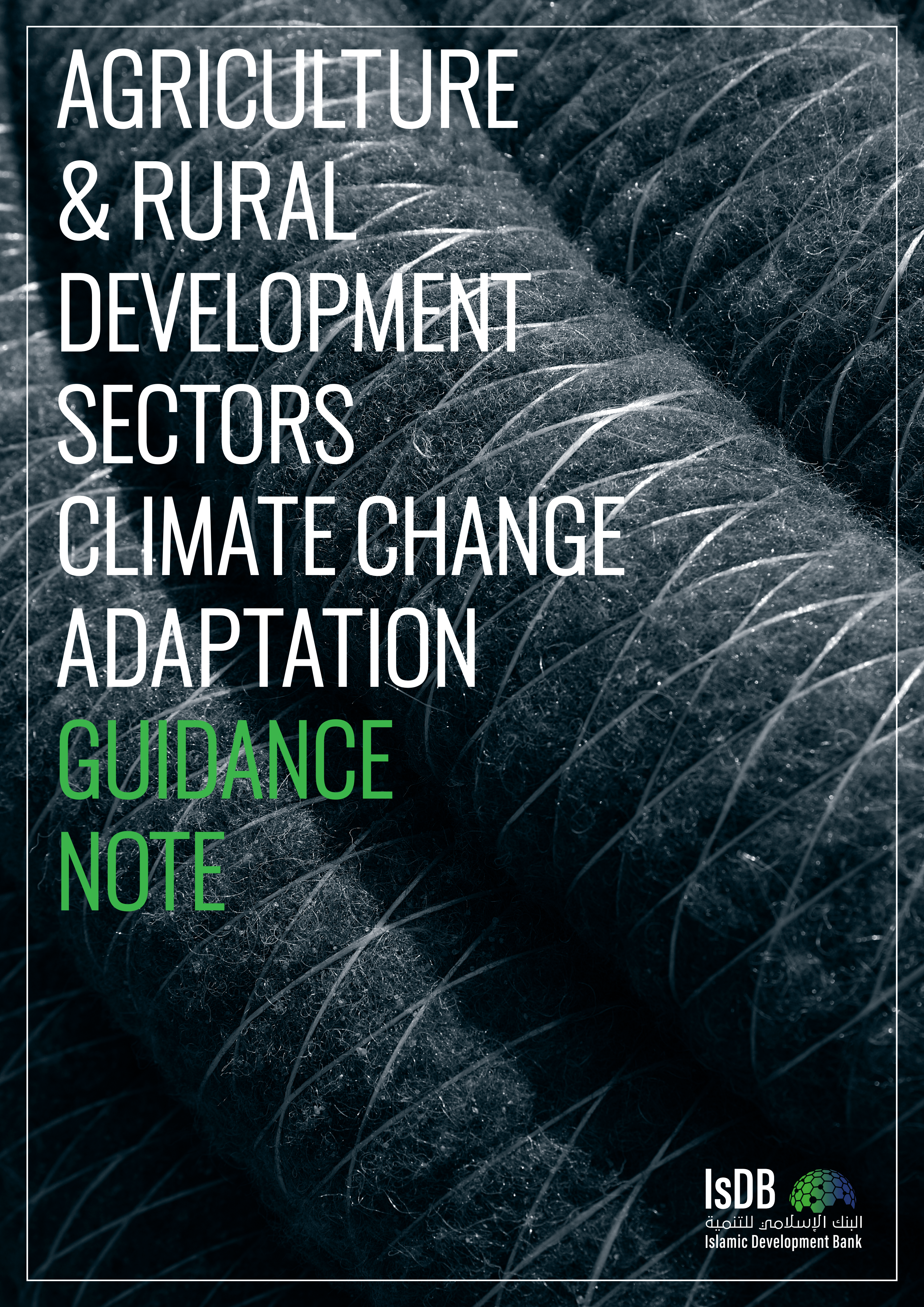
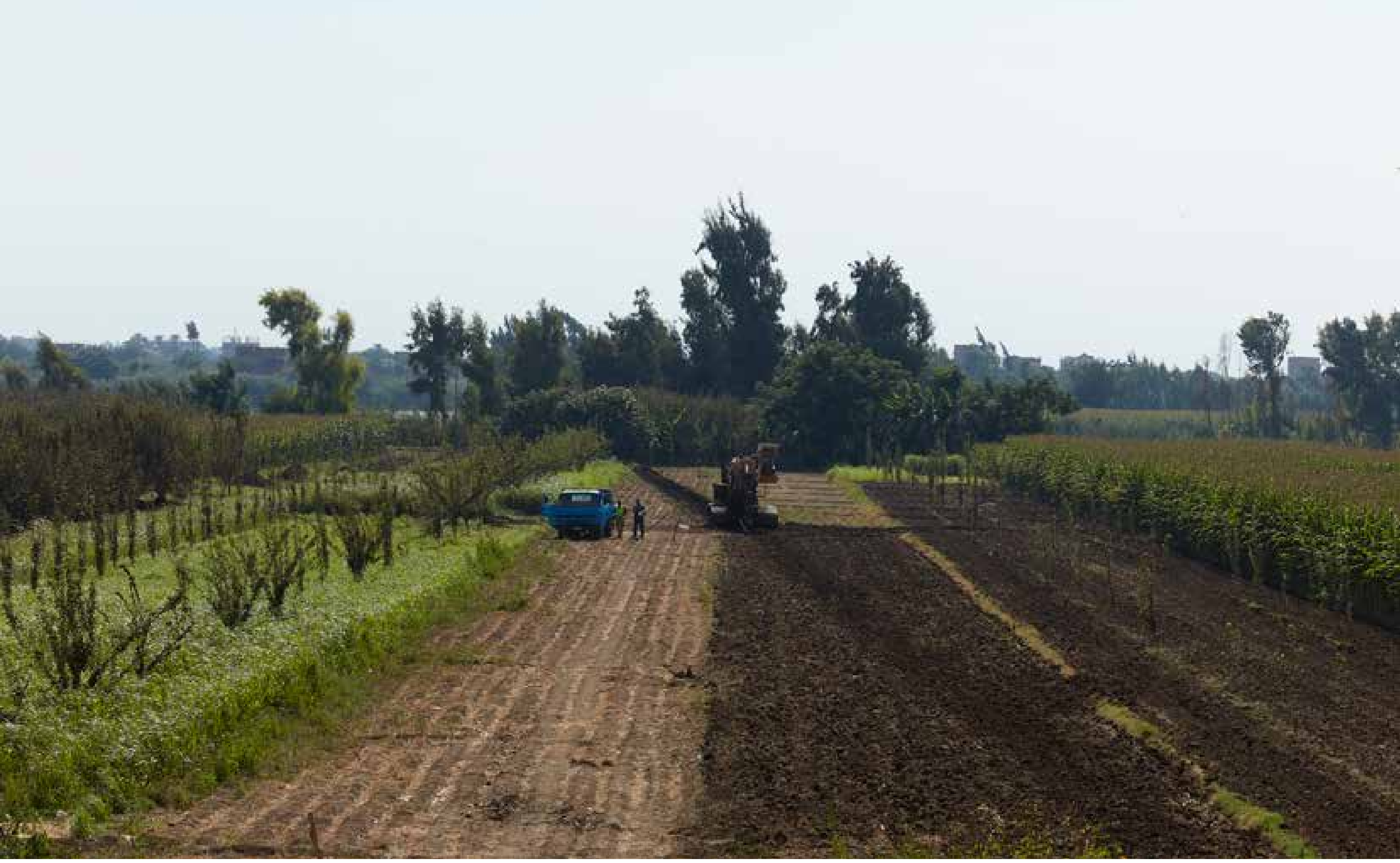


AGRICULTURE & RURAL DEVELOPMENT SECTORS CLIMATE CHANGE ADAPTATION GUIDANCE NOTE

IsDB
البنك الإسلامي للتنمية
Islamic Development Bank



Acknowledgments

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The main author of this guidance note was the World Resources Institute (WRI), technical consultant to the Islamic Development Bank. Special thanks to Lauren Sidner (WRI) and Michael Westphal (WRI) for their effort in this work.

Disclaimer

1. About this Guidance Note

This guidance note on the agriculture and rural development sectors was prepared by the World Resources Institute (WRI) for the Islamic Development Bank (IsDB) to enable IsDB project teams to integrate information on climate risks into project design. It applies to agriculture and rural development projects involving physical assets. For the purposes of this note, the agriculture and rural development sectors include the following:

- Crop production projects, including rainfed and irrigated production systems
- Livestock production projects
- Aquaculture projects
- Projects relating to postharvest elements of the food value chain, including postharvest storage, processing, distribution, and marketing
- Rural housing projects

After a brief background on projected climate changes in the regions where IsDB operates and their projected impacts on the agriculture and rural development sectors (Section 2), Section 3 explains the purpose of this note within a broader climate risk management process. It describes the steps involved in managing a project's climate change risks—beginning with climate risk screening, followed by project impact and adaptation assessments, and ending with project implementation. Section 4 then describes the process of determining potential climate impacts on agriculture and rural development projects and identifying adaptation options to address those impacts. Section 5 presents an approach to evaluate adaptation options, and Section 6 concludes with a case study that demonstrates a practical example of this approach.

2. Background: Climate Change and the Agriculture and Rural Development Sectors

In 2017, a total of $3.9 billion was approved from IsDB's Ordinary Capital Resources. (IsDB 2017). Of the total, 18.4 percent went to agricultural and rural development (IsDB 2017). IsDB operates in four core regions: the Middle East and North African, sub-Saharan Africa, Europe and Central Asia, and Asia and Latin America.[1] Observed and projected climate changes vary across these regions.

Throughout much of Africa, mean temperatures have increased by at least 0.5°C over the last 50 to 100 years, with minimum temperatures rising faster than maximum temperatures. Much of the region lacks sufficient data to draw conclusions about trends in annual precipitation. However, in the western and eastern Sahel regions, annual precipitation has likely decreased, and in parts of eastern and southern Africa, it has likely increased. In terms of model projections, it is likely that land temperatures over Africa will rise faster than the global average, particularly in the more arid regions. There is considerable uncertainty regarding projected precipitation patterns in sub-Saharan Africa, but there is greater model agreement that precipitation will increase in east Africa and decrease in north and southwest Africa. Across the continent, climate change is expected to exacerbate existing water stress (Niang et al. 2014).

In the past century, much of Asia has experienced warming trends and increasing temperature extremes. There is little agreement on projected precipitation patterns at a subregional scale, but under a higher warming scenario (Representative Concentration Pathway [RCP] 8.5), precipitation is likely to increase at higher latitudes by the middle of the 21st century and in parts of eastern and southern Asia by the late 21st century. Water scarcity is expected to be a major challenge for most of Asia due to increased water demand and poor water management (Hijioka et al. 2014). In Europe, future climate projections vary regionally, with projected temperature increases throughout the region, precipitation increases in northern Europe, and precipitation decreases in southern Europe. Across the continent, climate projections indicate a marked increase in heat waves, droughts, and heavy precipitation events (Kovats et al. 2014).

Lastly, significant trends in precipitation and temperature have been observed in Central America and South America, but the patterns vary regionally. Increased warming has been observed throughout the region, with the exception of the Chilean coast. Increases in temperature extremes have been measured in Central America and most of tropical and subtropical South America, while more frequent extreme rainfall in southeastern South America has produced more landslides and flash floods. Under the RCP 8.5, climate models project a mean reduction of 10 percent in annual precipitation for Central America (with a reduction in summer precipitation) by 2100, a decrease of 10 percent for tropical South America east of the Andes, and an increase in 15 to 20 percent for southeastern South America. One major concern is the melting of the Andean cryosphere, which is altering the seasonal distribution of streamflow.

The projected impacts of climate change on agricultural production vary geographically and are highly dependent on the overall warming and the degree of adaptation employed. One factor that will impact agricultural production is the degree to which elevated levels of carbon dioxide (CO_2) have a stimulatory impact on yields (known as *CO_2 fertilization*). While there is some uncertainty (and a lack of evidence in nontemperate regions), field studies indicate that C_3 plants (wheat, rice, cotton, soybean, sugar beets, and potatoes) will benefit more than C_4 plants (corn, sorghum, sugarcane). However, the impact will vary widely based on the availability of water and nutrients, with studies indicating that rainfed systems may benefit more from higher CO_2 concentrations than irrigated systems do (Porter et al. 2014).

Overall, there is high confidence that a rise of 4°C or more in global temperature, combined with increasing food demand, would pose large risks to food security, particularly in low-latitude regions. In the absence of adaptation, local temperature increases of 2°C or more will likely negatively impact production of major crops like wheat, rice, and maize in tropical and temperate regions. Projected impacts vary across crops and regions and adaptation scenarios: about 10 percent of projections for the period 2030–2049 show yield gains of more than 10 percent, and about 10 percent of projections show yield losses of more than 25 percent, with respect to the late 20th century. After 2050, the risk of more severe impacts increases, particularly for low-latitude regions (Porter et al. 2014).

In Africa, rising temperature and changes in precipitation are likely to decrease cereal production; high-value perennial crops may also experience yield losses due to temperature increases (Niang et al. 2014).In Asia, many rice-growing regions are near the heat stress limits for rice, and rising temperatures are expected to result in lower yields due to shorter growing periods. In Central Asia, cereal production could increase in Kazakhstan, while in Turkmenistan and Uzbekistan, frequent droughts could affect cotton production, and increased water demand for irrigation may exacerbate desertification. In the Indo-Gangetic Plains of South Asia, heat stress could result in a decrease of about 50 percent in the most favorable and high-yielding wheat areas, while sea-level rise will inundate low-lying areas and will significantly affect rice growing regions in Asia (e.g., Bangladesh) (Hijioka et al. 2014).

Climate change many have positive or negative impacts in northern latitudes; the potential for a longer growing season may be offset by, inter alia, water scarcity, increases in extreme weather events, or increased disease and pest outbreaks. On average, adaptation improves yields by the equivalent of approximately 15 to 18 percent of current yields, but the projected benefits of adaptation are greater for crops in temperate, as opposed to tropical regions, with wheat- and rice-based systems more adaptable than those of maize (Porter et al. 2014).

3. Project Climate Risk Management

This guidance aims to help project teams incorporate climate change considerations into project planning and design. It will support the broader climate risk management process, which begins with climate risk screening and concludes with project implementation. Figure 1 below briefly summarizes the climate risk management process.[2] Though the terminology and precise sequencing of steps vary, many comparable institutions, including multilateral development banks and bilateral development agencies, apply these steps in one form or another. See Appendix 1 for a glossary of key terms used in Figure 1 and throughout the note.

The first phase of the process is climate risk screening. IsDB plans to begin using Acclimatise Aware, a climate risk screening tool, for this phase.[3] It will use Aware at the early concept stage for all projects involving physical assets.

In addition to generating an overall climate risk ranking, Aware identifies key climate risk areas for the project, based on project category and location. If the initial climate risk screening using Aware indicates that a project has some level of climate risk, project impact and adaptation assessments follow. This guidance note is meant to support those phases of the climate risk management process.

Climate risk screening and project impact assessment together establish the climate change vulnerability context of a project. That context informs the adaptation assessment that follows, which aims to identify those measures best suited to reduce climate vulnerability, thereby establishing a direct link between specific project activities and the overall objective of reducing climate vulnerability. The sections that follow discuss project impact and adaptation assessments in greater detail.

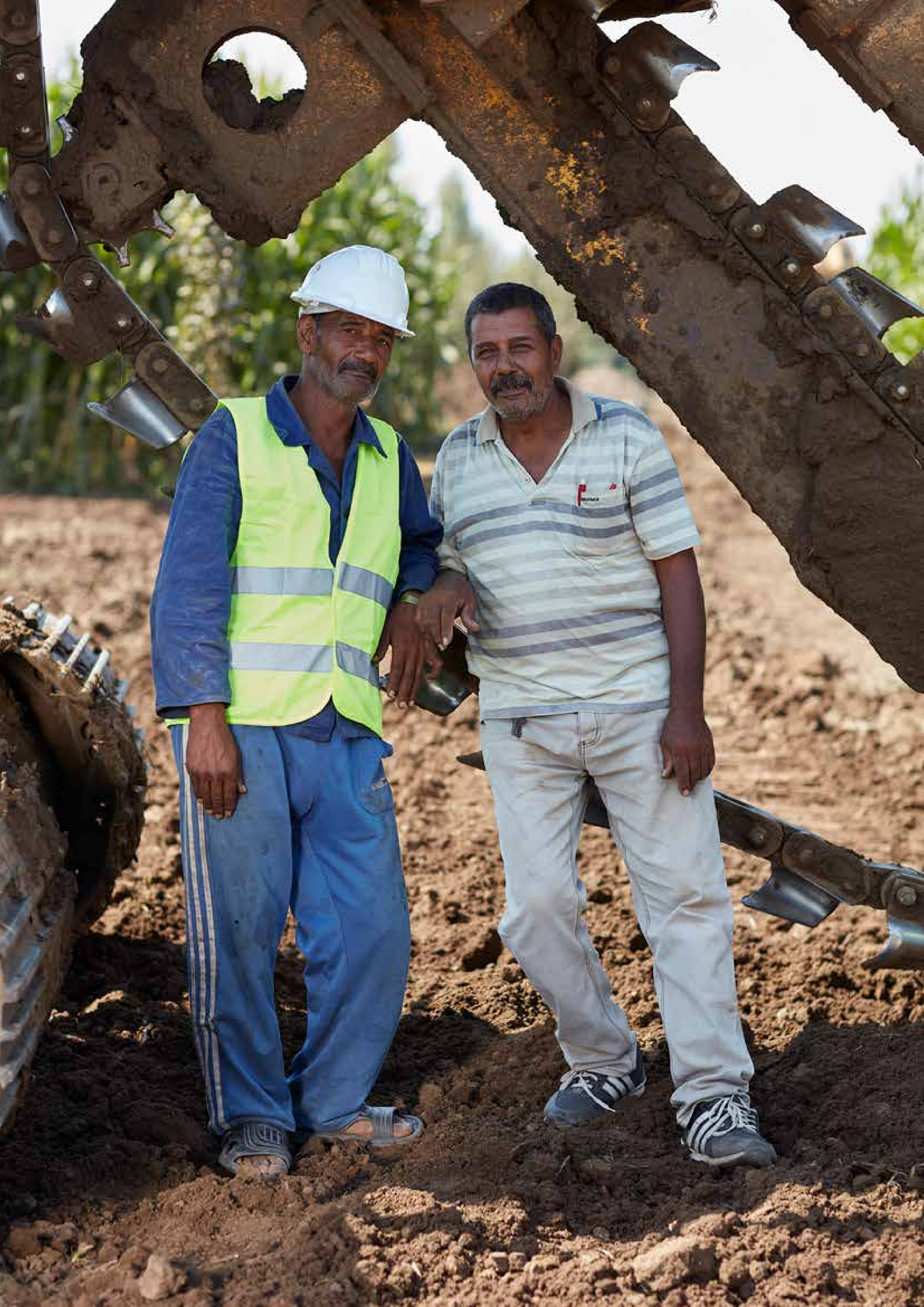

FIGURE 1: CLIMATE RISK MANAGEMENT PROCESS

CLIMATE RISK SCREENING

Preliminary, rapid assessment of the risks posed to a planned project as a result of climate change. Tools and methodologies used include Acclimatise, Aware; World Bank, Climate and Disaster Risk Screening Tool; International Institute for Sustainable Development, Community-Based Risk Screening Tool—Adaptation & Livelihoods (CRiSTAL).

PROJECT IMPACT ASSESSMENT

- Identify the climatic variables of interest for the project. These may include meteorological (e.g., temperature, precipitation); hydrologic (e.g., runoff volume, groundwater recharge, soil moisture); and other environmental (e.g., sea-level rise) variables. When their impacts are harmful, these variables are referred to as climate hazards.

ADAPTATION ASSESSMENT

- Establish adaptation objective.
- Identify adaptation options.
- Use a multi-criteria approach to appraise adaptation options (e.g., functional effectiveness, technical feasibility, affordability, stakeholder acceptability, etc.).

IMPLEMENTATION

- Establish implementation arrangements for selected adaptation measures (determine roles and responsibilities; identify needs for technical support and capacity building, etc.).

Sources: ADB 2014; ADB 2012; USAID 2015; GIZ 2014

• Identify the changes in environmental conditions (or *system impacts*) likely to follow from changes in the above variables (e.g., reduced raw water quality, increased evapotranspiration, increased frequency of floods).	• Determine the *vulnerability* of different project components to changes in environmental conditions. Vulnerability is a function of th project's exposure, sensitivity, and adaptive capacity to a specific climate hazard.

• Conduct economic assessment of shortlisted adaptation options.	• Select adaptation strategy.	• Stakeholder engagement is critical to all of these steps.

• Provide for ongoing monitoring and evaluation.

This guidance note can help to inform these steps.

4. Identifying Potential Impacts and Adaptation Options

As explained above, the Aware climate risk screening tool identifies the key climate risk areas based on the project's type and location. Project teams can use this information, along with expert judgment and other available climate data, to determine the climate hazards most likely to be relevant for a project. The World Bank's Climate Change Knowledge Portal[4] and The Nature Conservancy's Climate Wizard[5] are two examples of publicly available tools for identifying location-specific climate information (USAID 2017).[6] Additionally, the web mapping tool, Aqueduct Commodities, provides more localized information on water scarcity and agricultural production (WRI). From there, project teams can begin to evaluate the likely impacts and potential adaptation responses. This section provides tools to support this evaluation.

Identifying Potential Impacts

The decision trees below can guide project teams in identifying potential climate vulnerabilities of projects involving crop production (Figure 2); livestock production (Figure 3); aquaculture (Figure 4); postharvest elements of the food value chain (Figure 5); and rural housing (Figure 6). For example, if the Aware tool flags sea-level rise as a key risk area for a food processing facility project, a project team would see that coastal inundation and erosion could physically damage the facility, causing delays or increasing maintenance requirements. It could also cause power outages, which would disrupt facility operations (see Figure 5).

However, project teams must be aware of several important caveats in using the decision trees. First, the trees provide a generalized overview of potential impacts, but climate change is likely to affect the agriculture and rural development sectors in diverse and highly context-specific ways (Fanzo et al. 2018). Impacts, such as reductions in crop yield, are likely to vary across different geographies and agro-ecological zones, different production systems, and different socioeconomic contexts (Fanzo et al. 2018).

Second, the different climate drivers cannot be viewed in isolation. Instead, project teams must consider how the various drivers interact with each other. Some climate drivers may amplify one another, while others counteract one another (FAO 2018). At the same time, a variety of nonclimate factors, such as population growth, land-use change, economic development, and urbanization, pose significant challenges to the agriculture and rural development sectors (USAID 2014). In many instances, these nonclimate stressors interact with climate stressors in similarly complex ways (USAID 2014). For example, population growth and rising incomes are likely to drive up future global food demand as changing climate conditions strain agricultural productivity (FAO 2016).

Third, some agricultural production may benefit from certain climate drivers. Some of these potential benefits are highlighted in the decision trees, but it is important to note there is considerable uncertainty about the extent of potential benefits and how different climate drivers will interact. One example is the carbon dioxide (CO_2) fertilization effect referenced above: elevated atmospheric CO_2 may increase the productivity of some crops, but the extent of potential production gains from CO_2 fertilization remains uncertain (World Bank 2009). Moreover, the net effect of such gains and potential losses associated with other climate drivers is highly uncertain. For instance, it is possible that in some regions, increased yields stemming from CO_2 fertilization will be offset by elevated temperatures (World Bank 2009). There is also evidence to suggest that elevated atmospheric CO_2 can reduce the nutritional quality of some crops, so some increases in yield could also be effectively offset by diminished nutritional value (Vermeulen et al. 2014). Similarly, warmer temperatures and longer growing seasons may increase productivity in some high-latitude and high-altitude regions, but changes in other climate conditions, such as declining rainfall, could temper potential gains (World Bank 2009).

Finally, the decision trees primarily focus on the potential physical impacts of climate change, but climate change could impact the agriculture and rural development sectors in diverse ways, including direct and indirect physical impacts and a variety of nonphysical impacts. Potential nonphysical impacts include market, legal, employment, and reputational impacts. Climate change could cause shifts in demand or changes in comparative advantage across regions. For instance, rising temperatures and extreme heat could prompt increased refrigeration requirements in postharvest storage and distribution (Brown et al. 2015). It could also affect labor markets, altering supply or demand for rural labor. Changing conditions could also lead to revised regulatory requirements. For example, increased risk of mycotoxin contamination (Stathers et al. 2013)[7] in stored products during rising temperatures could lead to more stringent phytosanitary requirements for cross-border marketing of goods (Stathers et al. 2013).

Because nonphysical impacts tend to be context- and project-specific, they are not the focus below. The precise legal impacts, for example, will depend entirely on the legal and regulatory framework in the project country or the specific contractual arrangements underlying a project.

That said, upon identifying potential physical project vulnerabilities, project teams should consider whether such vulnerabilities could have follow-on, nonphysical consequences for a particular project.

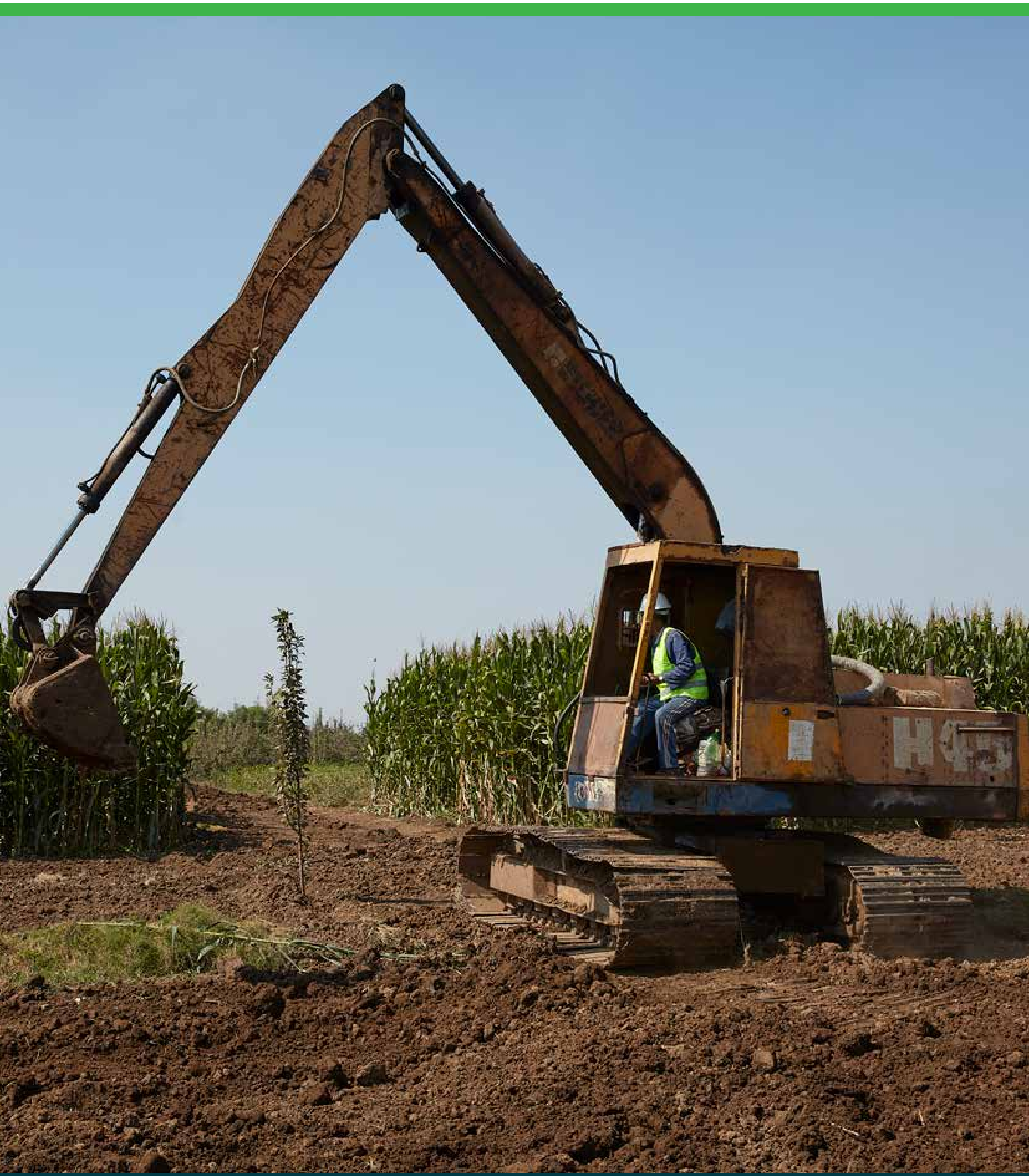

FIGURE 2: DECISION TREE FOR CROP PRODUCTION PROJ

CLIMATE HAZARD

Atmospheric CO_2 increase	Temperature increase

SYSTEM IMPACTS

Increased incidence of some weeds	Increased incidence of some pathogens and other plant pests	Potential changes in distribution and abundance of some insects, pollinators, and natural enemies of plant pests

PROJECT VULNERABILITIES

Increased pest pressure and risk of plant diseases; productivity decline or crop losses; increased use of pesticides; increased labor demand for weeding	Potential lack of pollinators or mismatch between crop flowering periods and active periods of pollinators	Increased evaporative losses from irrigation delivery infrastructure and bare soil

ADAPTATION OPTIONS

✓Adopt improved integrated pest and disease management techniques ✓Adopt more disease resistant varieties; provide access to and training on new varieties ✓Improve capacity for surveillance and early detection of pest invasions ✓Increase diversity of crops to hedge against risk of individual failure; diversify through intercropping ✓Diversify sources of income; pursue nonfarm income-generating activities	✓Monitor and evaluate pollinators to better understand climate risks to the services they provide ✓Identify and preserve the natural habitats of wild pollinator species ✓Develop corridors of suitable habitats that ensure food and nesting resources are available for pollinators ✓Diversify sources of income; pursue nonfarm income-generating activities	✓Improve water collection, storage, and distribution hardware to reduce water losses (e.g., line canals, cover channels, use piping) ✓Minimize evaporative losses from bare soils (e.g., organic or plastic mulching)

ECTS (page 1)

Shifts in agroclimatic zones; changes in crop phenology

Increased evapotranspiration rates

Higher mean growing season temperatures; more frequent heat waves and temperature extremes

Rising winter temperatures; reduced occurrence of frost

Increased crop water demand;more rapid depletion of soil moisture; increased risk of water deficit

Increased heat stress may reduce productivity and increase risk of crop failure or decrease labor productivity/ health; decreased suitability of some crops for some regions

Longer growing seasons and possible increased productivity in some areas; cropping may become feasible in previously unsuitable areas

- ✓Identify supplemental sources of irrigation water for irrigated systems
- ✓Implement irrigation systems in previously rainfed systems
- ✓Enhance soil moisture retention (e.g., conservation agriculture, mulching, terracing, cover cropping)
- ✓Implement conservation agriculture and other practices to improve soil quality and enhance soil moisture retention (e.g., cover crops, crop rotation, balanced use of fertilizers and manure)
- ✓Implement agroforestry systems to increase water infiltration and reduce erosion
- ✓Switch to less water-intensive crops or drought-resistant varieties; provide access to and training on new varieties
- ✓Alter planting dates to better match seasonal conditions to crop characteristics
- ✓Implement weed control techniques to reduce competition for water and transpiration losses by weeds

- ✓Adopt crop species or varieties with greater heat tolerance; provide access to and training on new varieties
- ✓Increase diversity of crops to hedge against risk of individual crop failure
- ✓Alter planting dates to better match seasonal conditions to crop characteristics (e.g., earlier planting to reduce exposure to mid-summer extreme heat)
- ✓Implement agroforestry or other intercropping systems to provide shade and reduce temperature
- ✓Evaluate alternative uses of crop land
- ✓Diversify sources of income; pursue nonfarm income-generating activities

FIGURE 2: DECISION TREE FOR CROP PRODUCTION PROJ

CLIMATE HAZARD

Decreasing precipitation and drought

Sea-level rise and storm surge

SYSTEM IMPACTS

Soil moisture depletion; increased erosion, land degradation, and desertification

Diminished rainfall, reduced streamflow and inflows to reservoirs and aquifers

PROJECT VULNERABILITIES

Reduced soil quality; loss of arable land due to land degradation and wind erosion

Water supply sufficiency and reliability reduced; productivity decline or crop failure

Increased salinity of water and soils in coastal areas; reduced freshwater availability; productivity decline or crop failure; loss of arable land

ADAPTATION OPTIONS

Irrigated & Rainfield Systems

- ✓Implement conservation agriculture and other practices to improve soil quality and enhance soil moisture retention (e.g., crop rotation; balanced use of fertilizers and manure; cover cropping; terracing, etc.)
- ✓Implement agroforestry systems to increase water infiltration and reduce erosion
- ✓Adopt drought-resistant varieties; provide access to and training on new varieties
- ✓Explore opportunities to share water across uses (e.g., integrated crop-aquaculture systems)
- ✓Alter planting dates to better match seasonal conditions to crop characteristics
- ✓Implement weed control techniques to reduce competition for water and transpiration losses by weeds

Irrigated Systems

- ✓Improve water collection, storage, and distribution hardware to reduce water losses (e.g., line canals, cover channels, use piping)
- ✓Adopt irrigation technologies and practices that use less water (e.g., drip irrigation, improved irrigation scheduling, deficit irrigation)
- ✓Implement demand-management policies (e.g., overconsumption water tariffs, temporary drought surcharge rates)
- ✓Identify supplemental sources of irrigation water (e.g., rainwater harvesting, reuse of marginal water sources)

Rainfield Systems

- ✓Provide access to supplementary irrigation where possible and sustainable

ECTS (page 2)

Increase in precipitation or increased frequency of extreme precipitation events

Saltwater intrusion	Increased flood risk	Increased runoff; increased soil erosion	Increased incidence of weeds, insects, pathogens, and other plant pests

Damage to crops; damage to the irrigation or drainage infrastructure; field waterlogging; inability to cultivate land; delays in planting or harvesting	Decreased soil quality could limit yields; increased pollution and siltation of water storage areas could limit availability of water for irrigation	Increased pest pressure and risk of plant diseases; productivity decline or crop losses; increased use of pesticides

✓Adopt more saline-tolerant crop varieties; provide access to and training on new varieties
✓Limit saltwater intrusion (e.g., establish physical or hydraulic barrier, aquifer recharge)
✓Identify alternative sources of irrigation water
✓Consider alternative uses of land (e.g., aquaculture)

✓Adopt flood-resistant or short-duration crop varieties; provide access to and training on new varieties
✓Increase water capture and storage to avert flooding
✓Increase flood protections using built and/or green infrastructure
✓Improve climate data collection and forecasting; implement early warning systems
✓Incorporate flood risk into infrastructure design; climate-proof irrigation infrastructure
✓Improve drainage systems (e.g., drainage tiles, pumps)
✓Desilt drainage canals and strengthen bunds

✓Enhance soil stability and productivity (e.g., conservation agriculture, mulching, cover cropping)
✓Build structures (e.g., earth bunds, terraces, buffer strips) to limit runoff and erosion
✓Implement agroforestry systems to reduce soil erosion and runoff

✓Adopt improved integrated pest- and disease-management techniques
✓Adopt more disease-resistant varieties; provide access to and training on new varieties
✓Improve capacity for surveillance and early detection of pest invasions
✓Increase diversity of crops to hedge against risk of individual crop failure

FIGURE 3: DECISION TREE FOR LIVESTOCK PRODUCTION

CLIMATE HAZARD

Atmospheric CO_2 increase

Decreasing precipitation and drought

SYSTEM IMPACTS

Change in pasture composition

Water scarcity

Saltwater intrusion

Increased flood risk

PROJECT VULNERABILITIES

Reduced freshwater availability (drinking and servicing water)

Reduced availability of pasture and feed supplies; decreased nutritional quality of forage; potential overgrazing

Flooding could physically harm livestock or damage supporting equipment and facilities

ADAPTATION OPTIONS

- ✓Identify alternative sources of water supply (e.g., boreholes, rainwater harvesting)
- ✓Promote water-use efficiency for these and competing water uses
- ✓Protect water quality (e.g., measures to limit saltwater intrusion)
- ✓Adopt systems to manage competing water uses (including conflict-management system)

- ✓Adjust stocking densities to feed availability
- ✓Implement system of rotational grazing
- ✓Purchase supplementary feed
- ✓Breed feed crops and forages for heat/drought/salinity tolerance
- ✓Implement agroforestry with fodder trees and legume shrubs to provide alternative feed resources, shade, and retain water
- ✓Employ crop residue management techniques (e.g., conservation tillage, mulching)
- ✓Irrigation feed crops and grasslands
- ✓Rehabilitate degraded grassland
- ✓Implement feed banks for livestock during drought
- ✓Adopt community-level rules to manage communal grazing/rangeland

PROJECTS

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

Temperature increase

Higher mean growing season temperatures; more frequent heat waves and temperature extremes

Rising winter temperatures; reduced occurrence of frost

Increased prevalence of certain livestock pathogens and parasites; expanded distribution of vectors

Heat stress can lead to diminished feed intake; declining rates of growth, survival, and reproduction; and reduced production of meat, milk, eggs

Longer growing seasons and possible increased productivity in some areas; decreased risk of harm from extreme cold

Increased risk of disease; increased use of veterinary medicines

- ✓Increase flood protections, including built and/or green infrastructure
- ✓Integrate flood management procedures (e.g., forecasting and early warning systems) in operational planning

- ✓Switch to more heat-tolerant species
- ✓Adopt/increase selective breeding to improve heat tolerance
- ✓Implement feeding modifications that reduce metabolic heat build up
- ✓Construct shade structures or provide cooling/insulation in enclosed facilities to reduce livestock exposure to extreme temperatures
- ✓Diversify sources of income; pursue nonfarm income-generating activities

- ✓Switch to more disease-resistant species
- ✓Adopt/increase selective breeding to improve resistance to disease
- ✓Upgrade animal housing structure for better pest and disease management
- ✓Adopt appropriate disease surveillance and control measures
- ✓Provide training on livestock disease prevention and control
- ✓Diversify sources of income; pursue nonfarm income-generating activities

FIGURE 4: DECISION TREE AQUACULTURE PROJECTS (pag

CLIMATE HAZARD

- **Atmospheric CO_2 increase**
- **Temperature increase**

SYSTEM IMPACTS

- Ocean acidification
- Higher temperatures may reduce the abundance or alter the ranges of some capture fisheries

PROJECT VULNERABILITIES

- Adverse effects on shell formation of cultured mollusks and crustaceans; adverse effects on pearl development
- Potential scarcity of raw materials used for feed in aquaculture; rising prices for feed
- Potential scarcity of wild seed for capture-based aquaculture
- Warming may increase growth and productivity in some areas

ADAPTATION OPTIONS

- ✓Switch farmed species or strains (e.g., away from shell-bearing organisms)
- ✓Switch to freshwater aquaculture
- ✓Close farms or relocate to other production zones
- ✓For pearls, culture in deeper waters or in new sites; Increase R&D for low pH tolerant strains

- ✓Find fishmeal and fish oil replacement
- ✓Switch to terrestrial-based feeds
- ✓Improve feed-management practices
- ✓Shift to noncarnivores or nonfed species

- ✓Implement system for hatchery-produced/ propagated seed
- ✓Promote more efficient use of available seed

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Higher water temperatures; increased stratification of water column and oxygen depletion

Increased prevalence and shifts in the distribution of pathogens and parasites

Increased heat stress could decrease productivity and growth and increase susceptibility to disease; species with narrow thermal range may no longer be farmed in some places

Increased incidence of harmful algal bloom that release toxins and deplete oxygen levels; increased mortality of stock

Increased risk of disease; increased mortality of stock

- ✓Farm species or strains with higher thermal tolerance; selective breeding to improve heat tolerance
- ✓Close farms or relocate to cooler areas
- ✓For pond systems, deepen ponds
- ✓Adjust crop calendars to account for higher temperature (i.e., moving practices to earlier/later to avoid temperature peaks)
- ✓Construct shade structures or plant shade trees to reduce thermal stress

- ✓Increase environmental, food safety, and quality monitoring in aquaculture facilities; improve disease-surveillance systems
- ✓Site facilities in areas less vulnerable to eutrophication and harmful algal blooms
- ✓Farm species and/or strains that tolerate low dissolved oxygen levels
- ✓Diversify species or product range to hedge against risk of individual stock failure
- ✓Diversify income-generating activities to include nonaquaculture-related activities
- ✓Invest in depuration facilities
- ✓Promote best management practices and biosecurity measures to reduce risk of disease

FIGURE 4: DECISION TREE AQUACULTURE PROJECTS (pag

CLIMATE HAZARD

- **Decreasing precipitation and drought**
- **Sea-level rise and storm surge**

SYSTEM IMPACTS

- Reduced water levels, flow rates, and overall water availability
- Saltwater intrusion
- Coastal inundation and erosion

PROJECT VULNERABILITIES

- Limited access to water for farming or for use in producing feed; higher cost to artificially maintain pond levels
- Some water bodies may become unsuitable for aquaculture if water quality is diminished by reduced inflow or if retention periods are shorter than the minimum period needed to attain marketable size
- Increased salinity could lower growth, increase mortality, or render some systems unsuitable for culture of freshwater species

ADAPTATION OPTIONS

✓Improve water-use efficiency
✓Explore opportunities to share water across uses (e.g., integrated aquaculture/ agriculture systems, aquaponics)
✓Switch to feed ingredients that require less water to be produced
✓Switch from pond aquaculture to other nonconsumptive water use aquaculture

✓Use of fast growing fish species
✓Consider risk in siting facilities; relocate to lower-risk areas

✓Shift to more saline-tolerant strains or species
✓Limit saltwater intrusion (e.g., establish physical or hydraulic barrier, aquifer recharge, coastal groundwater monitoring, etc.)
✓Close farms or relocate further upstream

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Increase in precipitation or increased frequency of extreme precipitation events

Increased flood risk

Extreme winds associated with storms/hurricanes

Increased runoff and transport of pathogens and other pollutants; reduced water quality

Saline intrusion or coastal erosion that make areas unsuitable for agriculture could create new opportunities for aquaculture

Loss of intertidal areas that act as nursery grounds and provide coastal protection, increasing exposure to storms and limiting availability of seed

Physical damage to aquaculture facilities and equipment, loss of stock, and mass release with potential impacts on biodiversity; loss of livelihoods

Increased pollution could lead to reduced productivity of freshwater aquaculture

- ✓Increase protection, restoration, and enhancement of wetlands and coastal forests
- ✓Adopt and implement living shoreline approach
- ✓Switch to inland aquaculture

- ✓Increase flood protections near facilities, including build and/or green infrastructure (e.g., rasied dykes in flood-prone pond systems or constructed wetlands)
- ✓Implement improved early warning and forecasting systems
- ✓Improve design to minimize mass release (e.g., nylon netting)
- ✓Encourage use of indigenous species to minimize impacts on biodiversity
- ✓Invest in stronger facilities and equipment (e.g., cages and mooring systems)
- ✓Close farms or relocate to less exposed areas (e.g., upstream, protected bays)
- ✓Diversity income-generating activities to include nonaquaculture-related activities

- ✓Shift to species with higher tolerance to poor water quality
- ✓Reduce land-based sources of pollution (e.g., agricultural and urban runoff)
- ✓Monitor water quality
- ✓Diversify income-generating activities to include nonaquaculture-related activities

FIGURE 5: DECISION TREE FOR POSTHARVEST SUPPLY CH

CLIMATE HAZARD

Sea-level rise and storm surge

Increase in precipitation or increased frequency of extreme precipitation events

SYSTEM IMPACTS

Coastal inundation and erosion

Increased flood risk

Extreme winds associated with storms/hurricanes

Increased variability/unpredictability in rainfall patterns

Increased incidence of insects, pathogens, and other pests

PROJECT VULNERABILITIES

Physical damage to storage, processing, and distribution facilities/systems, causing delays, and increased maintenance requirements; disruption to operations due to power outages

Rain exposure during drying or storage could increase risk of spoilage or contamination

Increased risk of spoilage or contamination (e.g., aflatoxin) in storage; increased storage losses due to insects; increased refrigeration needs, which increase costs

ADAPTATION OPTIONS

- ✓Increase flood protections near facilities, including built and/or green infrastructure
- ✓Increased wind/squall protection
- ✓Integrate flood-risk, risk of high winds into facility design (e.g., elevate key components, use water-resistant materials)
- ✓Relocate existing or planned facilities to lower-risk areas
- ✓Develop contingency plans
- ✓Implement early warning systems
- ✓Invest in improved storage (e.g., metal silos, water-tight containers
- ✓Switch to portable storage structures that can be moved in case of flood
- ✓Improve coordination within value chain to minimize transportation distances
- ✓Relocate critical hubs to lower-risk areas
- ✓*See Transport Sector Guidance Note for detail on distribution system adaptations*

- ✓Protect drying products from rain using covered drying structures
- ✓Adopt improved drying practices

HAIN PROJECTS

Atmospheric CO_2 increase

Temperature increase

Decrease in precipitation and drought

Shifting agroclimatic zones cause poleward shift in where crops are produced

Higher mean and extreme temperatures; more frequent heat waves

Increased wildfire risk

Reduced surface water levels, stream flows; increased water scarcity

Need to adjust processing, packaging, distribution infrastructure to reflect production shifts

Extreme heat can damage transportation infrastructure (e.g., rail tracks and roads); disruption, delays, and increased maintenance requirements

Potential distribution disruptions; reduced visibility requires road or airport closures; decreased navigability of inland waterways

Decreased availability and reliability of water for use in processing

- ✓Invest in improved storage (e.g., metal silos, hermetically sealed bags)
- ✓Increase smallholder access to improved storage facilities (e.g., through collective storage facilities)
- ✓Improve store hygiene, maintenance, and monitoring skills
- ✓Shade storage containers or keep them cool in indoor places
- ✓Treat grain to be stored for more than 3 months with appropriate grain protectant
- ✓Improve technology for early control and detection (e.g., rapid testing kids foodborne risks)
- ✓Improve efficiency of cooling systems to reduce storage/energy costs

- ✓Use crop suitability maps and climate projections to inform siting of processing, packaging, and distribution infrastructure

- ✓Improve coordination within value chain to minimize transportation distances
- ✓Develop contingency plans
- ✓*See Transport Sector Guidance Note for additional detail*

- ✓Relocate existing or panned processing facilities to less drought-prone area
- ✓Increase water storage capacity (e.g., water harvesting, communal ponds)
- ✓Introduce demand-side water efficiency measures

FIGURE 6: DECISION TREE FOR RURAL HOUSING PROJECT

CLIMATE HAZARD

Sea-level rise and storm surge

Increase frequency and intensity of extreme weather events

SYSTEM IMPACTS

Coastal inundation and erosion

Increased flood risk; potential risk of landslides/ mudslides

Increased risk of tropical cyclones

More frequent heat waves and temperature extremes; increased overnight temperature minimums; longer, more intense hot season

PROJECT VULNERABILITIES

Sanitation facilities may be flooded or filled with silt, which could cause structural damage, environmental contamination, and harmful health impacts

Flooding can damage or destroy houses, threaten safety of residents, and displace communities

Tropical cyclones can damage or destroy homes, threaten safety of residents, and displace communities

ADAPTATION OPTIONS

See Water Sector Guidance Note

- ✓Relocate existing communities to or site new communities in lower-risk areas
- ✓Use flood-resilient design features (e.g., elevate the plinth and door thresholds; use reinforced building materials; elevate electrical equipment)
- ✓Increase water capture and storage (e.g., retention ponds, infiltration trenches, rainwater harvesting)
- ✓Reduce impervious paving; plan developments in a way that leaves natural vegetation in place
- ✓Invest in improved drainage
- ✓Increase flood protections near communities, including build and/or green infrastructure
- ✓Implement early warning systems and ensure access to emergency shelter
- ✓Implement erosion and sedimentation control measures (e.g., swales, sedimentation pits, vegetation growth)

- ✓Site planning: relocate to lower-risk areas; site housing to reduce wind pressure (e.g., use of nonparallel roads, unequal distribution of houses)
- ✓Increase structural stability; incorporate posts, beams, and roof reinforcement into the structure; ensure that all building components are securely connected; strengthen foundations of housing structures; used reinforced windows
- ✓Include wind breaks in community design
- ✓Implement early warning systems and ensure access to emergency shelter
- ✓Include a solid, safe failure room in building design

Sources (Figures 2-6): ADB 2012; FAO 2016; FAO 2011; FAO 2017; Fanzo et al. 2018; IFPRI 2017; Lipper et al. 2018; Rojas-Downing et al. 2017; Thornton et al. 2015; Cochraine et al. 2009; IFAD 2014; Beuno and Soto 2017; Brown et al. 2015; Stathers et al. 2013; Khan et al. 2014; Tran et al. 2014; Sabbag 2013; Barnett et al. 2013; USAID 2013a; World Bank 2015; World Bank 2009.

TS

Temperature increase			Decrease in precipitation and drought
Increased risk of wildfire	Reduced surface water levels, stream flows; increased water scarcity		Altered soil and rock conditions may increase ground movement or differential settlement
Heat stress can cause heat-related illnesses and loss of productivity	Increased risk of loss of homes from fire	Reduced freshwater availability for household use	Damage to building foundation and facade from ground movement and subsidence
✓Incorporate consideration of thermal comfort into design, including building orientation and materials used ✓Improve thermal performance by insulating roofs and external walls, using light colored or reflective roofing material, or including a false ceiling/ radiant barrier ✓Maximize natural ventilation ✓Increase shading, including window shading ✓Plant trees and incorporate green spaces into planning	✓Relocate away from fire-prone areas ✓Incorporate fire-resistant design features and materials in buildings ✓Establish or improve early-warning and rapid-response systems for fire ✓Establish fuel breaks to slow fire spread ✓Implement forest/ vegetation management measures to reduce risk	✓Increase water capture and storage ✓Diversify water supply options (e.g., recycling, rainwater harvesting) ✓Increase water-use efficiency (e.g., low-flow toilets)	✓Site new or relocate existing communities to lower-risk areas ✓Enhance structural engineering standards to account for risk

Identifying Adaptation Options

Once a project team determines potential project vulnerabilities, it can proceed to identifying possible adaptation solutions. An important preliminary step is defining the objective of adaptation. In setting objectives, project teams should consider what vulnerabilities they seek to address and what their desired outcomes are. Seeking input from relevant stakeholders at this stage and throughout the process will improve the likelihood that the ultimate adaptation decisions are deemed successful (UK Climate Impacts Programme 2007).

Ideally, the objective would include specific timelines and measurable thresholds for what would and would not be considered successful adaptation. For example, the objective could be to achieve a certain level of flood protection (e.g., protect facility from physical damage by 100-year flood event or ensure facility remains fully operational during 50-year flood event) or a certain degree of resilience (e.g., ensure facility can resume operations within five days of a 100-year flood event) by a certain date.

Once the team defines its adaptation objectives, it should strive to compile a wide range of measures to meet those objectives. The above decision trees offer an initial, nonexhaustive list of potential adaptation options for addressing particular climate impacts.

Adaptation is context-specific, and the adaptation options identified in the decision trees will not be applicable or appropriate in all cases. For example, some may be technically infeasible in the project location. Others may not be sustainable due to high operational or maintenance costs. The steps described in Section 5 on appraising adaptation options will help project teams determine the appropriateness of different adaptation options for particular projects.

Additionally, because this guidance applies to projects involving physical assets, many of the options identified are structural or physical adaptation options. Such options are often referred to as “hard” adaptation options. They involve on-the-ground physical infrastructure and technical equipment, like upgraded irrigation systems or structural flood protections. Structural adaptation options also include a variety of ecosystem- or nature-based adaptation measures (Noble et al. 2014). There are also a variety of nonstructural (or “soft”) adaptation options. See Box 1 for more detail on soft adaptation options.

Box 1 | Soft Adaptation Options

Soft adaptation encompasses management, operational, or policy changes, as well as capacity-building and knowledge-management activities. Many soft adaptation measures are not specific to a particular subsector or category of project and, instead, are sensible across a wide range of projects. For example, improved data collection and forecasting capabilities, climate information services, and early warning systems may be critical to the success of projects in any of the subsectors this note covers.

Other examples of soft adaptation measures include **policy measures**, such as modifying building codes and standards for rural housing or infrastructure to increase their resilience; **capacity-building efforts**, like establishment of field schools to provide training on integrated pest management or on the use of new, more resilient seed varieties; **institutional changes** to support mainstreaming consideration of climate change into development and sector strategies; and **provision of other services**, like increasing farmer access to market information and transport options.

Building resilience often requires a combination of hard and soft adaptation measures, as well as engineered and nature-based infrastructure options (GEF-UNEP 2017). As such, in identifying adaptation options, project teams should consider a wide range of options. Moreover, the varied and complex ways agricultural systems interact with other sectors and systems means that adopting a narrow, sector-based approach to adaptation may not be appropriate. Adaptation measures for one sector or subsector may indirectly affect another sector or subsector, by impacting the ecosystems, water resources, or biodiversity on which it relies, for example. As such, an integrated, ecosystem-based approach is needed (DuBois et al. 2012). Consulting with a variety of stakeholders (including community and nongovernmental organizations, environmental specialists, engineers, vulnerable populations, and others) can help to identify a comprehensive list of adaptation options (ADB 2017a).

Finally, in identifying adaptation options, project teams should remember that adaptation measures will ideally be aligned with existing country or sector resilience plans.

5. Appraising Adaptation Options

A variety of approaches are available for evaluating and prioritizing among adaptation options.[8] One such approach, described below, is to use multi-criteria analysis to identify a short list of preferred adaptation options, followed by a more detailed, quantitative assessment of those options.[9]

At the outset, assessing the performance of different adaptation measures, whether in qualitative or quantitative terms, requires an understanding of future climate conditions. The adaptation options identified in the above decision trees vary widely in cost. The level of investment in adaptation that is economically justified will depend on the severity of potential impacts within the relevant time horizon. Accordingly, project teams must develop climate change scenarios representing plausible future states (ADB 2017b). They first identify the climatic and hydrological variables most relevant to project design. They can then use climate model projections, analysis of historic data, available studies, and expert judgment to develop assumptions about how those variables are likely to change over the project's life span (ADB 2017b). The World Bank's Climate Change Knowledge Portal, mentioned above, includes location-specific climate data and references to a variety of other climate data sources, and the Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre[10] provides general guidance on the use of scenarios and data in adaptation assessments. Additional analysis, including simulation modeling, may be required to determine how changes in primary climatic and hydrological variables can lead to more complex phenomena, such as drought or flooding (ADB 2017b). Finally, project teams can judge project performance in the context of probable future conditions.

Although climate projections are an imperfect representation of reality, they allow project teams to explore how the future may unfold and how the project will perform under different conditions. That said, uncertainty about future climate conditions creates important methodological challenges for adaptation decision-making, so this section concludes with a brief discussion of the importance of incorporating uncertainty into appraisal of adaptation options.

Multi-Criteria Analysis

Multi-criteria analysis allows for a qualitative and comparative assessment of different adaptation options. It is often used to assess factors that are not easily quantifiable in monetary terms or during preliminary stages when the precise cost implications of various options have yet to be developed (USAID 2015). Multi-criteria analysis should be conducted in a participatory manner that seeks input from the external stakeholders likely to be affected by the project and any potential adaptation measures (Trevor et al. 2011).

The project team would first identify the appropriate criteria for the given project. Possible criteria include the following (USAID 2015; European Commission 2013; Weiland and Troltzsch 2015):

- *Functional effectiveness*
  - Does the adaptation measure accomplish the desired outcome?
  - Does it do so within an acceptable timeframe?
- *Technical feasibility*
  - Is the measure technically feasible in the project location?
- Affordability
  - Are the upfront costs of the measure affordable?
  - Are operations and maintenance costs of the measure affordable?
- *Stakeholder acceptability*
  - Does the measure have cultural, economic, or environmental effects that could impact stakeholder or community acceptance?
- *Ease of implementation*
  - Are there factors (e.g., those related to human capital, availability of materials, or existing technical skills) that may impede implementation?
- *Flexibility/robustness*
  - How effective will the measure be in the face of uncertain future conditions?
- *Cobenefits*
  - Does the measure support other climate-related (e.g., carbon sequestration) or development objectives (e.g., economic security, private sector development, institutional strengthening)?

The project team would then agree on a scale or metric for each criterion. In some cases, quantitative metrics, like cost, may be available. In others, qualitative metrics can be translated into a numerical form (e.g., on a 1 to 5 scale) (USAID 2013b; Van Ierland et al. 2013). Project teams could also attach different weights to different criteria to reflect relative importance (USAID 2013b).

Next, the project team would score projects incorporating the different adaptation alternatives against each of the criteria. As described above, the performance of different options will depend on projected climate conditions. For example, evaluating the functional effectiveness of a planned shoreline protection measure would require sea-level-rise projections for the lifetime of the project.

Finally, the project team would compare the weight-adjusted scores of the various alternatives (UNFCCC 2011). The project team could use the outcome to produce a short list of preferred options that perform best against the selected criteria.

Detailed Economic Assessment

The remaining options can then be evaluated in greater detail using a quantitative economic assessment. Two possible techniques for economic assessment of adaptation options are cost-benefit analysis and cost-effectiveness analysis (GIZ 2013; UNFCCC 2011).

- Cost-benefit analysis

Cost-benefit analysis (CBA) involves quantifying (in present-value terms) and comparing the costs and benefits of an adaptation investment to determine its likely efficiency (UNFCCC 2011). CBA is generally the preferred technique, so long as all costs and benefits of adaptation can be expressed in monetary terms (GIZ 2013). Adaptation costs include direct costs, like initial investment and operating costs, as well as any indirect costs, like transitional costs or social welfare losses (UNFCCC 2011).

Adaptation benefits include benefits accrued and losses avoided as a result of an adaptation measure (IPCC 2007). As such, adaptation benefits are assessed relative to a project baseline (i.e., the project without adaptation).[11] The appropriate project baseline and net benefits of different adaptation options relative to that baseline are ultimately dependent on future climate conditions. Project teams first assess the costs and benefits of the project baseline under projected climate conditions. Where multiple future scenarios are plausible, there would be multiple baselines (European Commission 2013). They then assess the net benefits of various adaptation alternatives relative to the baseline(s).

Adaptation projects often involve impacts on things like public health, environmental quality, or cultural heritage. These sorts of nonmarket costs and benefits are difficult to quantify but should not be excluded from any economic analysis conducted. Instead, techniques like contingent valuation should be used to estimate nonmarket costs and benefits, where possible (UNFCCC 2011). Contingent valuation uses the stated preferences of impacted individuals to estimate the economic value of nonmarket goods, like ecosystem services. For example, contingent valuation could be used to estimate the monetary value of an artificial wetland's benefit to water quality by asking impacted individuals how much they would be willing to pay for an equivalent water quality improvement.

Having quantified all costs and benefits, project teams discount them to present value and aggregate them to compute the net present value (NPV) of each alternative. The NPVs of different adaptation options can then be compared to identify the most suitable option or options.

- Cost-effectiveness analysis

Cost-effectiveness analysis identifies the least cost option or set of options for achieving adaptation objectives (UNFCCC 2011). It can be applied when adaptation benefits are difficult to quantify and express in monetary terms.[12] Cost-effectiveness analysis may also be appropriate in situations where the issue is not *whether* to adopt adaptation measures but rather how to achieve a certain level of adaptation in the most cost-effective way.

Like cost-benefit analysis, this technique requires planners to quantify (in monetary terms) the various costs of adaptation options. Project teams quantify all costs, discount them to present value, and aggregate them. Rather than quantifying project benefits in monetary terms, project teams quantify them in physical terms (Watkiss et al. 2013). The unit of measurement depends on the adaptation objective. Project teams can then compare different options in terms of their cost effectiveness, measured as cost per unit of benefit delivered.

Incorporating Uncertainty into Adaptation Decision-Making

Traditional economic assessment techniques, like those described above, assume an ability to confidently predict future climate conditions or at least attach probabilities to possible future scenarios. In reality, there is considerable uncertainty about the speed, direction, and magnitude of future climate changes in many regions, particularly on the scale relevant to a specific project (Ranger et al. 2013). Uncertainty has countless sources, including uncertainty about emissions trajectory and uncertainty stemming from climate models and efforts to downscale model projections to regional or local levels, particularly in areas with complex topography (ADB 2015). Questions surrounding future socioeconomic development, population growth, and other nonclimate stressors only add to this uncertainty.

The presence of uncertainty does not invalidate techniques like cost-benefit analysis or cost-effectiveness analysis, but decision-makers must take uncertainty into account, and doing so might require them to alter their decision-making approach. Traditional decision-making processes predict future conditions and design projects that perform optimally under those conditions. Alternatively, if multiple future states are possible, probabilities of occurrence can be attached to the different future states, and projects can then be designed to maximize expected NPV. As uncertainty increases, however, this sort of "predict-then-act" approach becomes less applicable (Hallegatte et al. 2012).

Rather than using economic assessments to identify the optimal solution for a single, best-guess projection, decision-making under uncertainty is focused on increasing the robustness of a project—that is, the project's ability to fulfill its intended objective across a range of plausible futures (Hallegatte et al. 2012). Certain simple strategies exist for adding robustness to traditional decision-making processes (Ray and Brown 2015).

- *Incorporating safety margins into adaptation planning* (Hallegatte et al. 2012). Where the marginal cost is low, incorporating safety margins into adaptation planning is a practical way to deal with uncertainty over future conditions. Increasing the height of a planned sea wall to hedge against the worst-case scenario is an example of a safety margin strategy (Ray and Brown 2015). Factors such as incremental cost, consequences of system failure, and life span of the asset would all inform the size of any safety margin incorporated into a project (Ray and Brown 2015). This sort of conservative approach is especially important when the adaptation measure under consideration is irreversible (Hallegatte et al. 2012).
- *Stress testing the outcomes of economic assessments using sensitivity analysis* (Penning-Rowsell et al. 2013). Sensitivity analysis tests how changes in key parameters impact project performance (Ray and Brown 2015; Penning-Rowsell et al. 2013). In particular, project teams can test the sensitivity of the project's NPV to changes in uncertain variables, such as rainfall projections (ADB 2015). While a practical tool for exploring the possible impacts of uncertainty on project performance, sensitivity analysis is subjective, relying on judgment rather than empirical evidence, and as such, is of limited usefulness in the presence of substantial uncertainty (ADB 2015).
- *Identifying no-regret and low-regret measures to implement in the near term that will yield benefits regardless of the nature and extent of climate change.* No-regret and low-regret options are beneficial even if climate projections end up being incorrect (Hallegatte et al. 2012). An example is reducing leakage or evaporative losses from irrigation canals. One way to identify no- or low-regret strategies is to recognize present problems that can be cost-effectively addressed using measures that also reduce longer-term climate vulnerabilities, and, in fact, addressing current adaptation deficits is often an effective near-term, no-regrets strategy (Hallegatte et al. 2012).

Decision-making under uncertainty also emphasizes flexibility. Because uncertainty will decrease over time, flexible approaches that can be modified or reversed as more information becomes available are preferable (UNFCCC 2011). This includes both structural and planning flexibility. Structural flexibility involves engineering features so that infrastructure can be enhanced in the future if climate impacts are high. Planning flexibility refers to decision-making that is intentionally iterative and designed to be adjusted over time (UNFCCC 2011).

In situations of greater uncertainty (situations involving investments in long-lived infrastructure, for instance), project teams may need to turn to new, more complex methodologies specifically designed to support decision-making in the context of uncertainty. These include robust decision-making (Lempert et al. 2006; Lempert et al. 2013; Hallegatte et al. 2012; Swart et al. 2013), real options analysis (Swart et al. 2013; Hallegatte et al. 2012; Linquiti and Vonortas 2012), and portfolio analysis (Swart et al. 2013). The details of these methodologies are beyond the scope of this guidance, but briefly, robust decision-making uses sophisticated analytical tools to identify adaptation strategies that perform well over a wide range of possible future climates (Ray and Brown 2015). Real options analysis extends more traditional cost-benefit analysis to explicitly include valuation of the flexibility or adaptability of design options; it can be useful in deciding whether to invest in adaptation immediately or to delay investment (Hallegatte et al. 2012). Portfolio analysis guides the selection of a set of adaptation options (rather than a single option) that together perform well across a range of plausible future climates (Hunt and Watkiss 2013).

6. Case Studies

The following case studies provide illustrative examples of how the above processes might look in practice. The first describes an International Fund for Agricultural Development (IFAD) project underway in southern Mozambique, where rising temperatures, drought, and occasional heavy rainfall threaten the livelihoods of rural communities. The second introduces an Asian Development Bank (ADB) project seeking to modernize and, at the same time, climate-proof irrigation infrastructure in coastal Bangladesh.

A Value-Chain Approach to Climate Resilience in Southern Mozambique

IFAD's *Pro-Poor Value Chain Development Project in the Maputo and Limpopo Corridors (PROSUL)* in southern Mozambique began in late 2012 (IFAD 2012). It aims to sustainably increase returns from and climate resilience of several targeted value chains, including cassava and livestock (including cattle, goat, and sheep), that are critical to the livelihoods of smallholder farmers in the region. The project takes a value chain approach, seeking to address key production, processing, and marketing constraints to improve farmers' ability to produce ample high-quality products to respond to market opportunities without jeopardizing household food security.

The project targets 19 districts in three southern provinces, Maputo, Gaza, and Inhambane (IFAD 2012). A climate analysis conducted in connection with PROSUL evaluated current climate conditions and projected climate trends for the project area (African Climate and Development Initiative 2016).

- Current climate in the project area ranges from arid to semi-arid. The entire area is subject to frequent drought, and at the same time, the Limpopo River Basin occasionally experiences torrential rainfall, which can bring severe flooding.
- With regard to climate projections, the analysis concluded that average temperatures in both the inland and coastal project areas will rise; the number of hot days and nights in the region will increase; dry spells will become longer and more frequent; and the frequency of extreme precipitation events will increase. Modeling was inconclusive on changes in total annual rainfall.

The analysis also evaluated the impact of current and projected climate changes on the targeted value chains (African Climate and Development Initiative 2016).

- Cassava production in the region is entirely rainfed, and sufficient soil moisture is a key determinant of cassava yields. As a result, drought conditions are detrimental to cassava production. Additionally, heat stress and high humidity can cause infield rotting and may increase pest activity. But impacts are not limited to crop production. High temperatures and humidity can also increase postharvest losses where appropriate processing is not immediately available, and extreme rain events can impede access to markets by making already poor roads completely impassable.
- Livestock value chains are similarly vulnerable. High temperatures and lack of rain depress grass and forage productivity and quality, thereby limiting the quality and quantity of available grazing. Without grazing, farmers have to move animals, sometimes considerable distances, to alternative water and feed sources. High temperatures and humidity may also increase tick activity and disease transmission; and at the same time, heat stress and water scarcity increase animal susceptibility to disease. Current and projected climate conditions can also interfere with market access to livestock value chains. Getting animals to market is difficult both when water is scarce and when heavy rains make the roads impassable. Additionally, higher temperatures could threaten food safety without improvements to the postharvest cold chain.

The climate analysis clearly demonstrates that climate vulnerabilities are not limited to agricultural production (African Climate and Development Initiative 2016). As such, the PROSUL project adopts a value chain approach to adaptation, addressing vulnerabilities at the production, processing, and marketing stages. The project includes a variety of adaptation interventions; the following description includes a sampling of the interventions planned for different stages of the cassava and livestock value chains.

For cassava, the project will establish service hubs in each of the targeted districts. Hubs will provide cassava producers with high-yield, drought-tolerant, and disease-resistant planting material and appropriate weed-and pest-control inputs. Farmer field schools and demonstration sites will build the necessary capacity to support these and other on-farm adaptations. The service hubs will also include small processing units to produce cassava chips and flour and provide market information and technical assistance on the development of supply contracts with buyers.

For livestock, the project will establish fodder banks designed to alleviate forage scarcity in the dry season (IFAD 2012). It will improve water access for people and livestock through construction of multifunctional boreholes in remote areas. And it will improve access to veterinary services by developing a network of livestock veterinary stores and Animal Health Agents in the region. The project will establish cattle fairs, equipped with water, pens, and scales, in each target district to offer farmers better access and improved market conditions. Additionally, it will finance a new slaughterhouse, equipped with cold storage, meat processing, and packaging facilities.

Apart from the adaptation measures targeting specific value chains, PROSUL includes funding to improve local meteorological stations that collect quality data supporting improved decision-making with regard to the target value chains (IFAD 2012).

The project highlights the importance of addressing climate vulnerabilities throughout the value chain, from production inputs to market access. At the time of the midterm review in December 2016, the project had engaged over 5,000 cassava farmers through 174 farmer field schools and 44 demonstration plots; constructed 15 multifunctional boreholes and 8 improved cattle fairs; and upgraded 2 meteorological stations, among many other developments (IFAD 2016). As of March 2018, on-farm cassava productivity had increased three-fold, and initial signs suggested the construction of multifunctional boreholes and promotion of cattle fairs were proving beneficial for the livestock value chain (IFAD 2018). Expected project completion is December 2019; in the coming months, additional analysis is needed on the impact and efficacy of the various project interventions.

Climate-Proofing Irrigation Infrastructure in Coastal Bangladesh

The ADB *Irrigation Management and Improvement Project* aims to modernize the Muhuri irrigation system in the Chittagong division in southeast Bangladesh (ADB 2014b). The project seeks to improve agricultural water management and efficiency, while also improving the resilience of irrigation infrastructure to current and future climate vulnerabilities.

Located at the apex of the Bay of Bengal and at the confluence of the Muhuri and Feni Rivers, the project area is highly vulnerable to coastal cyclones and upstream river flooding during monsoon season (ADB 2014b. 2014c). At the same time, the region experiences water shortages during the winter dry months. In these periods, many farmers in the region rely on groundwater to supplement limited and irregular surface water supplies, but poor groundwater quality in much of the region constrains its use. Climate change is expected to exacerbate all of these challenges.

In conducting a climate risk assessment, the project team looked to studies conducted by the UK Met Office Hadley Centre, as well as studies conducted in connection with a parallel coastal embankment improvement project. The team also worked with the Institute of Water Modelling to conduct simulation modeling of rainfall intensities and other preliminary analyses. The key conclusions of the climate risk assessment, including projected climate changes and their potential implications for their project, are summarized below (ADB 2014a).

- The Hadley Centre projected an increase in both mean and extreme precipitation throughout the region. Annual precipitation could increase by as much as 10 percent in the vicinity of the Muhuri system. Increased runoff will increase the likelihood of flooding and the need to improve the system's drainage capacity.
- As precipitation patterns and monsoon rains become more variable, periodic dry spells and drought may become more frequent. Under climate change, studies suggest that the region will likely be exposed to moderate to high water stress, though the Hadley Centre acknowledged uncertainty in the magnitude of these changes. Greater variation in monsoon rainfall and an increase in the frequency and extent of drought will increase the need for irrigation throughout the year.
- The Hadley Centre also found that temperatures across Bangladesh are projected to increase by 3.0 to 3.5°C by 2100, and agreement across models was high (ADB 2014c). Higher temperatures will affect evapotranspiration and could therefore increase crop water requirements.
- There is considerable uncertainty on how climate change will affect the frequency of tropical cyclones in the region, but sea-level rise is likely to exacerbate storm surges during cyclones. Storm surge and increased wave impact could inundate the project area and physically damage irrigation infrastructure. Additionally, without adequate coastal protections, sea-level rise could result in salinization of agricultural lands.

The project design seeks to address these risks in several ways. To respond to projected increases in rainfall intensity, the project will increase overall drainage capacity. The drainage capacity of the system is currently based on a 1-in-10–year return period. The project will increase drainage capacity to a 1-in-25–year return period. Recognizing that the magnitude of these changes is difficult to quantify with certainty, the design of the project intentionally allows flexibility to add more drainage capacity in the future as more information becomes available (ADB 2014c).

The project will address potential water stress by expanding access to irrigation, increasing water-use efficiency and reducing water losses, and providing support services to farmers to encourage better crop water management. Currently, irrigation is only available during the period from January to April (ADB 2014c), and of a potential 38,600 hectares (ha) of cultivatable land; at present only about 11,300 ha are irrigated during the dry season (ADB 2014b). The project will provide access to irrigation throughout the year to around 17,000 ha by 2019 (ADB 2014b).

However, to support this expansion of irrigated area requires improvements in water-use efficiency and water conservation (ADB 2014c). The project will repair existing irrigation canals and add new, more efficient piped water distribution systems to improve water-use efficiency and minimize water losses. It will also integrate metering into the system and switch from a fixed rate to a volume-based system of charging, which has been shown to reduce overall water use. It is estimated that the project will increase irrigation efficiency by 39 percent through the use of piped distribution and prepaid metering systems (ADB 2014b). These efficiency improvements will be coupled with provision of agricultural support services to promote diversification away from rice to other, less water-intensive crops. The project will also conduct pilots and demonstrations of rice cultivation techniques that are less water intensive (ADB 2014c).

Finally, the project accounted for risks associated with sea-level rise and storm surge. The Muhuri irrigation system is protected by an existing coastal embankment, but it is in a state of disrepair. Deterioration of the existing embankment is impeding drainage and could allow saltwater intrusion (ADB 2014c). It also increases risk of damage and flooding in the event of a tropical cyclone. As such, the project will rehabilitate the embankment to the original design to provide a reasonable degree of protection in the near term. However, this is only an interim measure; more is needed to climate-proof the embankment. The Institute of Water Modelling conducted a preliminary analysis and found that the embankment would need to be raised and strengthened to address the risks of sea-level rise and storm surge. A separate project will conduct further assessments and implement the necessary upgrades (ADB 2014c).

Appendix I: Glossary

Adaptation. The process of adjustment to actual or expected climate change 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 change and its effects.

Adaptive capacity. The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.

Climate change. Climate change refers to a change in the state of the climate that can be identified (for example, via statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Exposure. The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Hazard. The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term "hazard" usually refers to climate-related physical events or trends or their physical impacts.

Impacts. The effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes.

Projection. A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Unlike predictions, projections are conditional on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized.

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.

Risk. The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term "risk" is used primarily to refer to the risks of climate-change impacts.

Risk management. Plans, actions, or policies to reduce the likelihood and/or consequences of risks or to respond to consequences.

Sensitivity. The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Uncertainty. A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior.

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.[13]

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Endnotes

1. For additional information on IsDB's operations, see https://www.isdb.org/where-we-work.
2. See Appendix 1 for a glossary of key terms used in Figure 1 and throughout the guidance note.
3. For more information on the Acclimatise Aware tool, see http://www.acclimatise.uk.com/analytics/applications/.
4. For more information on the World Bank Climate Change Knowledge Portal, see http://sdwebx.worldbank.org/climateportal/index.cfm.
5. For more information on The Nature Conservancy's Climate Wizard, see http://www.climatewizard.org/.
6. USAID (2017) also includes references to a variety of information sources, including various portals and webpages that provide climate data and related information.
7. Mycotoxins are toxic compounds that are naturally produced by some fungi. Fungal growth, which can cause food spoilage, and mycotoxin contamination, which can cause severe health problems or even death, are expected to increase with rising temperatures and crop stress.
8. See e.g., GIZ (2014); European Commission (2013); USAID 2015.
9. The proposed approach draws on European Commission (2013) and USAID (2015).
10. For more information on the IPCC Data Distribution Centre, see http://www.ipcc-data.org/index.html.
11. ECONADAPT Toolbox: Cost-Benefit Analysis; https://econadapt-toolbox.eu/node/12.
12. ECONADAPT Toolbox: Cost-Effectiveness Analysis; https://econadapt-toolbox.eu/cost-effectiveness-analysis.
13. All definitions in Appendix 1 taken from IPCC 2014, 1–32.