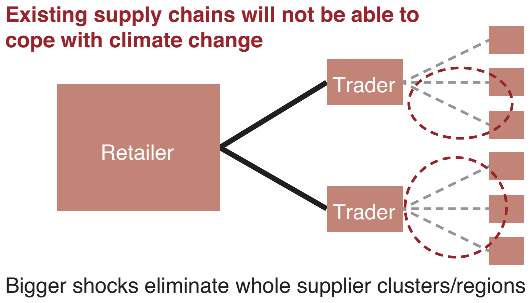
Significant gaps remain in the research on climate change impacts on global supply chains. The following is therefore only a first approximation of the kind of disruption risks climate change impacts could give rise to.

Production Disruptions and Repercussions

Agriculture supply chains are increasingly exposed to disruption risk from localized, regional and even global climate and weather risks. Commodities such as wheat, maize, and especially rice will face a greater magnitude of supply chain disruption risks going forward (Gledhill et al. 2013).

As climate change brings more frequent and more intense extreme events coupled with overall less conducive growing conditions (see previous chapter), produc-

FIGURE 2.4. ILLUSTRATION OF A LARGE CLIMATE AND WEATHER EVENT DISRUPTING ENTIRE PRODUCER CLUSTERS



tion disruptions of previously unknown scales are likely to occur. The schematic in figure 2.4 illustrates this process.

With climate change, the risk of supply chain disruptions of entire clusters of producers is increasing dramatically. Extreme events at novel scales will put traditional supply chain structures into question to the point where global commodities of the scale of coffee or cacao may encounter shortages and food retailers may temporarily have sourcing difficulties and be unable to offer them.

As supply chains become more and more globally integrated, the potential for worldwide shocks and price spikes further increases (PWC 2013). Highly locally concentrated commodities are particularly relevant to global supply chain disruption risks because climate and weather phenomena of limited geographic scope can already be sufficient to disrupt significant portions of global supply.

Supply disruptions that affect significant parts of global production also have the potential to increase counterparty risk. As disruptive climate and weather events trigger price volatility and risk factors across different members of the supply chain become more strongly positively correlated, counterparty risks can spread and endanger entire sub-sectors.

In a first of its kind public announcement, the UK retailer ASDA published results of a study which found that 95 percent of all fresh produce on offer is already at risk from climate change (Guardian 2014). The study was the first attempt by a food retailer to put hard figures against the impacts climate change will have on the food it buys from across the world.

Transport and Infrastructure

A number of extreme climate and weather events induced by climate change can impact both transportation and infrastructure. Pressure on prices may result from delays, destruction of commodities, and quality impacts. For instance, floods and landslides can disrupt the distribution of crops by damaging roads and bridges between fields and factories where the crops are processed (Doyle 2012). Ports or transport routes may temporarily close due to extreme weather. High temperatures cause rail tracks to expand and buckle. More frequent and severe heat waves may require track repairs or speed restrictions to avoid derailments. Tropical storms and hurricanes can also leave debris on railways, disrupting rail travel and freight transport. Heavy precipitation could also lead to delays and disruption. For example, the June 2008 U.S. midwest floods closed major east-west rail lines for several days (EPA 2013). In addition, coastal infrastructure and distribution facilities may be exposed to flood damage (PWC 2013). For instance, rain-induced landslides on transport roads in Colombia caused the price of green beans to increase in every market (Oxfam 2013).

Although the effects of weather on transport are visibly evident, there have not been many integrated assessments at either national or global levels of the impacts on transportation of changes in frequency, severity, and seasonality of extreme weather events. The effects of infrastructure disruption on food availability are widely recognized, but they remain a "known unknown" in the context of understanding potential future climate change impacts on food security. This is an area of major vulnerability that warrants further attention and research (Oxfam 2013).

Storage

Another major aspect of commodity supply chains that may be impacted by climate change is storage infrastructure and process. Food storage infrastructures such as warehouses may be damaged or destroyed by extreme weather events such as flooding and storms (Doyle 2012). Storage costs may rise due to strains on electricity grids, air conditioning, and refrigeration from increasing temperatures.

Higher temperatures will significantly affect food safety, with perishable foods such as fruits and vegetables especially vulnerable. Storage life is constrained by temperature, as increased bacterial growth rates halve storage for every 2–3°C increase up to 10°C. Communities may be exposed to unsafe levels of aflatoxin from stored maize, as throughout a season farmers sell and buy back maize locally (Vermuelen et al. 2012). Late rains during crop harvests increase moisture content in grains and increase costs of drying.

Under heavy rain conditions, produce in storage may rot due to low capacity, leading to a decreased supply that can result in sudden rising prices. Insufficient storage capacity and rain exposure and extreme weather may cause grains to rot. Rains during the wheat harvest elsewhere may lead to grain spoilage due to a lack of capacity for drying and storage, affecting the price and quality of crops.

Climate change will increase the unpredictability of rain patterns, indicating increasing disparities in resilience between nations with sufficient storage capacity and those without. As with transportation impacts, storage impacts are likely to hit developing nations hardest, due to the lack of resilient infrastructure. However, there is little research to date on the impacts of increasing climate variability and longer-term climatic trends on major food storage facilities or on the performance of more traditional food storage systems, such as home-built granaries.

Conclusion

The interaction between high food prices overall and additional price volatility induced by production shocks fueled by climate change will likely lead to socially and politically explosive dynamics on the consumer side, further explored in the following chapter.

Additional research is required to fully understand the relevance of climate change impacts on future food price volatility and agricultural supply chains.

ENABLING ENVIRONMENT RISKS

This section focuses on the implications of climate change risks on the enabling environment.

The enabling environment is composed of the regulatory, political, conflict, macroeconomic, and trade environments of a given agriculture sector. It has distinct characteristics at global, regional, and national levels and plays a key role in shaping the supply chain and the sector as a whole. Enabling environmental risks include political developments, changes in regulation, arising conflict, or trade restrictions that lead to financial losses.

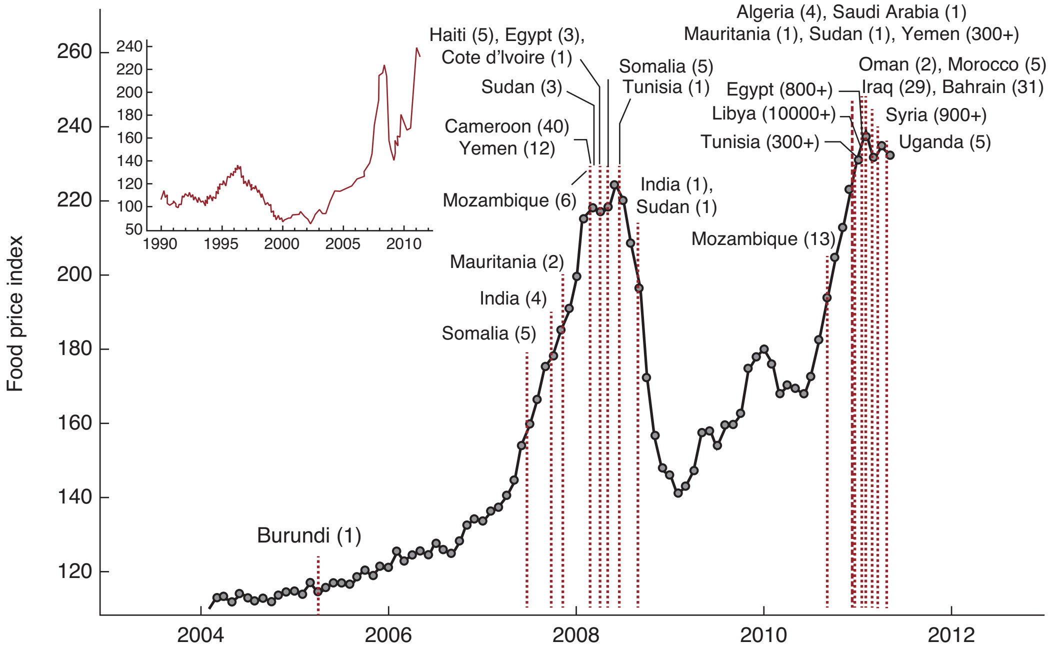
Production and market risks resulting from more frequent, extreme, and uncertain climate and weather events have the potential to lead to, and be complicated by, enabling environment factors. Due to the complex nature of the social, economic, and political motivations behind the governmental and individual decision making involved are even more difficult to predict and identify with certainty than risks at production and market levels.

An active area of research, a number of potential indirect channels of climate change's influence on the enabling environment have been identified in literature. For instance, there is ample historic precedent that supply shocks triggered by climate and weather events have resulted in reactive trade and domestic support policies, as recently as the 2008 food price shock.

Climate change is one of many variables influencing enabling environments. While causal impacts can often be plausibly argued between climate change and developments at the enabling environment level, attribution will often remain elusive. Moreover, amid a concert of other factors, the scale of importance of climate change impacts is hard to assess and its impacts should therefore not be overstated.

Political and regulatory risks. In times of uncertainty countries may resort to ad hoc, isolationist measures. Price volatility—particularly when concerning basic food commodities—can bring significant uncertainty. Common responses to supply and price shocks include panic-buying, hoarding, subsidizing imports, and placing export controls on impacted commodities (Oxfam 2012). Protectionist measures such as these may amplify risks (Ahmed and Martin 2009). Trade-restricting policy responses to higher food prices exacerbated price increases; for example, changes in border protection measures accounted for an estimated 45 percent of the world price increase for rice and 30 percent of the increase for wheat in 2006–08 (World Bank 2014c). Through increases in weather and climate shock driven

FIGURE 2.5. TIME DEPENDENCE OF FAO FOOD PRICE INDEX FROM JANUARY 2004 TO MAY 2011



Source: Lagi et al. 2011.

production disruptions, climate change may contribute to more volatile market environments and ultimately indirectly contribute to increasing regulatory risk.

Red dashed vertical lines correspond to beginning dates of "food riots" and protests associated with the major recent unrest in North Africa and the Middle East. The overall death toll is reported in parentheses. Inset shows FAO Food Price Index from 1990 to 2011.

Throughout history, food price spikes have triggered political instability, for instance in the form of riots. Figure 2.5 shows a measure of global food prices, the UN Food and Agriculture Organization (FAO) Food Price Index and the timing of reported food riots in recent years. In 2008 more than 60 food riots occurred worldwide in 30 different countries, 10 of which resulted in multiple deaths, as shown in the figure. After an intermediate drop, even higher prices at the end of 2010 and the beginning of 2011 coincided with additional food riots (in Mauritania and Uganda), as well as contributing to the broader protests and government changes in North Africa and the Middle East known as the Arab Spring. Conversely, there are comparatively fewer food riots when the global food prices are lower (Lagi et al. 2011).

Conflict over scarce natural resources. Temperature and rainfall events have a complex relationship with the potential for local resource conflict. Local disputes over grazing lands for livestock may be influenced by resource scarcity partially caused by climate change impacts, especially heat waves and droughts. Temperature extremes are associated with stock losses for pastoralists, which could increase the potential for associated conflicts. Lack of rain may also decrease forage in the areas where herding is common, forcing herders to gather in temporary homes, competing for the same limited grazing land and forage resources for their livestock (Stark 2011). Farmers and cattle keepers requiring water during the dry season have increased potential for conflict over water resources when long-term drought further limits rainfall.

Results of a study on rainfall, temperature, and conflict correlations in East Africa indicated that temperature increases had more influence in raising violence than precipitation variability (O'Loughlin et al. 2012). Greater precipitation decreased conflict but the study found that drier than normal conditions had no significant effect. Overall, both temperature and precipitation were only modest indicators of conflict relative to other factors.

Impacts from climate change are projected to significantly increase the numbers and the permanency of migratory movements as a result of extreme events, potentially leading to considerable population redistribution. Some areas at risk of migration are connected to existing conflicts; climate change-induced natural disasters could exacerbate existing enabling environment conditions that, combined, may lead to sudden migration events (Friedman 2014).

Conclusion

As climate change brings more frequent and intense extreme events, it is likely to have a negative impact on enabling environment risks, for instance increasing the probability of adverse interventionist trade policies, food price spike related political instability and conflict over natural resources. At the same time, climate change is only one of many variables driving such developments and should be seen in proportion.

CHAPTER THREE

IMPLICATIONS OF CLIMATE CHANGE FOR ARM

This section examines the implications of climate change for agriculture risk management. For an introduction into the basic concepts of ARM, please refer to appendix B.

WHAT ARM CAN CONTRIBUTE TO MEETING THE CHALLENGES OF CLIMATE CHANGE

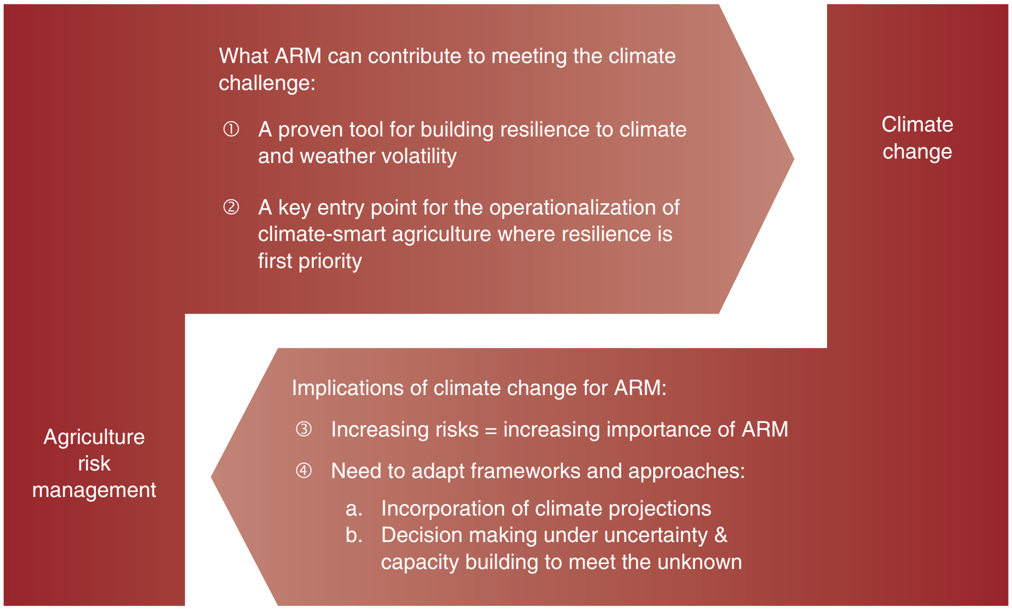
A proven tool for managing risks today and building resilience to climate and weather variability tomorrow:

Agricultural risk management is ideally placed to support all actors in dealing with the increased agricultural risks climate change will bring. ARM was designed to help production, market, and enabling environment risks. While climate change may introduce new types of extreme events in some locations, it most frequently will translate into "more frequent and intense—of the same" hazards. ARM frameworks and approaches can point the way to the identification of optimal mitigation, transfer, and coping strategies—and have a track record of successfully accomplishing the task.

Agriculture risk management therefore needs to be seen as a key part to identify short and medium term solutions to the challenges climate change poses to agriculture and food systems. ARM tools are proven, tested, and readily available: Many countries have risk management frameworks and systems in place that can be further developed and "climate-proofed." For example, cutting edge risk management approaches already integrate important principles of effective extreme event risk management, including taking an integrated systems approach, community-level participation and the use of local and community knowledge in synergy with national and international policies and actions (IPCC 2012).

Agricultural risk assessment and RM strategies can therefore provide crucial support to food systems during the structural transitions that will be part of adaptation processes, but ARM is no substitute for longer term strategic adaptation planning.

FIGURE 3.1. ILLUSTRATION OF KEY MUTUAL POINTS OF RELEVANCE BETWEEN CLIMATE CHANGE AND AGRICULTURE RISK MANAGEMENT



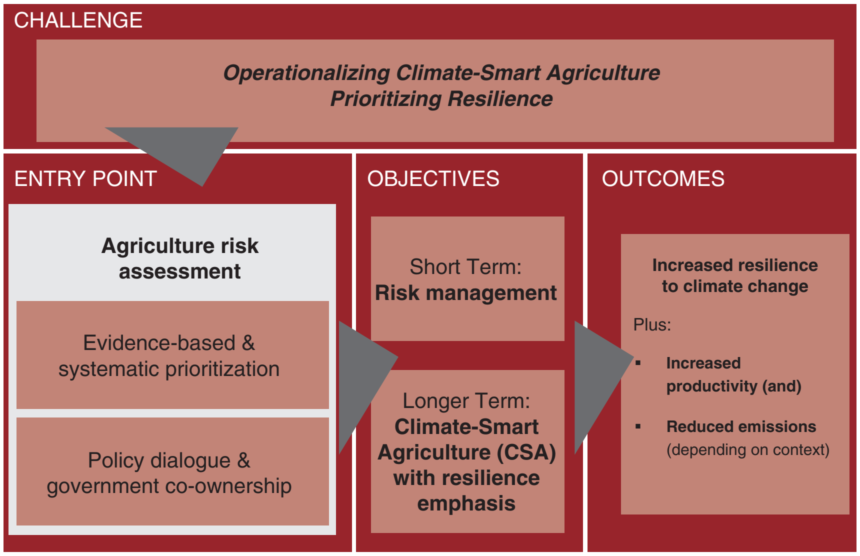
Adaptation to climate change will take time. Agricultural production and the broader food system are highly fine-tuned instruments closely adapted to and shaped by local conditions that exhibit significant levels of inertia: human capacity, productive infrastructure, or market access are often all specific to a production system comprising of a defined set of crop and livestock products.

In some contexts, climate change will affect growing conditions in such a way, that important crops or livestock species are pushed beyond what they can tolerate. During the processes of structural adjustment that adaptation in such contexts will require, ARM can be an important tool to manage volatility during transition and cushion the effect on those able to adapt least rapidly. For instance, production of some crops will continue even as growing conditions are increasingly far from optimal. As production becomes increasingly risky, ARM can help manage those risks and support the process of assigning roles in risk mitigation, coping, and transfer to different stakeholders.

It is important to note, however, that ARM's role is mainly to help manage risks around the trend, not the trend itself. That is, ARM has to be careful in avoiding contributing to maladaptation. Maladaptation can occur when a system spends resources in a misguided attempt to adapt existing production systems to the changing climate without hope for longer term sustainability. For instance, if a production area is projected to lose suitability for a given crop in the medium term but ARM tools such as a government subsidized agricultural insurance schemes are deployed to extend the life of production in the face of ever-increasing risks and reduced yields, resources may go to waste. Instead, the optimal adaptive response may be to change production systems entirely and invest the available resources support this transition rather than extending the lifetime of a lost cause. Similarly, climate change impacts in the medium turn can affect the (cost-)effectiveness of risk management interventions implemented today, such as irrigation infrastructure. Therefore, periodic risk assessments become quite important for reprioritizing risk and interventions in a changing risk context overtime to avoid the risk of maladaptation.

ARM needs to work hand-in-hand with adaptation planning to avoid the risk of maladaptation and to ensure an optimal flow of information from ARM to adaptation planners. Through its periodic production data analysis and risk profile update, ARM will often be well placed to spot the risk of suitability loss far in advance and needs to ensure that it makes this knowledge available to the broader agriculture planning and adaptation community.

FIGURE 3.2. SCHEMATIC ILLUSTRATING HOW ARM CAN OFFER A PATHWAY TO ACHIEVING RESILIENCE FOCUSED CSA OUTCOMES



In this way, although not always made explicit, agriculture risk management tools in effect help build resilience to climate change. While the term "resilience" may refer to somewhat different concepts in the climate change and risk management communities, many of the tools ARM commonly deploys also appear in adaptation or resilience building projects. These include early warning systems, irrigation infrastructure or improved agronomic or *climate-smart* agriculture practices such as agroforestry or conservation agriculture.

A key entry point for the operationalization of climate-smart agriculture where resilience is the first priority:

Climate-smart agriculture (CSA) is an approach that aims to achieve three outcomes simultaneously: increased productivity, enhanced resilience, and reduced emissions. CSA has generated significant interest in recent times and attempts to operationalize the concept are currently under development.

Where resilience is the main focus of CSA, agricultural risk assessments present a proven and attractive entry point for operationalization, with two advantageous key features that stand out (see figure 3.2).

First, agriculture risk assessments offer a well-established systematic risk prioritization process, starting from data gathering to option evaluation on to solution development. Risk data from the past are systematically collected and synthesized with climate projection data to identify future risks from climate and weather events, particularly possible trend changes in key variables such as precipitation or temperature. The assessments take a holistic, integrated view including both direct (production level) and indirect risks (markets and enabling environment level).

Key risks identified are then matched with potential solutions. Solutions are processed through a prioritization matrix, allowing to simultaneously consider a range of goals starting with resilience, productivity, and environmental and sustainability goals. The approach can be further expanded to include additional dimensions such as nutrition, gender, or value chain approaches.

The results of this process are highly contextualized priorities, including at local level (community, district, region), and can be designed to cover the full potential "triple win" of CSA (see figure 3.3). In continuation to the risk assessment, prioritized potential solutions are then further developed through solution assessments.

The second key feature is the attractiveness of agriculture risk assessments as a vantage point for government dialogue.

FIGURE 3.3. EXAMPLE OF A PRIORITIZATION MATRIX FROM THE NIGER COUNTRY AGRICULTURE RISK ASSESSMENT USING OPTION FILTERING APPROACH (WORLD BANK 2013a)

	Scalability	Relative Cost	Ease of Implementation	Return Time	Adverse Impact on Environment	Potential Impact on Poverty Alleviation
Drought tolerant/improved seed varieties (M)	High	Medium	Medium	Short	Low	High
Soil and water conservation (M)	High	Medium	Medium	Medium	Low	High
Irrigation (M)	Low	High	Low	Short-medium	Moderate	High
Early detection and destruction of locusts (M)	High	Medium	High	Short	Moderate	Low
Community-level food and fodder banks (M, C)	High	Medium	Medium	Short	Low	High
Vaccination programs (M)	High	Medium	Medium	Medium	Low	High
Contingent financing (C)	High	Low	High	Short	Low	Low
Shortening emergency response time (C)	Medium	Low	Medium	Short	Low	Low
Strategic de-stocking (C)	Low	Medium	Low	Medium	Low	Low
Insurance (T)	Low	Low	Medium	Medium	Low	Low

Source: Authors.

Note: M is Mitigation, C is Coping, and T is Transfer.

Across all steps, the agriculture risk assessment process is highly collaborative and involves strong country co-ownership. For instance, risk assessment processes are initiated based on country demand. Government representatives are involved at every stage of the process. This close involvement enables a process of prioritizing investment, policy, and technical assistance opportunities as well as the development of longer term action plans for operationalizing CSA.

The quantification and monetization of agricultural risks is an ideal tool to generate interest not only from Ministries of Agriculture, but from Ministries of Finance and Planning due to the often unexpectedly large losses to government budgets and country trade balances caused by agricultural risks. Monetization helps generate a sense of immediacy and urgency, given its focus on past and currently ongoing losses. Once the relevance of the problem and the need for action are established, doors are opened toward leveraging further political support for action on more future-facing issues, such as climate change.

Finally, ARM as it is understood here, is a continuous process rather than a one-off investment. As with best adaptation building practice, regular activities under an ARM umbrella can help monitor climate risks as they develop and maintain momentum over time. Risk assessment is an iterative and dynamic process which needs to be incorporated as a periodic exercise to gauge from time to time the risk profile of agricultural sector and principal commodities (see figure 3.4). The context and structure of agricultural sector changes over time and risks needs to be re-assessed periodically to situate old risk in a new context; identify new risks; adapt old solutions or develop new solutions in response to evolving risk profile of agricultural sector.

In summary, agriculture risk assessments represent a useful entry point that enables managing the short term (risks) while building a key bridge to the longer term (resilience and climate-smart agriculture with resilience focus) if it is adopted as a periodic exercise to gauge changing scenarios over time.

FIGURE 3.4. RISK ASSESSMENT AND MANAGEMENT CYCLE

HOW ARM NEEDS TO ADJUST UNDER THE "NEW NORMAL"

As risks in agricultural systems increase with climate change, so will the importance, as well as the challenge, of managing them:

Under risky growing conditions, ARM can be the difference between an agriculture sector that accumulates capital and improves productivity and one that stagnates or even dwindles. For instance, risky agriculture sectors with poorly managed risk suffer from a lack of incentives for investment, see stakeholders forced to diminish their asset base to absorb shocks and see investment opportunities in prevention go to waste. With ever greater shares of production at risk, it will become increasingly critical to have optimal systems in place to manage them and avoid unsustainable loss levels. Please refer to appendix B for background on the World Bank's approach to ARM.

The more variable climate and weather conditions are, the more diverse and frequent risks arise and the more challenging effective risk management will become. The key parameter is variability. Higher variability means more frequent and extreme deviations from the norm and therefore less predictable risks. In addition, climate change introduces the added complexity of a moving baseline. The past is no longer always the best guide for the future, as discussed in the next section. Even volatility becomes more dynamic over time. The entire risk landscape starts to shift.

For ARM to protect production systems and supply chains struggling with the impacts of climate change around the world, global ARM capacity will need to be significantly strengthened at all levels. Many countries have only rudimentary ARM systems and their food systems remain highly vulnerable even to today's more moderate threats. ARM in its modern form is still a relatively recent element of the development toolbox and has yet to be fully scaled up. Finally, as risks increase, so do the costs of mitigating, coping with, or transferring them.

In the same vein, as risks increase, so will the return on investment for ARM. The benefits of successful ARM are well known: Every risk mitigated, successfully coped with, or transferred in efficient ways helps avoid losses, protects food security, reduces the cost of credit for farmers and creates incentives for investment in the medium- to longer-term. Benefits often add up to significant sums. As risks of potential losses increase, so does the value of avoidable losses for producers and other members of the value chain. Put differently, the more risks there are, the more value can be added—and protected—through ARM.

Farmers are particularly vulnerable to climate change and ARM can play a key role in protecting them. All risks are eventually transmitted across the agriculture sector (and along the various supply chains), but production risks such as weather shocks and pests and diseases generally affect farmers the most. Farmers are also the members of the supply chain with the lowest adaptive capacity, the highest incidence of poverty and are therefore highly vulnerable. In particular, they often still lack access to effective risk transfer solutions and are forced to rely on traditional community-based mechanisms that will be overwhelmed with the kind of weather and climate shocks climate change will bring.

To maximize its positive contributions in meeting the climate challenge, ARM will need to incorporate a number of adjustments to its frameworks

and approaches to accommodate the "new normal" of climate change into the RM strategies:

a. Need to incorporate projections of future climate and weather conditions

Since under climate change the past is no longer the only, or necessarily best, guide for the future, agriculture risk management will need to adjust its methodologies.

To date, historic records over several decades have provided risk managers with high quality information and enabled them to create precise risk profiles for given locations, activities, and hazards. They were also able to accommodate some internal variability or natural climate variation through the observation and integration of trends. Both historic averages and trends remain key pieces of information in the "New Normal" because of their precision and their continued strong predictive power in the short to medium term.

Going forward however, climate change projections will become an additional required element. As discussed above, climate change is expected to increase climate variability and the frequency of extreme climate and weather events. Since these are at the core of many of the risks ARM manages, projections will be an important tool of predicting risk profiles. Climate change projections can supply important information for decision making in ARM contexts.

Unfortunately, climate projections still suffer from a set of deficiencies that complicate their use. Climate modeling results contain sometimes large amounts of uncertainty due to an only partial scientific understanding of the hugely complex global climate system and due to uncertain future human carbon emissions. Models are much better at predicting certain variables at certain timescales (average seasonal temperature or yearly rainfall) than others (frequency of temperature extremes or intensity of daily rainfall events). Model precision also declines as scale becomes more local.

These complexities will require ARM to update and modify its tools and approaches to accommodate future data and to integrate uncertainty into decision making. Each context will require careful weighing of historic data and existing trend information with future projections. This will be particularly important and challenging where projections indicate a trend reversal or non-linear changes compared to historic trends. Also, timescales for ARM will need to be more clearly defined than in the past.

Climate projections should for instance be consulted:

- » Early on in a risk assessment, when the broader context is defined, the climate context could be routinely examined in addition to the client, programmatic, risk, and agricultural contexts. This may help flag countries where climate change may be of particular relevance from the go.[6]
- » During the risk prioritization phase as part of the initial assessment, to ensure prioritization is "climate-smart."
- » During the solutions assessment, it is important to assess the climate-smartness of options being developed. For instance, where physical infrastructure investment options such as irrigation networks are considered as a means to reduce vulnerability to risk events such as droughts, it would be essential to consult projections on future precipitation. Since these investments have long lifetimes of over 20 years, climate conditions could be significantly different from today and directly impact the viability of the project in question.

b. Decision making under uncertainty and capacity building to meet the unknown

Climate change brings uncertainty. Climate projections always come with point estimates ("best guess") surrounded by sometimes large confidence intervals ("ranges"). Deriving policy conclusions can therefore be difficult. Moreover different climate models can sometimes disagree starkly in their projections of elementary climate variables.

There are a number of available methodologies derived from statistical decision theory that can help reach "robust" decisions under uncertainty. Robust here describes options that perform "reasonably well" under a

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[6] Tools to support this process are available, for instance in the form of the Climate Risk Screening Tools developed by the World Bank, available under https://climatescreeningtools.worldbank.org/

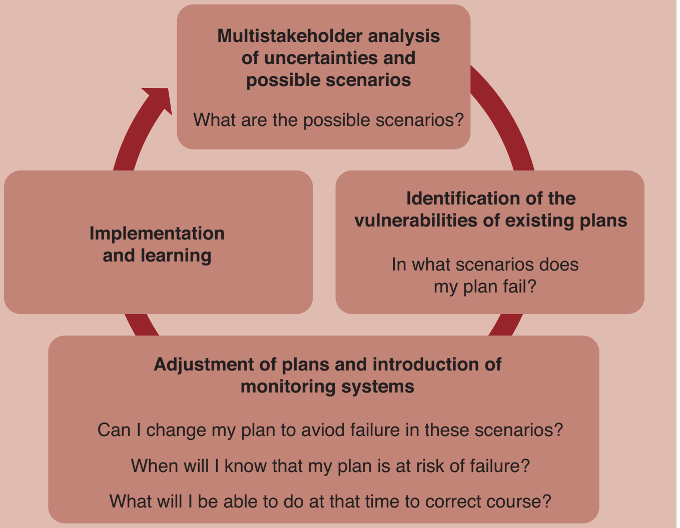
BOX 3.1. MAKING ROBUST DECISIONS DESPITE DEEP UNCERTAINTIES ABOUT THE FUTURE

Governments invest billions of dollars annually in long-term projects. Physical structures like irrigation infrastructure, roads and dams often last for decades and need to be useful throughout their lifetimes (Kalra et al. 2014). Similarly, structural decisions in agriculture, such as introducing irrigation or shifting cropping systems can shape the sector for many years to come. Yet deep uncertainties pose formidable challenges to making near-term decisions that make long-term sense. Climate change and other socio-economic uncertainties can have serious consequences on development efforts.

Traditional decision approaches have been asking, *"Which investment option best meets our goals given our beliefs about the future?"* Such approaches, sometimes called "Predict-then-Act," rely on our accurately predicting and then reaching consensus on what the future will bring (Bonzanigo and Kalra 2014). But, disagreement about the future can lead to gridlocks. Worse, if one project is designed for a future that then does not materialize, losses will be high.

Methods that identify robust decisions have been recommended for investment lending but are not yet widely used. These methods, sometimes called "Deliberation-With-Analysis," ask different questions: *How do options perform across a wide range of potential future conditions? Under what specific conditions does the leading option fail to meet decision makers' goals? Are those conditions sufficiently likely that decision makers should choose a different option?* (Lempert et al. 2013). These methods do not seek to suggest an optimal investment, but rather one that performs well no matter what the future may bring. These investments are generally called robust choices.

FIGURE B3.1.1. AN ITERATIVE PROCESS OF DECISION MAKING TO PROMPT ROBUST ACTION IN THE FACE OF UNCERTAINTY



Source: WDR 2014 team.

These methods have been mainly applied in the United States and Europe. Recently, the World Bank has begun to test them in the developing context. A number of ongoing World Bank projects are applying these state-of-the-art methods to water management in Lima, Peru; urban wetland management for flood protection in Colombo, Sri Lanka; and hydropower investments in Nepal.

range of different potential scenarios (Anton et al. 2012). While not maximizing usefulness for any particular scenario, they maximize safety and flexibility. Some methodologies help in dealing with knowledge gaps (Ben-Haim 2006), others propose frameworks to determine likely "weights" of different options (Etner et al. 2011), attempt to identify "no regret" options (Stakhiv 1998) or develop models where decision can be taken without first having to agree on the probabilities of different scenarios (Kalra et al. 2014; see box 3.1 and figure B3.1.1).

Options that fulfill the robustness criteria often tend to involve capacity building in different shapes and forms. Early warning systems or an empowered extension service for instance contribute to adaptive capacity and are often robust investments because their strengths can come to play independent of the future climate scenario that actually materializes.

These methodologies could find application in a number of agriculture risk management decisions. For instance:

- During the risk prioritization phase as part of the initial assessment, it will be important to assess different options' sensitivity to climate projections. This could help prevent deprioritizing certain options that are deemed somewhat unlikely but would have heavy impacts if they occurred.
- During the solutions assessment, if there is significant uncertainty over what the future climate will be like while investment with long lifetimes are being

considered. In such cases, it would be beneficial to assess the sensibility of the options considered to different climate scenarios and deploy robust decision making methods if the decision does appear sensitive to the range of uncertainty at hand.

Conclusion

Climate change is a reality today and presents a significant threat to the global agriculture and food systems tomorrow. Impacts on agriculture risks in particular are manifold, clearly negative overall and downright alarming for some agricultural production systems and commodities.

Agriculture risk assessments are a key process to identify risk management strategies today and to build resilience tomorrow. It offers a pragmatic take on the often all too theoretical concept of resilience based on a holistic systems approach to avoiding losses and building risk management capacity at production, market, and enabling environment levels. As such, agriculture risk assessments can serve as a key entry point to the operationalization of climate-smart agriculture where resilience is the first priority.

The conceptual framework presented in this chapter hopes to make progress on the incorporation of climate change implications into agriculture risk management approaches. Ultimately, it aspires to contribute to the mainstreaming of ARM in client countries as a way to help them thrive in the face of climate change.

REFERENCES

ADB (Asian Development Bank). 2012. "Addressing Climate Change and Migration in Asia and the Pacific." *Agriculture and Migration*, 27–38. http://www.adb.org/sites/default/files/pub/2012/addressing-climate-change-migration.pdf.

Alcamo, J., N. Dronin, M. Endejan, G. Golubev, and A. Kirilenko. 2007. "A New Assessment of Climate Change Impacts on Food Production Shortfalls and Water Availability in Russia." *Global Environmental Change* 17 (3): 429–44.

Alexandratos, N., and J. Bruinsma. 2012. "World agriculture towards 2030/2050: the 2012 revision." ESA Working Paper No. 12-03, FAO, Rome. http://www.fao.org/docrep/016/ap106e/ap106e.pdf

Antón, J., et al. 2012. "A Comparative Study of Risk Management in Agriculture under Climate Change." *OECD Food, Agriculture and Fisheries Papers*, No. 58. http://dx.doi.org/10.1787/5k94d6fx5bd8-en.

Arzt, J., W. R. White, B. V. Thomsen, and C. C. Brown. 2010. "Agricultural Diseases on the Move Early in the Third Millennium." *Veterinary Pathology Online* 47(1): 15–27.

Batima, P. 2006. "A Final Submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC)." Project No. AS 06. The International START Secretariat, Washington, DC. http://ipcc-wg2.gov/njlite_download.php?id=5854.

Battisti, D. S., R. L. Naylor. 2009. "Historical Warnings of Future Food Insecurity with Unprecedented Seasonal Heat." *Science* 323: 240–44.

Bengtsson, L., K. I. Hodges, M. Esch, N. Keenlyside, L. Kornblueh, J. Luo, and T. Yamagata. (2007). "How May Tropical Cyclones Change in a Warmer Climate?" *Tellus* 59: 539–61.

Ben-Haim, Y. 2006. *Info-Gap Decision Theory: Decisions under Severe Uncertainty.* Academic Press, Oxford, UK.

Bonzanigo, L., and R. N. Kalra. 2014. "Making Informed Investment Decisions in an Uncertain World: A Short Demonstration." World Bank Policy Research Working Paper No. 6,765, World Bank, Washington, DC.

Burgess, R., O. Deschenes, D. Donaldson, and M. Greenstone. 2013. "The Unequal Effects of Weather and Climate Change: Evidence from Mortality in India." Unpublished working paper.

Burke, E. J., S. J. Brown, N. Christidis. 2006. "Modeling the Recent Evolution of Global Drought and Projections for the Twenty-first Century with the Hadley Centre Climate Model." *J. Hydrometeorol* 7: 1113–25.

Byerlee, D., X. Diao, and C. Jackson. 2005. "Agriculture, Rural Development, and Pro-poor Growth Country Experiences in the Post-Reform Era." *Agriculture and Rural Development Discussion* Paper 21, World Bank, Washington, DC.

CGIAR 2013. "Adapting to extreme events in Southeast Asia through sustainable land management systems." https://ccafs.cgiar.org/research/projects/adapting-extreme-events-southeast-asia-through-sustainable-land-management-syste-0#.VYRl0DJdXQQ.

Confino, Jo. 2014. "Asda: 95% of our fresh produce is already at risk from climate change." *Guardian Newspaper,* April 25, 2014. http://www.theguardian.com/sustainable-business/asda-food-waste-risk-climate-change.

Dai, A. 2011. "Drought under Global Warming: A Review." *Wiley Interdisciplinary Reviews: Climate Change*, 2(1): 45–65.

Easterling, D., et al. 2000. "Climate Extremes: Observations, Modeling and Impacts." *Science Magazine* 289 (5,487): 2068–74. http://www.sciencemag.org/content/289/5487/2068.full.

Etner, J., M. Jeleva, and J. M. Tallon. 2011. "Decision Theory under Ambiguity." *Journal of Economic Surveys*. doi: 10.1111/j.1467-6419.2010.00641.x

FAO (Food and Agriculture Organization). 2006. "Food Security." *Policy Brief*, Number 2 (June). FAO, Rome, Italy.

———. 2013. "The State of Food Insecurity (SOFI). The multiple dimensions of food security." FAO, Rome, Italy. http://www.fao.org/publications/sofi/2013/en/.

FAO, IFAD, IMF, OECD, UNCTAD, WFP, World Bank, WTO, IFPRI, and UN HLTF. 2011. "Price Volatility in Food and Agricultural Markets: Policy Responses." http://www.oecd.org/tad/agricultural-trade/48152638.pdf.

Friedman, L. 2014. *Heat Stress, Not Flooding, Drives Most Climate Migrants*. E & E Publishing. http://www.eenews.net/stories/1059993474?utm_source=hootsuite&utm_campaign=hootsuite.

Gornall, J., et al. 2010. "Implications of Climate Change for Agricultural Productivity in the Early Twenty-first Century." doi:10.1098/rstb.2010.0158.

Government of Western Australia. 2013. "Potential Frost Changes Due to Climate Change." Department of Agriculture and Food. http://grains.agric.wa.gov.au/node/frost-%E2%80%94-science.

Gualdi, S., E. Scoccimarro, A. Navarra. 2008. "Changes in Tropical Cyclone Activity Due to Global Warming: Results from a High-Resolution Coupled General Circulation Model." *Journal of Climate (*21): 5204–28.

Hansen, J., M. Sato, and R. Ruedy. 2012. "Perception of climate change." *Proceedings of the National Academy of Sciences (PNAS)* 109 (37). http://pubs.giss.nasa.gov/docs/2012/2012_Hansen_etal_1.pdf.

Hatfield, J., et al. 2014. "Climate Change Impacts in the United States: The Third National Climate Assessment." In *U.S. Global Change Research Program*, edited by J. M. Melillo, Terese (T. C.) Richmond, and G. W. Yohe: 150–74. doi:10.7930/J02Z13FR.

Hess, U., K. Richter, and A. Stoppa. 2004. *Weather Risk Management for Agriculture and Agri-Business in Developing Countries.* IFC, Washington, DC. https://www.agriskmanagementforum.org/sites/agriskmanagementforum.org/files/Documents/Weather_Risk_Management.pdf.

Inter-American Development Bank (IDB) and FAO. 2013. *Climate Change and Agriculture in Jamaica: Agricultural Sector Support Analysis.* FAO, Rome, Italy. http://www.fao.org/docrep/018/i3417e/i3417e.pdf.

IPCC. 2012. "Summary for Policymakers." In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, edited by C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, and P. M. Midgley. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* Cambridge, U.K., and New York, U.S.A. Cambridge University Press. 1–19.

———. 2013. "Summary for Policymakers." In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley. Cambridge, U.K., and New York, U.S.A. Cambridge University Press

———. 2014. "Summary for Policymakers." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White. Cambridge, U.K., and New York, U.S.A. Cambridge University Press. 1–32.

Jarvis, A., C. Lau, S. Cook, E. Wollenberg, J. Hansen, O. Bonilla, and A. Challinor. 2011. "An integrated adaptation and mitigation framework for developing agricultural research: synergies and trade-offs." *Experimental Agriculture* 47(02): 185–203.

Jaramillo, J., E. Muchugu, F. E. Vega, A. Davis, C. Borgemeister, A. Chabi-Olaye. 2011. "Some Like It Hot: The Influence and Implications of Climate Change on Coffee Berry Borer (*Hypothenemus hampei*) and Coffee Production in East Africa." *PLoS ONE* 6(9): e24528. doi:10.1371/journal.pone.0024528.

Jones, P. G., and P. K. Thornton. 2008. "Croppers to Livestock Keepers: Livelihood Transitions to 2050 in Africa Due to Climate Change." *Environ. Sci. Policy.* doi:10.1016/j.envsci.2008.08.006.

International Rice Research Institute (IRRI). 2009. *Rice Doctor—Rice Knowledge Bank.* http://www.knowledgebank.irri.org/RiceDoctor/information-sheets-mainmenu2730/in-the-field-mainmenu-2736/heavy-rainfall-mainmenu-2783.html.

Kalra, N., S. Hallegatte, R. Lempert, C. Brown, A. Fozzard, G. Stuart, A. Shah. 2014. "Agreeing on robust decisions : new processes for decision making under deep uncertainty." *Policy Research Working Paper* No. 6906, World Bank, Washington, DC.

Kastner, T., M. J. Ibarrola Rivas, W. Koch, and S. Nonhebel. 2012. "Global Changes in Diets and the Consequences for Land Requirements for Food." *Proceedings of the National Academy of Sciences of the United States of America* 109(18): 6868–72. http://www.pnas.org/content/109/18/6868.abstract.

Kettlewell, P. S., R. B. Sothern, W. L. Koukkari. 1999. "U.K. Wheat Quality and Economic Value Are Dependent on the North Atlantic Oscillation." J*ournal Cereal Science* 29: 205–209.

Knapp, K. R., M. C. Kruk, D. H. Levinson, H. J. Diamond, and C. J. Neumann. 2010. "The International Best Track Archive for Climate Stewardship (IBTrACS): Unifying Tropical Cyclone Best Track Data." *Bulletin of the American Meteorological Society* 91: 363–76.

Kumar, K. K., K. R. Kumar, R. G. Ashrit, N. R. Deshpande, and J. W. Hansen. 2004. "Climate Impacts on Indian Agriculture." *International Journal of Climatology* 24: 1375–93.

Kristjanson, P. M., P. K. Thornton, R. L. Kruska, R. S. Reid, N. Henninger, T. O. Williams, and P. Hiernaux. 2004. "Mapping livestock systems and changes to 2050: Implications for West Africa. Sustainable crop–livestock production for improved livelihoods and natural resource management in West Africa." ILRI, Nairobi. https://www.ilri.org/InfoServ/Webpub/fulldocs/SustainableCropLivestock/Pg028_044%20Kristjanson%20and%20Thornton.pdf.

Lempert, R. J., S. W. Popper, D. G. Groves, N. Kalra, J. R. Fischbach, S. C. Bankes, B. P. Bryant, M. T. Collins, K. Keller, A. Hackbarth, L. Dixon, T. LaTourrette, T. Reville, J. W. Hall, C. Mijere, and D. J. McInerney. 2013. *Making Good Decisions without Predictions.* Research Brief 9701. RAND Corporation.

Lipper, L., et al. 2014. "Climate-Smart Agriculture for Food Security." *Nature Climate Change* 4: 1068–72. doi:10.1038/nclimate2437.

Lobell, D. B. and C. B. Field. 2007. "Global Scale Climate–Crop Yield Relationships and the Impacts of Recent Warming." *Environmental Research Letters* 2 014002 doi:10.1088/1748-9326/2/1/014002.

Lobell, D. B., and S. M. Gourdji. 2012. "The Influence of Climate Change on Global Crop Productivity." *Plant Physiology* 160(4): 1686–97.

Luo, Q. 2011. "Temperature Thresholds and Crop Production: A Review." *Climatic Change* 109(3–4): 583–98.

Martin, W. and K. Anderson. 2011. "Export Restrictions and Price Insulations during Commodity Price Booms." *American Journal of Agricultural Economics* 94(2): 422–27.

McDonald, R. E., D. G. Bleaken, D. R. Cresswell, V. D. Pope, C. A. Senior. 2005. "Tropical Storms: Representation and Diagnosis in Climate Models and the Impacts of Climate Change." *Climate Dynamics* 25: 19–36.

Mueller, V., C. Gray, and K. Kosec. 2014. "Heat Stress Increases Long-Term Human Migration in Rural Pakistan." *Nature Climate Change* 4(3): 182–85.

National Oceanic and Atmospheric Administration (NOAA). 2015. *Glossary*. http://w1.weather.gov/glossary/

National Research Council. 2011. *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia.* The National Academies Press, Washington, DC.

Nelson, G. C., M. W. Rosegrant et al. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options* 172. International Food Policy Research Institute: Washington, DC.

OECD. 2009. *Managing Risk in Agriculture: A Holistic Approach.* OECD Publishing, Paris. doi:10.1787/9789264075313-en.

O'Loughlin, J., et al. 2012. "Climate Variability and Conflict Risk in East Africa, 1990–2009." *PNAS* 109 (45).

Oxfam. 2012. "Extreme Weather, Extreme Prices." *Oxfam Issue Briefing.* https://www.oxfam.org/sites/www.oxfam.org/files/file_attachments/20120905-ib-extreme-weather-extreme-prices-en_3.pdf.

Porter, J. R., M. A. Semenov. 2005. "Crop Responses to Climatic Variation." *Philosophical Transactions of the Royal Society B* 360: 2021–35.

Prudhomme, C., et. al. (2013). "Hydrological Droughts in the 21st Century, Hotspots, and Uncertainties from a Global Multimodel Ensemble Experiment." Proceedings of the National Academy of Sciences.

Schlenker, W., and M. J. Roberts. 2009. "Nonlinear Temperature Effects Indicate Severe Damages to U.S. Crop Yields under Climate Change." *Proceedings of the National Academy of Sciences* 106(37): 15594–98.

Schubert, R., and H. J. Schellnhuber. 2009. *Climate Change as a Security Risk.* Routledge, London, U.K.

Sirohi, S., and A. Michaelowa. 2007. "Sufferer and Cause: Indian Livestock and Climate Change." *Climatic Change* 85 (3–4): 285–98.

Sivakumar, M. V. K., H. P. Das, and O. Brunini. 2005. "Impacts of Present and Future Climate Variability and Change on Agriculture and Forestry in the Arid and Semi-arid Tropics." *Climate Change* 70: 31–72.

Stakhiv, E. Z. 1998. "Policy Implications of Climate Change Impacts on Water Resources Management." *Water Policy* 1(2): 159–75. doi: 10.1016/S1366-7017(98)00018-X.

Stark, J. 2011. "Climate Change and Conflict in Uganda: The Cattle Corridor and Karamoja." *USAID Office of Conflict Management and Mitigation* (No. 3). Discussion paper. U.S. Agency for International Development, Washington, DC.

Thornton, P. K. 2010. "Livestock Production: Recent Trends, Future Prospects." *Philosophical Transactions of the Royal Society of London B: Biological Sciences 365*(1,554): 2853–67.

Thornton, P. K., J. van de Steeg, A. Notenbaert, M. Herrero. 2009. "The Impacts of Climate Change on Livestock and Livestock Systems in Developing Countries: A Review of What We Know and What We Need to Know." *Agricultural Systems* 101(3): 113–27.

Union of Concerned Scientists (UCSUSA). 2011. "Heavy Flooding and Global Warming: Is There a Connection?" http://www.ucsusa.org/global_warming/science_and_impacts/impacts/heavy-flooding-and-global-warming.html#.VYR2DzJdXQQ.

Vara Prasad, P. V., K. J. Boote, L. Hartwell Allen, and J. M. Thomas. 2003. "Super-Optimal Temperatures Are Detrimental to Peanut (*Arachis hypogaea L.*) Reproductive Processes and Yield at Both Ambient and Elevated Carbon Dioxide." *Global Change Biology* 9(12): 1775–87.

Walthall, C. L., et al. 2012. "Climate Change and Agriculture in the United States: Effects and Adaptation." *USDA Technical Bulletin* 1935. USDA, Washington, DC.

Warner, K., and T. Afifi. 2014. "Where the Rain Falls: Evidence from 8 Countries on How Vulnerable Households Use Migration to Manage the Risk of Rainfall Variability and Food Insecurity." *Climate and Development* 6(1): 1–17.

Webster, P. J. 2008. "Myanmar's Deadly Daffodil." *Nature Geoscience* 1(8): 488–90.

Welch, J. R., J. R. Vincent, M. Auffhammer, P. F. Moya, A. Dobermann, and D. Dawe. 2010. "Rice Yields in Tropical/Subtropical Asia Exhibit Large but Opposing Sensitivities to Minimum and Maximum Temperatures." *Proceedings of the National Academy of Sciences* 107(33): 14562–67.

Werz, M., and L. Conley. 2012. "Climate Change Migration and Conflict in Northwest Africa: Rising Dangers and Policy Options across the arc of Tension." 2012/04. Center for American Progress. http://www.americanprogress.org

Wheeler, T. R., P. Q. Craufurd, R. H. Ellis, J. R. Porter, and P. V. Prasad. 2000. "Temperature Variability and the Yield of Annual Crops." *Agriculture, Ecosystems & Environment* 82(1): 159–67.

Willenbockel, D. 2012. "Extreme Weather Events and Crop Price Spikes in a Changing Climate: Illustrative Global Simulation Scenarios." *Oxfam Policy and Practice: Climate Change and Resilience* 8(2): 15-74.

Wollenweber, B., J. R. Porter, and J. Schellberg. 2003. "Lack of Interaction between Extreme High—Temperature Events at Vegetative and Reproductive Growth Stages in Wheat." *Journal of Agronomy and Crop Science* 189(3): 142–50.

World Bank. 2008. Agriculture for Development. *World Development Report 2008*. Washington, DC: World Bank.

———. 2011. *Philippines—Typhoons Ondoy and Pepeng: Post-Disaster Needs Assessment—Main Report*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/2778?show=full.

———. 2012. *Turn Down the Heat: Why a 4°C Warmer World Must Be Avoided*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/2012/11/17097815/turn-down-heat-4%C2%B0c-warmer-world-must-avoided.

———. 2013a. *Agricultural Sector Risk Assessment in Niger: Moving from Crisis Response to Long-Term Risk Management*. Washington, DC: World Bank. http://hdl.handle.net/10986/13260.

———. 2013b. *Implementing Agriculture for Development: World Bank Group Agriculture Action Plan (2013–2015)*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/2013/01/17747135/implementing-agriculture-development-world-bank-group-agriculture-action-plan-2013-2015.

———. 2014a. *Turn Down the Heat: Confronting the New Climate Normal*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/20595.

———. 2014b. *Reducing Climate Sensitive Disease Risks*. Report Number 84956-GLB. http://documents.worldbank.org/curated/en/2014/04/19567115/reducing-climate-sensitive-disease-risks.

———. 2014c. *Food Price Watch*. 5 (17). http://www.worldbank.org/content/dam/Worldbank/document/Poverty%20documents/FPW_May%202014_final.pdf.

———. 2015. *Effective Agricultural Risk Management: Nuanced World Bank Assistance*. Forthcoming. Washington, DC: World Bank.

APPENDIX A

OVERVIEW OF THE IMPACTS OF CHANGING CLIMATE AVERAGES ON AGRICULTURE

Temperature Rise on Crops

Different types of crops have different responses to increased temperatures. Wheat, rice, maize, soybeans, barley, and sorghum are the six most widely grown crops in the world, which are produced in over 40 percent of global cropland area, and provide 55 percent of non-meat calories and over 70 percent of animal feed (Lobell and Field 2007). Increased temperatures resulting from climate change since 1981 can be estimated to have resulted in annual combined production losses of 40 million tons ($5 billion) due to the negative impact these temperature changes have overall on these major cereal crops, in some areas offsetting a significant portion of yield gains from technology improvements (Lobell et al. 2012). Wheat and maize in particular experienced production decreases of 5.5 and 3.8 percent respectively, while soybeans and rice averaged no loss or gain from temperature increases (Lobell and Field 2007).

Although the repercussions of climate change on food production will vary enormously from region to region, higher average growing season temperatures have the potential to significantly impact agricultural productivity. A significant increase in mean seasonal temperature could shift harvest times for many crops, requiring agricultural adaptation to these average changes (Gornall et al. 2010). In warmer areas such as seasonally arid and tropical regions, where some crops are already growing in maximum temperatures at which they can survive, increased temperatures can lead to extended heat stress and water loss. These areas could be expected to experience severe losses even with only a 2°C temperature change, partially due to cereal harvest reduction as well as a potential lack of adaptive capacity. Most, but not all, middle and higher latitude locations would be more likely to experience an increase in agricultural production under a similar level of average warming, with the potential to increase wheat production by nearly 10 percent, counter to a similar percentage loss in low latitude areas under 2°C warming (World Bank 2010; figure 2). However, if mean global temperature warms by 2–4°C, agricultural productivity is likely to decline worldwide, in every region. Extreme negative impacts on agricultural production globally can be expected from an average temperature rise of 4°C or more.

Developing countries fare especially poorly in these projections, worse for all crops under multiple scenarios compared to developed country production (World Bank 2010). Negative effects of temperature change on agricultural productivity are especially pronounced in Sub-Saharan Africa and South Asia, in which all major crops are expected to experience yield reductions under climate change, while East Asia and the Pacific have more mixed results dependent on crop and climate models. However, rice production will be negatively affected by temperature increases, while wheat and maize are mixed. In high latitude countries such as the Russian Federation, more favorable temperatures and longer planting periods combined with improved technology could result in significant gains in potential agricultural land (Fisher et al. 2005). However, extreme events are likely to reduce these benefits, with significant impacts from temperature extremes.

Precipitation Change on Crops

Higher temperatures will increase evaporation, and eventually will also increase average rainfall (Nelson 2014). It is difficult to project exact changes in average precipitation regionally because regional precipitation depends strongly on changes in atmospheric circulation, which depends on the relative rate of warming in different regions.

There are often a number of complicated climate factors influencing precipitation change projections specific to a given location, such as monsoon circulation and evaporation potential (Meehl et al. 2007). Nonetheless, there is increasing confidence in projections of an overall increase in precipitation in high latitudes. Simultaneously, many parts of the tropics and sub-tropics are expected to experience an overall decrease in precipitation (IPCC 2007). For instance, large increases have been projected in the southern United States, while low-latitude tropics would experience decreasing average rainfall. In some of these models, India is expected to experience increasing precipitation, while others do not predict this, illustrating the wide range of precipitation change projections from different climate scenarios (Christensen et al. 2007).

Increased water stress will occur both in rain-fed and irrigated agricultural lands. Mean precipitation change is especially important to identify for rain-fed areas, however, which account for over 80 percent of total agricultural production. Future precipitation changes will influence the magnitude and direction of climate impacts on crop production. Even small changes in mean annual rainfall in a single year can impact productivity. A change in growing season precipitation by one standard deviation can be associated with as much as a 10 percent change in production (Lobell and Burke 2008).

Average rising temperatures could also lead to an increase in crop irrigation needs, due to increased evapotranspiration and longer growing seasons. Water needs for agriculture could increase by 5 to 20 percent or more by the end of the century, thus placing extra water stress on crops. Regionally, irrigation requirements in the Middle East, North Africa, and Southeast Asia could increase by at least 15 percent (Fisher et al. 2006). However, precipitation changes also indicate decreased water needs in some areas, such as China, though uncertainties about these variances make such projections difficult to estimate.

Due to the combined impacts of the expansion of warming oceans and increased water from melting ice, sea-level rise is one of the most consistent climate impact projections. Increases in mean sea level threaten to inundate agricultural lands and salinize groundwater in the coming decades to centuries. Sea-level rise is expected to eventually inundate many small islands and coastal land in areas with low capacity to respond through adaptive measures such as sea walls.

Agricultural crop vulnerability is clearly greatest where large sea-level rise occurs in conjunction with low-lying coastal agriculture. Sea-level rise would likely impact many mid-latitude coastal areas and increase seawater penetration into coastal aquifers used for irrigation of coastal plains (World Bank 2012). In Bangladesh, 40 percent of productive land is projected to be lost in the southern region of Bangladesh for a 65 cm sea level rise by the 2080s. While the largest impacts from sea level rise may not be seen for many centuries, relatively little work has been done to assess the impacts of mean sea-level rise on agriculture.

Impacts of Changing Climate Averages on Livestock

Livestock production systems will be affected in direct and indirect ways (see table A1.1) and changes in productivity are inevitable. Increasing climate variability will undoubtedly increase livestock production risks as well as reduce the ability of farmers to manage these risks. Direct impacts include changes on quantity and quality of feed crops and grazing systems (Thornton et al. 2009). Current evidence suggests that grazing areas in lowland sites with low rainfall see the largest reduction in yield during dry seasons (Sirohi and Michaelowa 2007). Increases in temperature and changes in rainfall and its variability can lead to feed scarcity and consequently reduced feed intake that can have an impact on productivity (milk production and weight gain) and even mortality (Thornton and Cramer 2012). In addition to affecting livestock directly on their physiological processes, and indirectly on crop and rangeland resources, heat stress can also have an effect on livestock vector-borne disease (Nelson et al. 2014) through changes in the distribution of ticks, mosquitos, flies, and others (Thornton and Cramer 2012). Increasing temperatures are also expected to amplify the water needs of livestock. Taking into account potential reductions in water availability, this need is expected to curtail livestock development (Thornton and Cramer Eds. 2012). Extreme events will also impact livestock. Droughts, heavy rains, flooding, and cyclones have all been found to have effects on livestock. In India alone, flooding has caused losses of nearly 94 thousand cattle annually on average (Sirohi and Michaelowa 2007). Droughts are even more serious in the country. In one particularly large drought in 1987, one state lost more than half of its 34 million cattle (Sirohi and Michaelowa 2007).

TABLE A1.1. DIRECT AND INDIRECT IMPACTS OF CLIMATE CHANGE ON LIVESTOCK PRODUCTION SYSTEMS

Grazing systems	Non-grazing systems
Direct impacts	
Extreme weather events	Water availability
Drought and floods	Extreme weather events
Productivity losses (physiological stress) owing to temperature increase	
Water availability	
Indirect impacts	
Agro-ecological changes:	Increased resource price, for example feed and energy
Fodder quality and quality	Disease epidemics
Host–pathogen interactions	Increased cost of animal housing, for example cooling systems
Disease epidemics	

Source: Thornton 2010.

Pests and Diseases on Crops and Livestock

Weather exerts an influence on all stages of host and pathogen life cycles, and the development of disease, and climate change threatens the control of pest and disease invasions, including insects, plant diseases, and invasive weeds. Increasing average temperatures, warmer winter minimum temperatures, changes in precipitation patterns, and water shortages are all climate factors that favor pest and disease invasions. The impacts of climate change on the spread and incidences of crop pests are complex and as yet the full implications in terms of crop yield are uncertain, but could be substantial.

Studies indicate that temperature increases may extend the geographic range of some insect pests. For instance, with a 1°C increase in temperature a northward shift in distribution of between 165 and 500 km is indicated for the European corn borer, a major pest of grain maize. La Roya coffee rust has attacked coffee plants in Central and South America at higher altitudes as the climate warms (Oxfam 2013). Over the next 10–20 years, oilseed rape disease could both become more severe in its current area and spread to more northern regions (Evans et al. 2008). Temperature increases may also advance invasions in the growing season, when the crop is at early development and is susceptible. Precipitation increases are also likely to favor the development of fungal and bacterial pathogens (Parry 1990). Some pests, including aphids and weevil larvae, respond positively to higher levels of atmospheric carbon dioxide (Staley and Johnson 2008; Newman 2004). Aphids may also benefit from increased temperatures, which prevent them from dying in large numbers during the winter and may allow the species to disperse earlier and more widely (Zhou et al. 1995). As a result of rainfall-based migration patterns, precipitation variability due to climate change may affect locust occurrences in sub-Saharan Africa (Cheke and Tratalos 2007).

Climate change impacts have had profound effects on the distribution of animal diseases, and will further transform the ecology of numerous pathogens. The current trend regarding the ever-increasing globalization of the trade of animals and animal products ensures that agricultural diseases will continue to follow legal and illegal trade patterns with increasing rapidity. In recent years, many agricultural diseases have given cause for concern regarding changes in distribution or severity. Foot-and-mouth disease, avian influenza, and African swine fever continue to cause serious problems (Arzt 2010).

In the next twenty years, while the distribution of these diseases may be affected by some climate-related shifts in the areas suitable for vector-borne diseases such as malaria and bluetongue, these are not expected to have as much of an impact in the short term (Woolhouse 2006). However, in the United Kingdom, change in the extent, amount, and seasonal timing of helminthes (parasites) has resulted from climate change impacts, especially higher temperatures (Van Dijk et al. 2010). These kinds of shifting disease patterns resulting from climate change will require awareness and preparedness as well as early detection and diagnosis of livestock parasitic disease, and may become more prevalent as temperatures rise (Gornall et al. 2010).

Although the direct impacts of climate change on livestock disease over the next two to three decades may be relatively muted, knowledge gaps concerning many existing diseases of livestock and their relation to climate and other factors make this a very important topic to pursue (King et al. 2006).

Food Quality

Climate change affects nutrition by disrupting supply of food (like yields). There is new evidence, however, that higher atmospheric carbon dioxide concentration changes the nutrient value of crops and might also change the variety of foods available (Nelson 2014). Studies have found that elevated carbon dioxide is associated with lower concentrations of zinc and iron in wheat, rice, field peas, and soybeans, as well as lower protein content in wheat and rice (Myers et al. 2014). The International Rice Research Institute (IRRI) is also expecting rice quality to decrease due to higher temperatures (Nelson 2014). Protein content of cereals such as wheat and rice may have already declined in the past century due to atmospheric changes (Burns et al. 2010). Leaves will also contain up to 20 percent less protein affecting the nutritional intake of grazing animals (Burns et al. 2010).

In addition to protein and carbohydrates, plants contain other chemicals too that protect them from herbivores and disease-causing pathogens. Depending on factors such as the amount consumed at one time, a person's health, age, and weight, and the accompanying amount of protein ingested, the consumer can tolerate these natural toxins. At higher carbon dioxide levels, however, plant resources that would have otherwise been directed toward powering photosynthesis, are directed instead toward the chemicals which protect the plants but might harm those that consume them. The effects on human nutrition are not fully known (Burns et al. 2010).

APPENDIX B

INTRODUCTION TO THE WORLD BANK'S AGRICULTURAL RISK MANAGEMENT APPROACH

Risks arising from the "damaging whims of nature, including pestilence, and diseases" are nothing new for agriculture. All of the previously discussed hazards, climate, and weather related risks that climate change will bring have existed and created challenges ever since agriculture was practiced. One of the key tools developed to help build resilience toward and reduce vulnerability to these (and other) risks, is agricultural risk management.

ARM as practiced by the Agricultural Risk Management Team (ARMT) at the World Bank typically involves the following sequence:

1. **Risks assessment and prioritization:** Analysis of the three principle types of agricultural risks and their prioritization, based on probability of occurrence and severity of losses.
    a. Production risks: Weather events (droughts, floods, hurricanes, cyclones, sudden drops or increases in temperature, frost, and so on), pest and disease outbreaks, bush fires, windstorms, and so on are major risks that lead to production volatility.
    b. Market risks: Risks like commodity and input price volatility, exchange rate and interest rate volatility, and counterparty and default risks usually materialize at the market level but have backward linkages to the farm gate, thereby affecting all stakeholders.
    c. Enabling environment risk: Changes in government or business regulations, macro-economic environment, political risks, conflict, trade restrictions, and so on are all major enabling environment risks that lead to financial losses.
2. **Stakeholders' assessment:** This entails analysis of the role of different stakeholders across the agricultural sector and understanding of their risk management capacity. For simplicity, the sector is analyzed across three layers:
    a. Producers (micro): Marginal, small, and medium sized farmers are the backbone of the agricultural sector in most developing countries.

FIGURE B2.1. AGRICULTURAL RISK MANAGEMENT FRAMEWORK

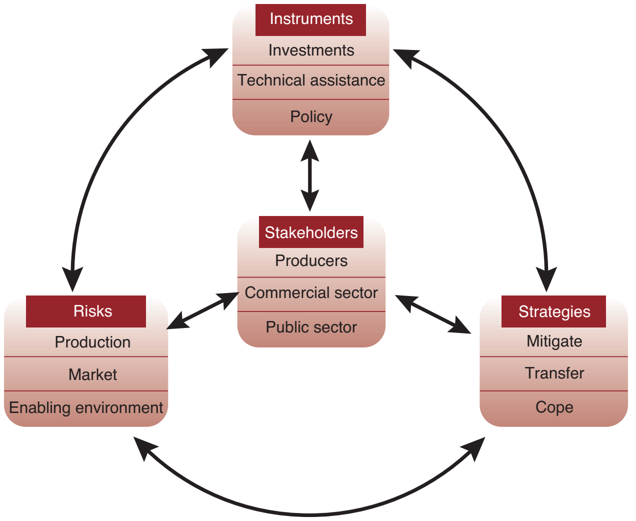
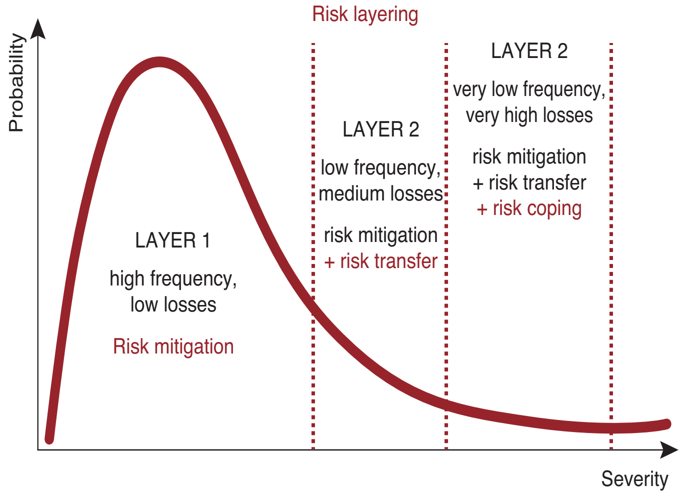


FIGURE B2.2. ILLUSTRATION OF RISK LAYERING APPROACH



   b. Commercial sector stakeholders (meso): Commercial stakeholders, including traders, middlemen, wholesalers and retailers, financial institutions, input providers, and so on.
   c. Public sector (macro): Public sector institutions, parastatals, government, and donors.
3. **Risk Management Strategies:** The principle strategies to manage agricultural risks can be classified into:
   a. Mitigation: Activities designed to reduce the likelihood of an adverse event or reduce the severity of actual losses. Risk mitigation options are numerous and varied (for example, irrigation; use of resistant seeds; improved early warning systems; and adoption of better agronomic practices).
   b. Transfer: This entails the transfer of risk to a willing party, for a fee or premium. Commercial insurance and hedging are the well-known forms of risk transfer.
   c. Coping: This involves improving resilience to withstand and cope with events, through ex-ante preparation. Examples include social safety net programs, buffer funds, savings, strategic reserves, contingent financing, and so on.
4. **A risk layering approach**, based on the probability of occurrence and potential losses, is used to select an appropriate risk management strategy.
   » All standard text may be set in lowercase (e.g. “high frequency, low losses – risk mitigation”).
   » In the last column, add spaces in “very low frequency.”

Implementation Instruments: Translating risk management strategies into concrete action requires deployment of several instruments which can be classified under:

1. Agricultural investments: Financial investments in irrigation infrastructure, drought and pest tolerant seed varieties, soil and water conservation, weather infrastructure, or investment in improving systems (for example, agriculture extension systems or disease surveillance systems).
2. Technical assistance: This is geared toward building capacity of local stakeholders (for example, training in price risk management; feasibility studies for various instruments; flood risk modeling work; developing early warning systems).
3. Policy support: Improved risk management might entail policy reform (for example, changes in policy to improve access to agricultural inputs; changes in information policy to make weather information easily accessible to all; government procurement, storage, and grain release policies to manage strategic reserves).

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