Food and Agriculture Organization of the United Nations

MANAGING RISKS TO BUILD CLIMATE-SMART AND RESILIENT AGRIFOOD VALUE CHAINS

THE ROLE OF CLIMATE SERVICES

Managing risks to build climate-smart and resilient agrifood value chains

The role of climate services

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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ABBREVIATIONS AND ACRONYMS

ACRE	Agriculture and Climate Risk Enterprise
ART	African Roots and Tubers
ASEAN	Association of Southeast Asian Nations
CCAFS	Research Programme on Climate Change, Agriculture and Food Security
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CRA	climate risk assessment
CRAFT	Climate-resilient Agribusiness for Tomorrow's East Africa
CRM	climate risk management
CSA	climate-smart agriculture
CSIRO	Australian Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse gas
IACSA	International Alliance for Climate-Smart Agriculture
ICT	Information and Communications Technology
IDEAM	National Meteorological and Hydrological Services of Colombia
IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
IPCC	Intergovernmental Panel on Climate Change
LTAC	Local Technical Agroclimatic Committee
NAP	national adaptation plan
NDC	nationally determined contributions
PET	polyethylene terephthalate
RASFF	Rapid Alert System for Food and Feed
ReCAP	Research for Community Access Partnership
SDG	sustainable development goal
SENAMHI	National Meteorology and Hydrology Services of Peru
SIDS	small island developing states
SME	small and medium enterprise
UNICEF	United Nations Children's Fund
USDA	United States Department of Agriculture
UV	ultraviolet light
WFP	World Food Programme
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

It is widely acknowledged that climate change and weather extremes pose myriad threats to agriculture and agrifood systems globally. Projected changes in rainfall patterns, temperature, seasonal trends and more extreme weather events are key drivers of food insecurity and malnutrition globally, adversely affecting agrifood production and food availability, access, utilization and stability. This report takes a novel approach to systematizing the links between climate risks, the key stages of the agrifood value chain and the potential of climate services to boost the resilience of agrifood systems.

Agrifood value chains consist of four core functions: production, aggregation, processing and distribution of agrifood products. Key stages of the agrifood value chain include production and harvest, storage and refrigeration, processing and packaging, markets, trade and consumption, with transport as a crucial element throughout. Climate risks impact all stages of the value chain, disrupting the activities, actors and livelihoods that depend on it, compounding food loss and waste, and worsening food insecurity. The risks and impacts vary depending on the commodity and geographical location of interest, as well as on socioeconomic vulnerability and adaptive capacity of the target system.

This work provides a preliminary analysis of the key climate risks affecting agrifood value chains and opportunities for climate services that reach stakeholders involved in all stages, from agrifood production to distribution, as detailed above.

The report highlights the role of climate services in sustaining climate resilience as one of numerous potential investment options for enhancing climate risk management across agrifood value chains. The final outputs and outcomes of the report are, therefore, aimed at multiple stakeholders, including policymakers, climate-related finance mechanisms, international development organizations and the private sector. The report calls on academic researchers to conduct further research on the topic and on national and international funds to invest in the design and development of projects dedicated to supporting the climate-proofing of agrifood value chains worldwide.

What are climate services?

Climate services provide information to specific people to enable them to make timely, climate- and weather-informed decisions. They can build the resilience of agrifood producers and value chain actors to climate impacts that threaten agrifood systems. Climate services provide opportunities to effectively and comprehensively mainstream climate risk management into all stages of the agrifood value chain, increasing its sustainability and efficiency to changing climate conditions. They enable value chain actors to base short- and long-term decisions on historical, current and future climate and weather effects and to tailor climate-resilient infrastructure, technologies and practices, to context-specific environmental, social and economic conditions.

This report explores climate services from two main angles:

- **Tailored climate services for specific steps of the agrifood value chains:** real-time weather information, including early warning systems for disaster risk prevention and reduction; medium- and long-range weather forecasts for the production of agrometeorological advisories for agricultural production and harvest and short-term interventions; seasonal weather forecasts for agricultural planning and decision-making, information on the availability of natural resources, including water, land, renewable energy sources, for input supply, food storage and processing, as well as long-term infrastructural interventions.

- **Cross-cutting climate services for agrifood value chains:** climate risk assessments for climate-resilient business strategies, climate-proofing post-harvest and transportation infrastructure and large-scale policymaking strategies; evaluation of socioeconomic vulnerability and infrastructure (buildings, roads, availability of and access to information and communication technology (ICT)); evaluation of the capacity of extension services and value chain actors to effectively use climate information and incorporate it into decision-making strategies; financial services combined with climate and weather-based information for insurance against extreme weather events and to improve access to funding for actors that adopt climate services schemes; technical/advisory services to build capacity and raise awareness on how to reduce and manage climate and disaster risks; training and educational courses on accessing and using climate information services, tools and platforms, and climate-resilient practices.

How can climate services strengthen agrifood chains?

Climate risks pose a threat to the Sustainable Development Goals (SDGs). To counteract this, climate services play a key role on risk reduction and the sustainable use of resources. This report evaluates climate services as an overarching approach to improving the sustainability and climate resilience of agrifood value chains and agrifood systems, by enabling the coordinated implementation of practices that consider climate change impacts and the potential risks that affect performance throughout the chain. The development of climate services has significant potential to reduce food losses and waste, boost revenue of farmers and businesses and to enhance national income by supporting value-adding practices at key steps of agrifood value chains. Climate services enable value chain actors to improve their decision-making capacity by providing systematic access and supporting the use of climate and weather-based information tailored to agrifood activities, to deal with climate and socioeconomic risks, including price fluctuations and climate-driven health crises, enhancing resilience and development through investment in adaptation action.

The implementation of climate services along the agrifood value chain has multiple applications and spans sectors from agriculture to energy and water use, health and safety, and disaster risk reduction. This cross-sectoral approach underscores the importance of coordination to build the resilience of agrifood systems. It is crucial, therefore, to emphasize how climate-resilient agrifood value chains contribute to both climate adaptation and mitigation objectives. This requires comprehensive climate-resilient practices that are sustainable in the long term to minimize environmental impacts. Interlinked practices make the management of natural and human resources more efficient, while monitoring the climatological, meteorological, hydrological and environmental factors that affect food loss at early stages of the chain, and food waste at distribution and consumption stages.

Global access to such services has been limited for small-scale producers and value chain actors or lacked coordination between actors engaged at different stages. While climate services often exist for agriculture, energy use, health, disaster risk reduction and transportation separately, they are often not well coordinated or tailored to specific steps of the agrifood value chain. Comprehensive production of climate services and coordinated communication remains a substantial gap – and, hence, an opportunity – to scale up investment across agrifood value chains.

Barriers to the development of agrifood climate services:

There are numerous barriers to the development of climate services throughout the agrifood value chain, including:

- **Need for reliable data.** In developing countries, due to limited investment in data collection, storage and dissemination facilities, there is not always a consistent flow of timely and reliable climate and weather forecast information tailored to user needs and socioeconomic characteristics.

- **Limited technology and innovation.** Equitable access to energy, ICTs and the Internet is insufficient especially in developing countries and in rural areas. There is often a larger technology and access gap across marginalized, vulnerable or disadvantaged groups.

- **Heterogeneity of agrifood value chains.** Value chains differ depending on the type of production, geographical area, climate zone and political and economic development of the country involved. There are challenges related to identifying a common strategy for assessing different and complex socioecological systems, as well as to tailor the assessment to the environmental, social and economic context of the agrifood value chain in question, with a specific understanding of climate hazards, exposure, vulnerability and adaptive capacity.

- **Lack of communication and capacity-building.** Communication difficulties between value chain actors and a lack of leadership from public institutions are a key barrier for building climate-resilient agrifood value chains. These challenges hamper opportunities for collaboration, particularly in relation to building capacity for small-scale value chain actors using climate and weather-based ICTs; boosting vertical and horizontal networking and sharing of information; enhancing public–private partnerships; and fostering participatory climate risk management processes.

- **Lack of investment.** While both public and private investments in climate adaptation are fundamental and urgent in light of current trends and future climate scenarios, they fall short relative to investments in mitigation. What's more, climate assessments and methodologies that can justify climate finance for adaptation often focuses on the effects on yield and production. Greater understanding of the climate risks affecting agrifood value chains beyond production and methodologies for assessing their impacts are needed to boost recognition and finance from targeted funding initiatives for projects and interventions that focus on post-harvest agricultural value chains.

- **Limited policy support.** The lack of consistent public and private financing initiatives for climate adaptation projects and strategies aimed at the post-harvest stages of the agrifood value chain is a major challenge that is not being systematically addressed in countries' nationally determined contributions (NDCs).

Policy recommendations and investment opportunities

This report highlights the importance of developing climate services as a key investment opportunity for ensuring climate resilience along the agrifood value chain. To this end, it identifies a number of key investment opportunities and makes a series of policy recommendations in key areas, which we summarize here.

- **Identify climate risks to agrifood value chains and potential for solutions through climate services in NDCs and National Adaptation Plans (NAPs).** Climate services must be incorporated into NDCs and, from there, into local policy strategies and climate adaptation action plans. They must emphasize the role of private actors, from Small and Medium Enterprises (SMEs) to businesses and investment funds, in supporting the implementation of climate-resilient strategies, as well as the benefits deriving from doing so.

Mainstreaming the climate services framework, from the production of climate and weather information to the communication of tailored services to different users, would enhance collaboration and transfer of knowledge between actors along the chain.

- **Scale up equitable access to information and communication tools.** Invest in large-scale network systems that enable the digitalization of information and information systems accessed by value chain actors, support the systematization of mobile networks and facilitate the upscaling of relevant ICTs. Support climate-proofing infrastructural interventions where they are needed, including energy and access to electricity, by supporting the development of technological and Internet facilities, so that value chain actors can access, use and share climate information.

- **Build the capacity of value chain actors to use climate services and communication tools.** Capacity-building and technical assistance are required for extension service providers, input providers, the private sector and other actors, so that they can systematically customize and communicate climate services in a cost and time-effective manner to different actors along the agrifood value chain. There also needs to be participatory training and technical support for users, to enable them to effectively use the information and services they receive.

- **Integrate climate risk assessments into project design and business plans for agrifood value chains.** By boosting investment in the implementation of climate-proof technologies and infrastructure, climate services should increase the safety of farmers and other actors against disaster risks, reduce food losses and food waste. This entails strengthening early warning systems, weather-informed agricultural advisory services and appropriate food storage facilities to prevent or reduce losses from extreme weather events at every stage of the agrifood value chain. Such measures must be combined with long-term adaptation planning and investment in technologies and infrastructure to climate-proof every step of the agrifood value chain.

- **Strengthen social protection systems and foster climate-resilient certification schemes to underscore the return on investment.** The return on investment will come from avoiding the substantial costs of repairing and recovering from disasters, as well as from increased trading opportunities, particularly in developing countries where adaptive capacity is low compared with high-income countries. To build climate resilience and provide environmental, economic and social benefits along the agrifood value chain, climate services should be complemented by climate-informed financial services, input supply, insurance schemes tailored to specific value chains and climate-informed market information.

- **Mainstream climate change discussions, including climate services, in forums addressing sustainable agrifood value chains,** to strengthen collaboration with research and development institutions, agricultural extension services and financial service providers, as well as to share information and knowledge on climate-resilient practices and technologies. The development of climate services tailored to each step of the agrifood value chain will enable stronger links between public institutions and private actors and improve information sharing, investments and support, capacity-building, governance and participatory management approaches, thus overcoming maladaptive processes focused primarily on sector-specific, small-scale interventions and practices.

This report provides significant primary information and recommendations on the development of climate services across the agrifood value chain with a view to systematically enhance sustainable and resilient opportunities. It also provides a basis for further research and investment funding in this area. Its findings could spark follow-up research and public and private investment.


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INTRODUCTION

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Climate change and weather extremes pose myriad threats to agriculture and agrifood systems globally (Mbow *et al.,* 2019; IPCC, 2022). Projected changes in precipitation patterns, temperature, seasonal trends and more extreme weather events are widely recognized as key drivers of food insecurity, already affecting availability, access, utilization and stability of food products (SOFI, 2018).

Agricultural climate resilience strategies and climate change risk assessments often focus on production, food and economic losses. However, climate impacts and losses can be seen at all stages of the agrifood value chain, from smallholder farmers to agri-businesses, consumers and governments. Reduced food availability, access, quality, safety and nutritional intake for utilization and consumption, as well as food price stability, compound the effects on agrifood systems and food security (Fanzo *et al.,* 2018; FAO, IFAD, UNICEF, WFP and WHO, 2021; Hansen *et al.,* 2019).

Agrifood systems account for an important share of energy consumption and natural resource use and have a major environmental impact, accounting for 31 percent of global greenhouse gas emissions (FAO, 2021a). Developed countries are primarily responsible for emissions at pre- and post-production stages, such as during the fabrication and use of agricultural inputs, agrifood processing and transportation, and at the consumption stage. In least developed countries (LDCs), emissions primarily occur in the production stage and during land-use change (FAO, 2021a). Climate risks are evident throughout the agrifood value chain, disrupting the activities and livelihoods of those who depend on production, harvest, storage, processing, transportation, markets and food consumption, and exacerbating agrifood loss and waste, food insecurity and malnutrition. The impacts vary depending on the climate, environmental characteristics and socioeconomic context at local, regional and national level. It is of the utmost importance, therefore, that climate risk assessments and management strategies consider the individual components of the agrifood system, as well as the interlinkages between them, to ensure comprehensive outcomes.

Small-scale producers are the backbone of food security and the rural economy, but they are also the most vulnerable to climate impacts. They have the greatest physical exposure and the least adaptive capacity due to socioeconomic barriers and a lack of efficient infrastructure and advanced technical expertise, among other things. The effects are often exacerbated by insufficient understanding and maladaptation, combined with limited or non-existent access to appropriate advisory services and extension support. Such services would enable farmers and other decision-makers throughout the agrifood value chain to adopt climate-smart and resilient interventions to prevent or minimize disruptions to agriculture and food products (Puri, 2014).

Farmers, collectors and traders' limited knowledge of how to add value to agricultural products leads to substantial quantitative and qualitative food losses and waste along the entire value chain, reducing producer income and posing threats to food security. A lack of coordination, partnerships, education and interaction between value chain actors compound existing challenges and undermine opportunities to render them climate-resilient. This also makes it difficult to determine the extent to which final consumers would prioritize the purchase of climate-smart and resilient food products, potentially undermining the profitability of climate-resilient agrifood value chains.
Key barriers to the development of effective climate risk management measures and policies include limited financial investments in agrifood value chains, particularly in supply systems, as identified by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) (Porter *et al.,* 2014; IPCC, 2014). In 2018, only five percent of all climate finance went to adaptation (WMO, 2020). Investment in climate mitigation has received significantly wider and more consistent support in the area of climate-smart and sustainable agrifood value chains because of the quantifiable nature of greenhouse gas (GHG) emissions and societal experience of global climate impacts. Climate adaptation, in contrast, particularly in the post-harvest stages of the value chain, is multisectoral and context specific.

In the agriculture sectors, adaptation efforts tend to focus on enhanced productivity and sustainable yields, and less on efforts to make agrifood value chains more resilient to the impacts of climate change.

More recently, the Food and Agriculture Organization of the United Nations (FAO) has been working to mainstream more holistic environmental, economic and socially sustainable approaches to agrifood value chain development. It has focused on the use of sustainable food value chain development frameworks (FAO, 2014) and on integrating gender-sensitive components to enhance inclusion (FAO, 2016). The Organization has also strengthened its relationships with the private sector and agri-businesses in a bid to promote due diligence and responsible agricultural supply chains (FAO and OECD, 2016). It has created methodologies for food value chain analysis that systematically address risks, integrate climate resilience and foster gender responsiveness to increase market access and development (FAO and UNDP, 2020). While the climate risks to food security are widely recognized (FAO, IFAD, UNICEF, WFP and WHO, 2021), this work systematizes climate services development with a view to improving the resilience of agrifood systems to climate change.

Building sustainable and climate-resilient agrifood value chains is not only critical to reducing hunger and poverty in developing countries, but also provides a key opportunity to address national priorities for climate change adaptation and mitigation (Wieben, 2019). NDCs and NAPs cite better value chain infrastructure and more robust energy systems for the agrifood sector as national priorities for climate mitigation and adaptation action. Proposed interventions are held up – particularly among LDCs and Small Island Developing States (SIDS) – as effective ways of enhancing the multisectoral environmental, social and economic aspects of agrifood systems in countries that are highly exposed and vulnerable to climate risk. User-centric climate services are increasingly being recognized as key to enhancing preparedness and risk management in both the agricultural and the transport sector.

Climate services encompass a range of tools and activities that bring climate information to certain users for timely, climate and weather-informed decision-making, including sustainable energy assessment tools. They can build the resilience of agricultural producers and value chain actors to climate impacts threatening agrifood systems (FAO, 2021b; Ferdinand *et al.*, 2021). Climate services tailored to value chains support actors in better managing climate risks that affect the availability and safety of agrifood products both at market and for home consumption (IFAD, 2015).

Climate services create opportunities to effectively and comprehensively mainstream climate risk management into all stages of the value chain, in addition to increasing sustainability and efficiency in the face of rapidly changing climatic conditions. They increase the efficient use of energy, water and land resources and minimize post-harvest food and economic losses by improving actors' capacity to monitor risks to the quantity and quality of food, as well as the performance of climate-resilient technologies and infrastructure. Agrifood value chain actors can base their short- and long-term decisions on historical, present and future climate and weather impacts, tailor climate-resilient infrastructure and technologies, and implement climate-resilient practices specific to environmental, social and economic contexts.

Access to such services for small-scale producers and value chain actors has been limited globally, however, particularly in those the post-harvest stages of the agrifood chain. Indeed, while climate services are available for use in agriculture, energy, health, disaster risk reduction and transportation, they are often not well coordinated between sectors or tailored to every step of the agrifood value chain. Substantial gaps remain and therein lies an opportunity to scale up investment in climate services.

The approach of this report to the development of climate services in agrifood value chains, from input supply, production, storage and processing to transportation, trade and consumption, is based on the World Meteorological Organization's (WMO) Global Framework for Climate Services.

The framework conceptualizes the use of climate services in cross-cutting sectors from agriculture to energy and water use, health and safety, and disaster risk reduction, emphasizing the importance of coordination to ensure the resilience of socio-ecological systems (WMO, 2017). This report, therefore, aims to highlight the opportunities for climate services development across agrifood value chains, emphasizing the potential links between the chain itself – from agrifood production to the distribution stages – and cross-cutting sectors such as energy, resource use, health and food safety, and disaster risk reduction. This will underpin countries' climate resilience priorities as they pertain to agrifood systems, as reported in their NDCs and NAPs (Wieben, 2019).

The present challenge calls for an integrated approach to preventing and reducing losses across the value chain, by using climate services such as early weather advisory and informed actions on climate adaptation. This comprehensive approach would enable policy- and decision-makers to align their activities and partnerships, so they could use climate services in a synergistic way. It would also enhance their climate adaptation capacity by considering the entire agrifood value chain as a unique and coordinated system rather than as a series of individual steps. The findings of this report highlight the need to increase research on and investment in the identification of climate risks, as well as opportunities to implement climate services at every step of the agrifood value chain. This should fuel the development of technical and adaptive governance pathways to enhance the resilience of agricultural systems to climate change.

The report aims to identify:

- the conceptualization of climate risk, climate services and climate resilience in the context of agrifood value chains;
- key climate hazards and impacts along the agrifood value chain;
- the potential for climate services development at each step of the value chain;
- case studies of climate services and climate-resilient practices tailored to specific food commodities and agrifood value chains in different regions and countries worldwide;
- barriers to the delivery of climate services and climate-resilient measures along the agrifood value chain; and
- policy recommendations and investment opportunities for the development of climate services that further "climate-proof" agrifood value chains.

This report compiles primary information and conclusions on the development of climate services across agrifood value chains with a view to systematically enhancing sustainable and resilient opportunities. Its finding could unlock research interest in future publications, as well as public and private investment, for example, in strengthening the relationship between youth, women and the use of climate services, or the relationship between climate services and sustainable energy development across agrifood value chains.

CLIMATE SERVICES FRAMEWORK FOR THE AGRIFOOD VALUE CHAIN

Climate services tailored to specific steps of the agrifood value chain

- Real-time weather information, including early warning systems for disaster risk prevention and reduction.
- Medium- to long-range weather forecasts to facilitate weather-informed agricultural advisories for agricultural production and short-term interventions.
- Seasonal weather forecasts for planning and decision-making and information on the availability of natural resources, including water, land, renewable energy sources, for input supply, food storage and processing, as well as long-term infrastructural interventions.

Cross-cutting climate services for agrifood value chains

- Climate projections and risk assessments for long-term climate-resilient business strategies and climate-proofing post-harvest and transportation infrastructure.
- Climate risk assessments for large-scale policymaking strategies, including the evaluation of socioeconomic vulnerability, the state of infrastructure, building and road development, the availability of and access to ICTs, and the capacity of extension services and value chain actors to effectively use climate information and embed it into decision-making strategies.
- Financial services combined with climate and weather-based information to provide insurance against extreme weather events, with a view to improve access to credit/funds for actors to adapt and/or recover faster before and after a hazard strikes.
- Technical/advisory services to build capacity and raise the awareness of stakeholders on how to reduce and manage climate and disaster risks along the food supply chain, including training and educational courses on accessing and using available climate information services, tools and platforms and best practices to ensure a long shelf-life for agrifood products (namely, storage, pre-treatment and packaging).

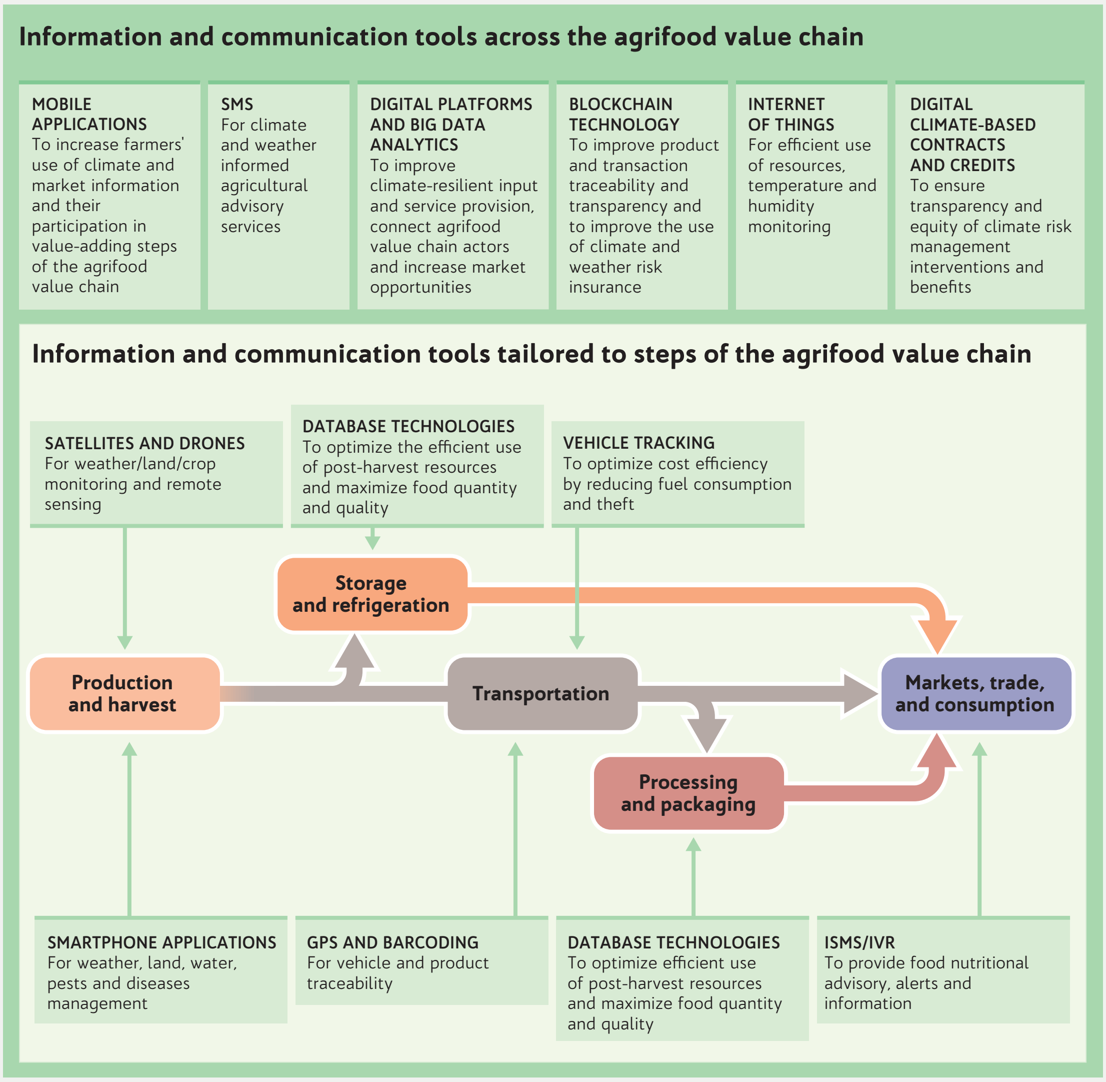
Identifying target users of climate services for agrifood value chains

- Climate services can be used by all agrifood value chain actors and stakeholders: input suppliers; food producers (farmers, agricultural cooperatives); individual actors and businesses (SMEs, multinational companies) involved in food storage, refrigeration, processing, packaging, transportation and logistics; traders and retailers; consumers; extension services; and policymakers (national and local governments).

Tailoring climate information to the needs of specific users

- Communication is tailored to user's capacity to access information through simple or more complex and affordable communication and information channels, tools and platforms – such as smartphone applications, websites, emails or texts provided and supported by public and/or private financial services – to enhance the exchange of good practice and experience of agricultural systems in certain geographical areas (see Figure 1).

Figure 1. Tailored information and communication options for agrifood value chains



Source: *Adapted from African Development Bank Group (AfDB), FAO, CGIAR Alliance of Biodiversity International Center & Big Data in Agriculture Platform. 2020a. Digital Agriculture Profile – Rwanda.* Rome. FAO. *www.afdb.org/en/documents/digital-agriculture-profile-rwanda.*

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African Development Bank Group (AfDB), FAO, CGIAR Alliance of Biodiversity International Center & Big Data in Agriculture Platform. 2020c. Digital Agriculture Profile – South Africa. Rome. FAO. *www.afdb.org/en/documents/digital-agriculture-profile-south-africa.*

Expected outputs from the provision of climate services

- The provision of tools and technologies for digital communication and climate and weather information services have the potential to support decision-making along the agrifood value chain, for example, by policymakers, private enablers, extension services and local and national governments, and to enhance governance on multiple levels, participatory management practices, networking and collaboration.

Final outcome: climate services and the SDGs (Figure 2)

By enhancing the ability of agrifood value chain actors to adapt to climate hazards, climate services can strengthen household agricultural productivity, increase their access to value-adding facilities along the chain and open up both domestic and international market opportunities (**SDG 1**). By enabling actors to make climate-informed decisions to prevent food loss and resource waste against climate risks, climate services can increase food security while enhancing stakeholders' nutrition and health (**SDGs 2, 3, 12**). This is achieved by building capacity among all actors and ensuring their equitable access to climate information and communication technologies, as well as their application in a consistent manner throughout the agrifood value chain (**SDGs 4, 5, 10**). Climate information and agricultural advisory services – which support the implementation of integrated water, crop and pest management practices tailored to regional climatological, meteorological and hydrological factors and improve the prevention and reduction of flood and drought risk – also facilitate access to and increase the efficient use of sustainable energy and natural resources (**SDGs 6 and 7**). Therefore, climate services can climate-proof post-harvest agribusiness facilities and infrastructure (**SDG 9**) and build the resilience of agricultural production and supply chains to climate and disaster risks, with both adaptation and mitigation co-benefits (**SDG 13)**. Thus, climate-based food loss and resource waste can be reduced (**SDG 12**), ultimately helping to protect, restore and promote the sustainable use of natural ecosystems (**SDGs 14 and 15**).

Overall, the systematic use of climate services would benefit both public and private stakeholders by increasing agricultural household profit and national economic growth, by spreading climate and disaster risk management strategies throughout the agrifood value chains in rural and urban agrifood systems (**SDGs 8 and 11**). Climate-resilient measures can be pursued through enhanced communication, opportunities for synergy and partnerships for climate resilience between public and private stakeholders (**SDGs 16 and 17**).

Figure 2. Climate services for agrifood value chains and SDGs

Source: Based on FAO. 2019a. *Climate-smart agriculture and the Sustainable Development Goals: Mapping interlinkages, synergies and trade-offs and guidelines for integrated implementation.* Rome. www.fao.org/3/ca6043en/CA6043EN.pdf.

2

CONCEPTUAL FRAMEWORK FOR CLIMATE-SMART AND RESILIENT AGRIFOOD VALUE CHAINS

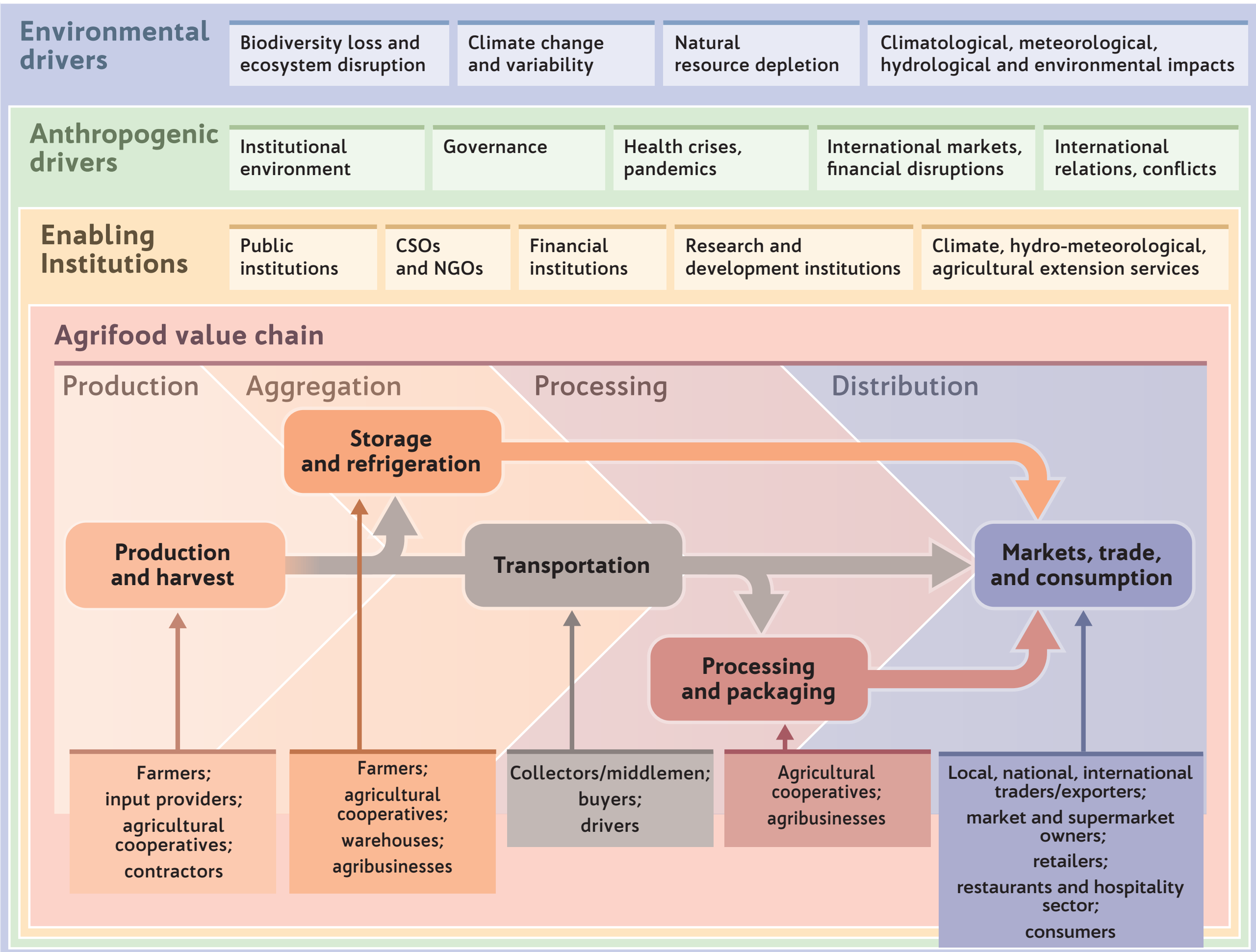
2.1 The agrifood system

Agrifood systems are characterized by complex social and ecological interactions, as well as the numerous actors and stakeholders involved in value chain activities from the production to consumption of products originating in agriculture, forestry, livestock and fishery systems. All the pillars of food security – food availability, access, utilization and stability – are impacted by the climate system, socioeconomic context and availability of natural resources from local to national and international level. Therefore, both mitigation and adaptation measures are fundamental to reducing GHG emissions and forging livelihoods that better absorb and recover from the impacts of climate change on agrifood systems (Mbow *et al.*, 2019; IPCC, 2022).

2.2 The agrifood value chain

In an agricultural context, an agrifood value chain can be defined as a set of actors and activities involved in bringing an agricultural product from production to final consumption, with value addition at each stage (Wieben, 2019). Agrifood value chains comprise four core functions – production (production and harvest), aggregation (storage and refrigeration), processing (processing and packaging) and distribution (markets, trade and consumption) – with transportation occurring throughout the chain and various interrelated actors involved at every step (FAO, 2014). Some of the integral steps that define an agrifood value chain from harvest to market are outlined in Figure 3.

Figure 3. Key steps along the agrifood value chain embedded in environmental, social and economic systems



Source: Adapted from Puri (2014); FAO (2014); FAO and UNDP (2020).

Value chains differ significantly depending on the anthropogenic drivers of the social and economic context and the geographical and climatic characteristics. A value chain approach is based on the prevailing governance system, and so relies on the interconnections and interactions between producers (farmers) and non-producers (input suppliers, collectors, processors, transporters and market traders), extended value chain actors (providers of financial and non-financial services), final consumers and waste-disposal managers (FAO, 2014). All stages of the value chain contribute to food availability, access, utilization and stability and are subject to social, economic and environmental factors that could undermine the delivery of stable, safe and high-quality agrifood products. The concept of "value" is key in acknowledging the interdependence between actors' needs and activities at every step of the agrifood production and supply chain. This can undermine or enhance the quality of the product depending on multiple variables. Therefore, delivering healthy, safe, abundant and nutritious agrifood products, and adding intrinsic economic, social and environmental value, requires a comprehensive vertical approach that considers both the private and public relationships between partners and stakeholders from local to international level (FAO, 2014).

2.3 Agrifood loss and waste

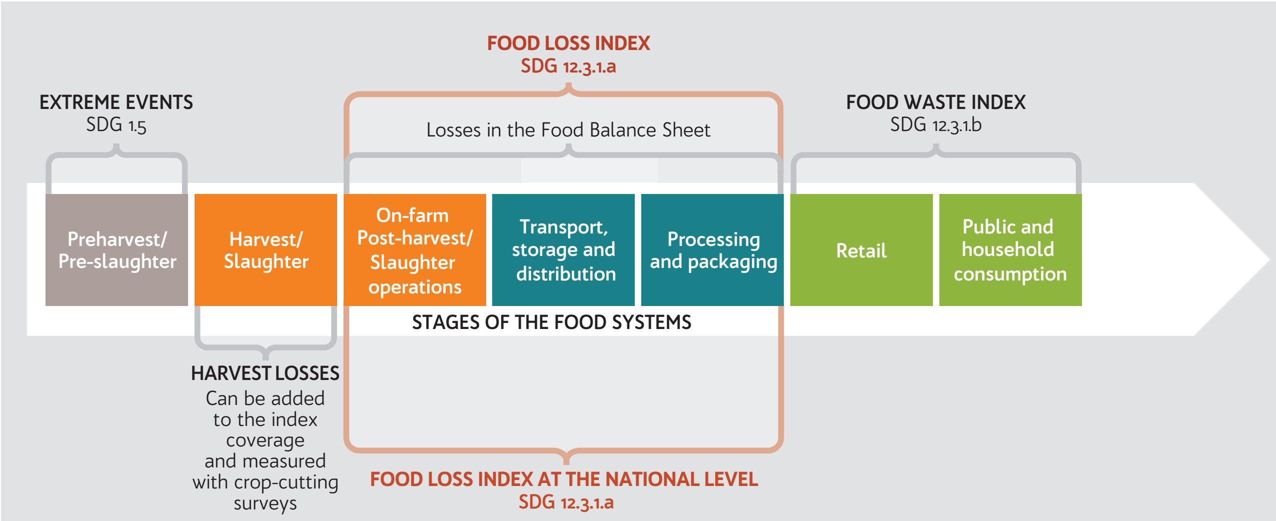
Agrifood loss and food waste mean different things depending on the stage of the agrifood value chain where they occur (Figure 4). Food loss occurs "upstream" at the pre- and post-harvest stages of the agrifood value chain, before the food reaches the retail, market and consumer stages. It is largely caused by unforeseen physical events. Quantitative food loss implies a reduction in yield and less food available for market and consumption. Qualitative food loss concerns a reduction in the nutritional value of the product caused by bacterial or fungal contamination, food spoilage or over-ripening (Misiou and Koutsoumanis, 2021). Food waste, in contrast, is food that is voluntarily discarded "downstream" in the retail, market, food service or consumption stages, when it could still be used for cooking, edible or non-edible by-products (Despoudi, 2016; FAO, IFAD, UNICEF, WFP and WHO, 2019).

In developed countries, food waste tends to occur at the consumption stage, largely driven by negligent behaviour and strict food standards. In LDCs, food losses tend to take place at critical junctures in the value chain, long before they reach the consumer, often caused by climatic and environmental constraints, along with a lack of appropriate infrastructure and technical knowledge to manage such risks (Puri, 2014).

Around 14 percent of food is lost and wasted throughout agrifood value chains globally. Cereals and pulses are primarily lost in the production and transportation stages, as detected in East and Southeast Asia. Perishable food commodities, such as fruits, vegetables, fish and meat, are most vulnerable in the post-harvest stages, as detected in sub-Saharan Africa (FAO, IFAD, UNICEF, WFP and WHO, 2020). The drivers of food loss and waste vary from stage to stage. They include, for instance, exposure to climate and weather hazards, a lack of adequate infrastructure and equipment, limited knowledge of appropriate practices and a dearth of economic resources.

Globally, food loss and waste come at an economic cost of USD 400 billion annually (FAO, 2021c), on top of the substantial environmental implications of resource waste and GHG emissions, as well as the negative social effects of reduced food availability and nutritional quality and higher food costs. The effects are most acutely felt in LDCs, where access to adequate amounts of food and nutrition is critical and varies between actors and stakeholders along the value chain according to their levels of vulnerability and adaptive capacity. Sustainable and efficient agrifood systems require the consistent prevention and reduction of food losses and waste at every step of the agrifood value chain (SOFI, 2020). Effective interventions and investments in climate change adaptation and mitigation measures need to consider an integrated approach, to address food loss and enhance productivity at the pre- and post-harvest stages and to tackle food waste at the processing, trade and consumption stages.

Figure 4. FAO Food Loss Index



[i] Losses occur during harvesting, for example in the case of cereals damaged during cutting or in the process of sorting or grading.
[ii] Loss factors have been compiled in a database made openly available at www.fao.org/food-loss-and-food-waste/flw-data

Source: FAO (2019b).

2.4 Climate resilience

Climate resilience is a consistent, robust adaptive capacity to withstand climate hazards and recover from impacts on social and ecological systems to achieve desired environmental, social and economic outcomes, both in the short and long term (Tendall *et al.*, 2015). In the context of agrifood systems and value chains, climate resilience is the ability of agriculture-related social and ecological systems to thrive long term, despite the climate risks to actors, natural resources and economic activities from production to consumption.

Climate resilience is, therefore, the capacity of all actors to prevent and respond to shocks to agrifood value chain development in a robust way, whereby actors are aware of the climate risks and able to make informed decisions based on this knowledge. Climate resilience boosts agricultural productivity vand profitability, reduces poverty and enhances the well-being of households and communities (FAO, 2021d).

It is imperative to acknowledge the trade-offs and interlinkages between the concepts of resilience and sustainability. Enhancing climate resilience without ensuring that environmental, economic and social sustainability requirements are met could lead to maladaptation, exacerbating long-term vulnerability to climate risks. For example, building new fossil fuel-powered storage and refrigeration facilities in developing countries might reduce food losses caused by climate impacts, but increase maintenance and energy costs and worsen environmental impacts and GHG emissions. Interventions to enhance climate resilience must, therefore, contribute to both climate change adaptation and mitigation.

Climate resilience must go hand-in-hand with sustainability. Sustainable and climate-resilient interventions aimed at agrifood systems and value chains simultaneously reduce hunger and poverty among value chain actors and stakeholders, without compromising the intra- and intergenerational availability of natural and human resources.

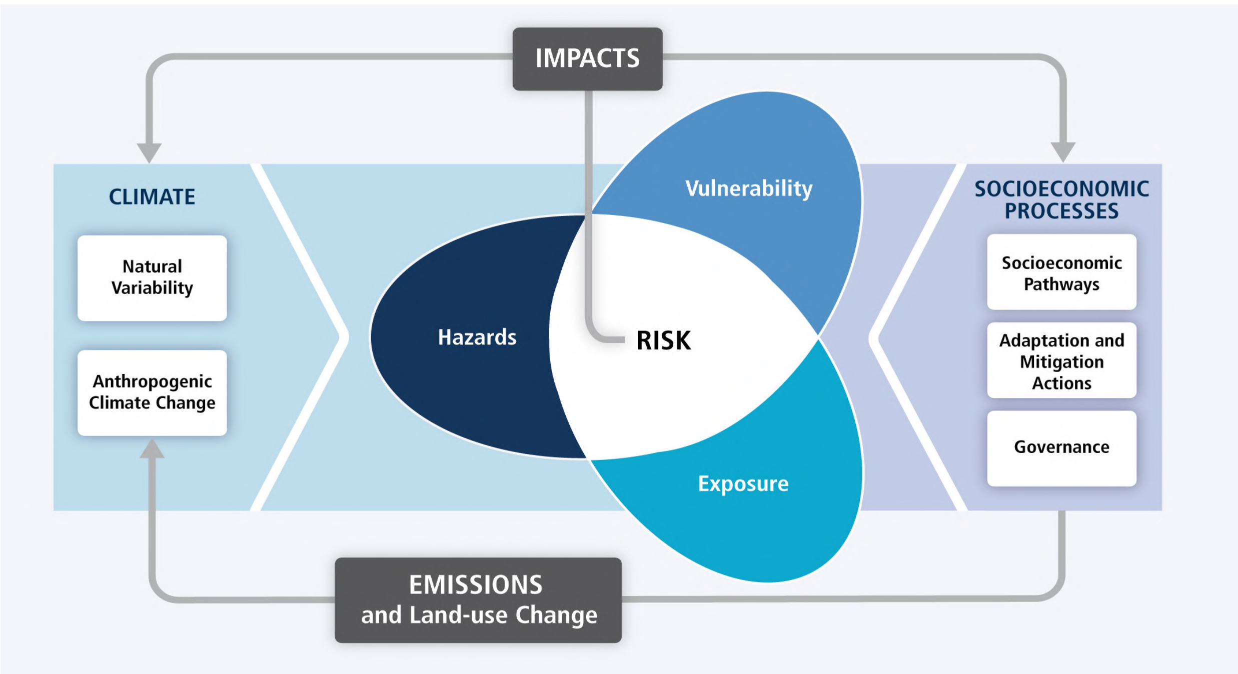
While every agrifood value chain differs according to the social, economic and environmental conditions involved, it is crucial that interventions are tailored to specific parameters. Climate-smart interventions to provide climate adaptation and mitigation co-benefits within agrifood value chains include (IFAD, 2015; FAO, IFAD, UNICEF, WFP and WHO. 2021):

- product diversification to enhance the flexibility of agrifood production and the adaptive management of resources;
- climate-proof infrastructure, retrofitting measures and renewable energy deployment (such as solar panels or bioenergy);
- integrated efficient resource management (land, water, energy, waste);
- the development and commercialization of climate- and weather index-based insurance schemes;
- stronger communication and collaboration between agrifood value chain actors and stakeholders, through capacity-building, participatory training interventions, the development of information and communication technologies, and information- and knowledge-sharing practices; and
- climate services – access to and use of tailored climate information as a basis for daily to long-term decisions on climate risks (FAO, 2021e).

2.5 Climate risk

Climate risk results from the interaction between climate and geophysical hazards, exposure to human and natural hazards over time, and the socioeconomic vulnerability and adaptive capacity of targeted populations or systems (Porter *et al.*, 2014; FAO, 2021d; IPCC, 2022) (Figure 5).

Figure 5. Risk of climate-related impacts



Source: IPCC (2014).

While analyzes of climate change risks to the agriculture sector often focus on production and yields, climate-related risks and food and economic losses are present at all stages of the agrifood value chain, from smallholder farmers to agri-businesses, consumers and governments, with consequences for the agrifood value chain and economic development. These impacts pose a threat to food security by reducing food availability, access, quality, stability and nutritional intake, as well as food price stability (Fanzo *et al.*, 2018; FAO, IFAD, UNICEF, WFP and WHO. 2021; Hansen *et al.*, 2019).

Climate risk assessments tailored to agrifood value chains will, therefore, consider different physical, social and economic datasets at global and regional level (FAO, 2021d), combined with qualitative consultations to evaluate climate risks and climate-resilient interventions throughout the chain (FAO and UNDP, 2020).

Climate risk management interventions in the agrifood sector could provide the rationale for greater investment in agricultural markets and value-adding post-harvest activities that are resilient to climate change. They could also help to commercialize climate-resilient agrifood products and by-products, to the benefit of smallholder farmers and other actors along the agrifood value chain, enhancing access to inputs, natural capital and climate-smart technologies and fostering more reliable, higher value agricultural productivity.

Still, substantial investments in and evidence of the returns of climate risk management have yet to be mainstreamed into agrifood value chains. This is particularly the case when it comes to the financial capacity of small-scale farmers and the most vulnerable communities and the benefits of improving linkages between pre- and post-harvest economic activities and connections to markets (Hansen *et al.*, 2019).

DEFINITIONS

- Climate hazards refer to the current and future climatological (drought, for example), meteorological (extreme temperatures, fog, storms or wind, for instance), hydrological (floods or geohazards) and environmental (land degradation and water pollution, for example) factors negatively affecting the social and ecological assets of agrifood value chains (as set out in detail in chapter 3).

- Human and natural exposure to climate hazards is determined by climate zone, geographical characteristics of targeted areas, population, environmental services and the agricultural and other socioeconomic activities undertaken.

- Vulnerability is determined by the social and economic conditions of the targeted population, for example, poor health, gender inequality, poverty, food insecurity and malnutrition. In the context of agrifood value chains, different actors may experience different levels of vulnerability. The greater direct impacts on the most vulnerable groups may have compounded effects on earlier or later stages of the value chain, indirectly affecting the entire chain.

- Climate risks can be partly or totally offset both in the short and long term by implementing climate adaptation and mitigation strategies (Porter *et al.*, 2014; FAO and UNDP, 2020).

- Adaptive capacity in the context of agrifood value chains lies in value chain actors' ability to prevent or reduce climate impacts by implementing climate-proof infrastructure and technologies, using effective practices and being able to access social, agricultural and disaster risk insurance programmes. It depends in large part on the support provided by public and private institutions through research and investment in technological developments and access to electricity, the Internet, post-harvest facilities and social protection measures (FAO, 2021d).

2.6 Climate-smart agriculture

Climate-smart agriculture (CSA) is an approach that helps guide actions to transform agrifood systems towards green and climate-resilient practices. CSA supports reaching internationally agreed goals such as the SDGs and the Paris Agreement. It aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible.

CSA supports FAO's Strategic Framework 2022–2031 based on the Four Betters: better production, better nutrition, a better environment and a better life for all, leaving no one behind. What constitutes a CSA practice is context-specific, depending on local socio-economic, environmental and climate change factors. FAO recommends the approach is implemented through five action points: expanding the evidence base for CSA, supporting enabling policy frameworks, strengthening national and local institutions, enhancing funding, and financing options, and implementing CSA practices at field level (FAO, 2022).

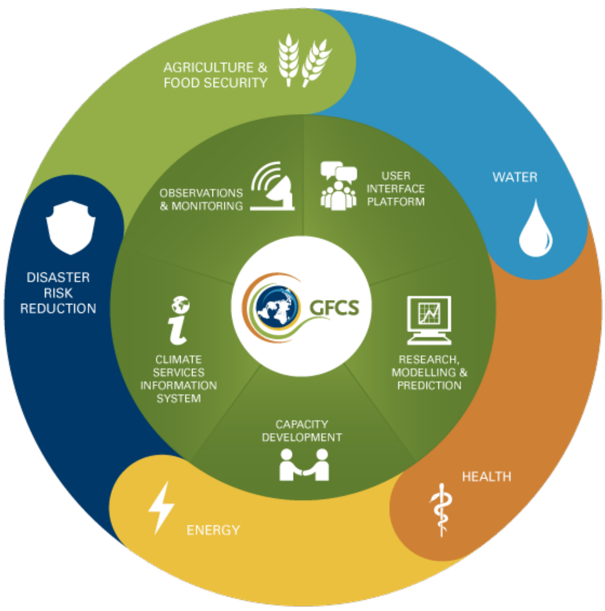
The CSA approach can help to build resilient agrifood systems by acting on the production phase, but it can also enhance the quality and nutrient properties of agrifood products, making them better able to overcome the challenging conditions of low-tech post-harvest chains frequently found in rural areas of developing countries (FAO, 2022). Key CSA practices to achieve these objectives include enhancing the efficient use of natural resources and farm inputs (e.g. fuels, energy, pesticides, mineral fertilizers); increasing or keeping carbon stored into the soil (e.g. through conservation agriculture); introducing improved varieties and breeding; and making farming systems more diverse (European Commission, 2021).

CSA practices and climate services have complementarities, ultimately accelerating the achievement of climate-resilient agrifood systems. For instance, in the production and harvest phases, early warning systems can enhance preparedness to extreme weather events, thereby optimizing the efficacy of CSA practices. On the other hand, the benefits of CSA practices can last in the post-harvest chains (e.g. by improving the shelf life of agrifood products), contributing together with climate services to reduce food losses and waste and improving food security.

2.7 Climate services

Climate services involve the production, translation, transfer and use of climate knowledge and information in climate-informed decision-making and climate-smart policy and planning (Climate Services Partnership, 2021). Climate services should be provided in a comprehensive, meaningful and user-friendly way that enhances early action and risk management capacity in the agriculture, water, energy and health sectors and against climate disasters (Figure 6). Climate services aim to enable targeted actors to base decision-making on strong evidence, supporting adaptation to and mitigation of climate change from the short/medium term to the long term by ensuring interventions and investments are underpinned by climate information (WMO, 2020).

Figure 6. Global Framework for Climate Services (GFCS)



Source: WMO (2021).

Climate and weather services are combined in a holistic approach involving the co-production of tailored advisory products with relevant institutions, stakeholders and users. The Global Framework for Climate Services (WMO, 2021) starts with the collection of weather and agronomic information (either ground-based or remotely), which is then processed by international, regional and national meteorological organizations, such as national hydrometeorological services. Communication with users is tailored to their capacity to access information through channels and tools of varying complexity and affordability, such as phone apps, websites, emails and SMS texts. These are underpinned by public and private financial services, as well as participatory approaches, to enhance users' capacity to use the information to make climate-informed decisions that are specific to the locality and sector in question and founded on a combination of experiential and acquired knowledge (O'Grady *et al.*, 2020; FAO 2021).

Climate services aim to provide detailed, actionable and accessible information tailored to specific users, such as farmers. Agricultural producers, however, can be highly dispersed across a country, making the effective delivery of climate and weather information more challenging. In addition, weather information can vary significantly from region to region, so farmers must receive information tailored to their geographical area and crop-specific to make real-time weather-informed decisions.

The use of differentiated sectoral information for agrifood value chains is key to supporting the decision-making capacity of different actors. For instance, combined analyzes of climate trends and weather variability that include impacts on crop yields or storage facilities can support farmers in decisions on when to sow or whether to invest in solar panels to power storage infrastructure. FAO outlines a framework for climate services focused on the "last mile", or agricultural users, in its recent Global Outlook for Climate Services in Agriculture (FAO, 2021b).

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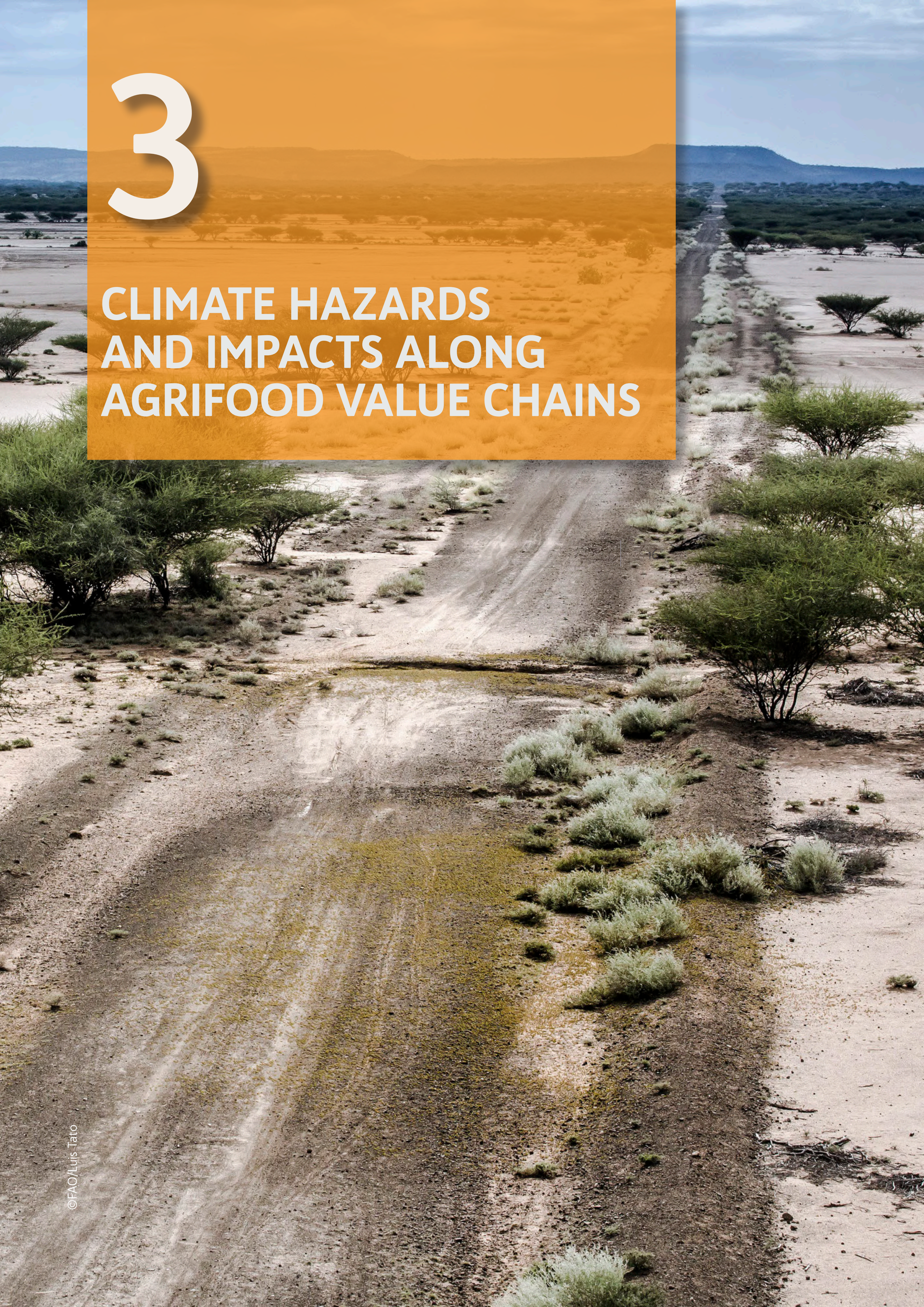
3

CLIMATE HAZARDS AND IMPACTS ALONG AGRIFOOD VALUE CHAINS



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As highlighted in section 2.4, climate risk is a function of hazard, exposure, vulnerability and adaptive capacity (IPCC, 2015). Economic losses as a result of climate-related risks and impacts can be observed at all stages of the agrifood value chain. As agrifood value chains are so diverse in terms of geographical parameters, food commodities and socioeconomic conditions, tailoring climate-resilient measures to local context and a given value chain requires identifying the hazards, exposure, vulnerability and adaptive capacity at every step of the agrifood value chain based on local data and context-specific assessments. Table 1 outlines climate hazards and impacts relevant to each stage of the agrifood value chain.

Every step of the value chain can be exposed to climate- and weather-related hazards (Davis et al., 2021). The extent of the impact will depend on the geographic area, the types of food commodities and social and economic assets and the degree of exposure and vulnerability of actors and infrastructure along the value chain. Farmers and small-scale producers are often the most vulnerable, as they may lack suitable technical and economic instruments and are less able to prevent and adapt to climate risks that affect production and yields. However, as farmers are located at the very first stage of the value chain, any impact on their activity will inevitably affect all actors further down the agrifood value chain, be it in terms of reduced quantity or quality of product. For instance, storage–processing–transportation facilities that rely on the supply chain of a single food commodity will suffer significant revenue losses if climate hazards impact a specific agricultural product, as they often have little flexibility to shift toother activities (Canevari-Luzardo and Pelling, 2019). This, in turn, will have an effect on incomes and livelihoods, undermining the performance of the value chain as whole.

Quantifying risk starts with identifying the hazards. At the storage stage, for example, extreme heat can spoil products if they are not sufficiently refrigerated or protected. Exposure is determined by the location of the storage facility and vulnerability of the infrastructure. Adaptive capacity is the ability of those involved in food storage to access suitable storage facilities and services in case of exposure to a climate hazard. The overall risk at this stage will depend on the degree of risk to each component in a given context.

The evaluation of climate risks at each individual step of the agrifood value chain is key to reducing vulnerability, enhancing adaptive capacity and business opportunities, and rendering the value chain resilient to short-term weather anomalies and long-term climate change. By identifying and assessing current and potential future risks to each step of the value chain, it is possible to prioritize different adaptation and/or mitigation options, determine the urgency of those options and identify the most appropriate investments accordingly. Lastly, it is crucial to assess the climate risk and climate resilience of the agrifood value chain in its entirety to ensure the coordination and to avoid tackling a particular risk in isolation, without recognizing the interdependence of actors and activities along the chain.

Table 1. Climate and weather-related hazards and impacts along the agrifood value chain

Weather-related hazards	Impacts at each step in the agrifood value chain				
	Production and harvest	Storage and refrigeration	Processing and packaging	Transportation	Markets and retail
Extreme heat	Reduced crop yields, food spoilage, rapid degradation, undermined food nutritional properties, decline in meat and milk quality, decrease in animal fertility, increase in animal mortality	Food spoilage, rapid degradation, undermined food nutritional properties, conditions for bacterial and fungal spread	Food spoilage, conditions for bacterial and fungal spread	Unfavourable driving conditions for food carriers, reduced food storage life	Food spoilage, impact on access to safe, healthy food, changes in consumer requirements
Extreme cold	Damage to crop growth and food spoilage; cold stress on livestock	Food spoilage	Food spoilage, increased energy demand	Frozen roads and food spoilage	Obstructed access to markets, changes in consumer consumption preferences
Agricultural, hydrological, socioeconomic drought	Reduced crop yields, food contamination, drought stress on animals, conditions for microbial growth	Reduced availability of rainfed and groundwater resources	Reduced access to rainfed and groundwater resources	Damage to road infrastructure	Changes to food prices and sales
Heavy rains and flooding	Rapid food deterioration, harvest delays, conditions for microbial growth and water-borne diseases, animal mortality, yield losses, coastal erosion	Damage to infrastructure, loss of food loads, water contamination, food spoilage, rapid degradation, contamination, conditions for bacterial and fungal spread	Damage to infrastructure and facilities, drying methods rendered ineffective, increased costs, food spoilage, rapid degradation, contamination, conditions for bacterial and fungal spread	Blocked roads, damage to infrastructure, risks for perishable food	Damage to infrastructure
Storms/winds	Damage to flowering and fruiting stages, soil and coastal erosion	Damage to infrastructure, loss of food loads	Damage to infrastructure and facilities	Unfavourable driving conditions	Obstructed access to markets

Table 1. *(Continued)*

Weather-related hazards	Impacts at each step in the agrifood value chain				
	Production and harvest	Storage and refrigeration	Processing and packaging	Transportation	Markets and retail
Sea level rise, higher sea temperatures, salinization	Less suitable conditions for fisheries and agriculture near coasts, increased algal and marine biotoxin growth	Damage to infrastructure	Damage to infrastructure, reduced food quality	Erosion, deterioration of coastal infrastructure	Changes to food availability, prices and sales
Landslides	Reduced crop yields, delayed harvests	Damage to infrastructure	Damage to infrastructure	Damage to infrastructure and vehicles	Damage to infrastructure
Wildfires	Reduced crop yields, delayed harvests	Damage to infrastructure	Damage to infrastructure	Damage to infrastructure	Damage to infrastructure, food losses
Pests and diseases	Crop damage, loss of agrifood products	Food spoilage, food losses, compromised food safety	Food spoilage	Food spoilage and compromised food availability	Reduced food quality and safety
Fog/dust/snow	Decrease in productivity, reduced crop yields	Changes in energy consumption to maitain optimal temperatures	Changes in energy consumption to maitain optimal temperatures	Impeded road and infrastructure visibility	Obstructed access to markets
Relative humidity	Food contamination by mould and mycotoxins	Food damaged by mould, stem rot	Food contamination, drying methods rendered ineffective	Increased risk of food spoilage, reduced food storage life	Reduced food quality and safety
UV radiation	Enhanced oxidation processes, vitamin losses, damage to food flavour and quality	Enhanced oxidation processes, vitamin losses, damage to food flavour and quality	Enhanced oxidation processes, vitamin losses, damage to food flavour and quality	Enhanced oxidation processes, vitamin losses, damage to food flavour and quality	Reduced quality of food for consumption

Source: Fanzo et al. (2018); Mbow et al. (2019); Pilli-Sihvola et al. (2016); Davis et al. (2021); Misiou and Koutsoumanis (2021).

4

CLIMATE SERVICES ACROSS AGRIFOOD VALUE CHAINS

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The exposure and vulnerability of agrifood value chains to climate hazards underscores the need to shift attention to a substantial gap in academic and empirical knowledge on the barriers to and opportunities for using climate services along entire agrifood value chains, as well as their potential to increase climate resilience by improving the adaptive capacity of all actors and infrastructures at each stage in the value chain (Campbell et al., 2018) .

Climate services consist of one potential adaptation solution to counteract climate risks to agrifood value chains. Their effectiveness is enhanced when climate services are paired with climate-informed adaptation solutions. In fact, by informing on spatial and temporal extent of climate risks to key socio-ecological and agricultural systems, they support the implementation of tailored adaptation investments, practices, and technologies (IPCC, 2022). For instance, improving access to digital services and technologies would help to increase agricultural productivity and reduce rural poverty, by rendering the use of natural and human resources more efficient and tailored to climatic conditions. However, there is scant information on available resources or demand for technological products and services in LDCs, hampering the selection of the most effective and innovative products to users of communication technology (Lonie et al., 2018). Agrifood value chains have failed to systematically adopt data-sharing systems and tailored advisory services provided directly by cooperatives or traders, or to properly use and invest in these services, resulting in a lack of coordination between actors and activities involved in pre and post-harvest stages (Despoudi, 2021). In addition, enabling technology is not uniformly distributed and used worldwide. Substantial gaps remain in the provision of stable Internet access to users globally.

While significant advances have been observed in the tailoring and application of climate services to the needs of the agriculture sector over the last decade (FAO, 2021b), apart from food production, progress has been limited. Climate services for product storage, processing, transport and market purposes also exist, but have been developed in isolation for specific sectoral functions. The coordination and mainstreaming of climate services across the entire agrifood value chain, therefore, has great potential to enhance the resilience and sustainability of agrifood systems (FAO, 2017).

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Different agrifood value chains require bespoke, context-specific analyzes of the challenges to and opportunities for climate service development (Lonie et al., 2018). Producing an actionable service, therefore, requires multidisciplinary expertise and local context-specific information. Different demographics and agricultural practices will attach different values to climate services. For climate information to be valuable to actors across the entirety of agrifood value chains, it must be combined with other relevant data and interpreted in the context of user needs.

Countless actors work interdependently in agrifood value chains, though they frequently lack collaboration and knowledge sharing. The main objective of value chain-specific climate services is to support key actors in making decisions by ensuring they have real-time information, so as to reduce the impact of climate risks on their activities and to enhance coordination to counter climate risks. Early action and informed decision-making thus contribute to the reduction of food and resource loss and waste along the value chain and enhance the nutritional quality of food by providing climate-resilient agrifood products to end markets worldwide. This is particularly the case in LDCs, where the socioeconomic and infrastructural conditions for achieving this are weaker and require more investment than in developed economies.

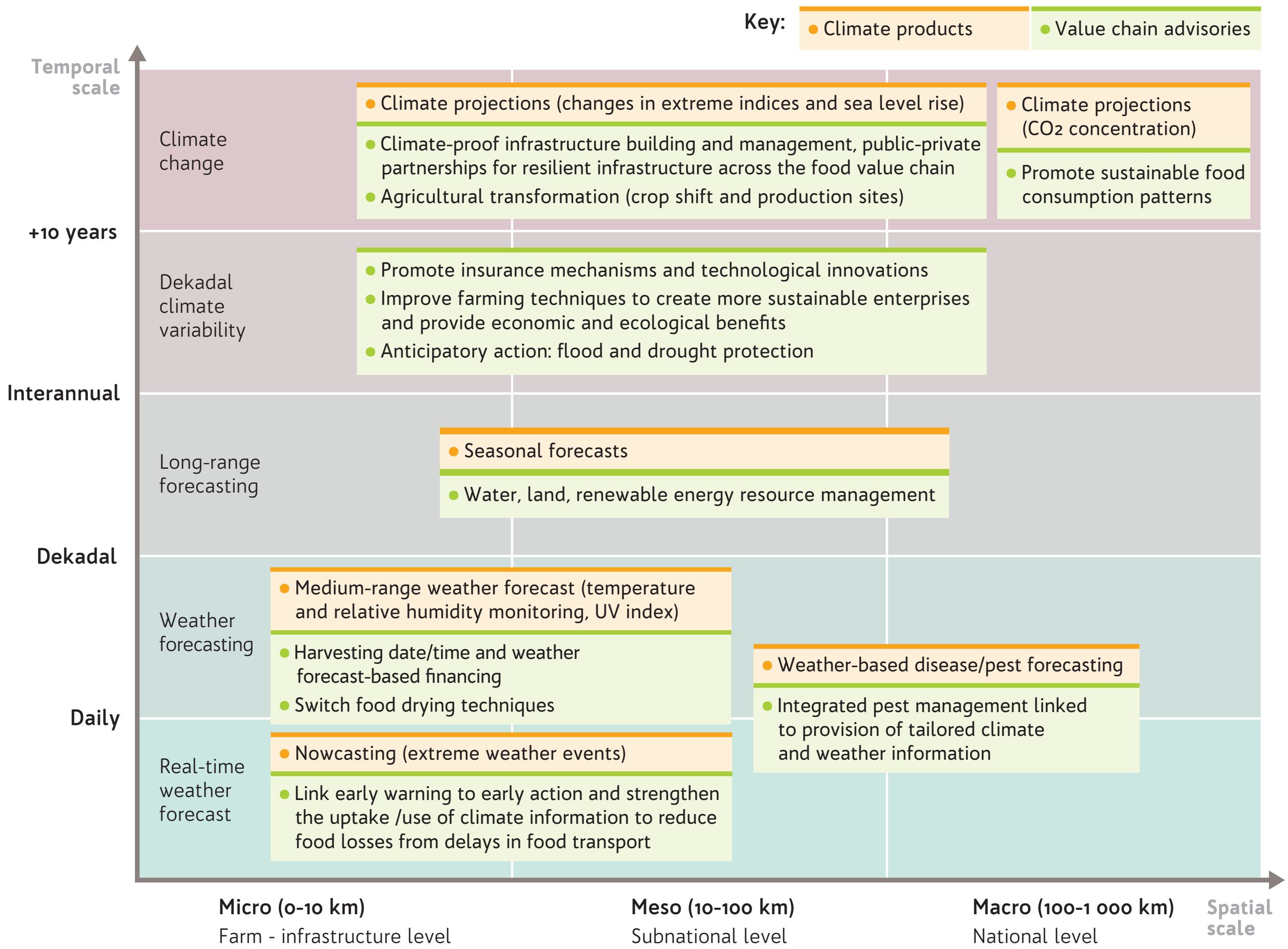
Various decisions at different points in time will require different information on climate-weather variables. Short-term decisions may concern the choice of crop, variety or other inputs to use before and during the production-to-harvest stages. At the same time, structural interventions, such as improving farming, storage or processing infrastructure, require medium- to long-term information. Climate-informed actions are, therefore, driven by climate information and agricultural advisory products provided over different time and spatial scales (Figure 7) to produce climate risk assessments for infrastructural development, climate services for short-term decision-making and sector-specific advisories.

Shorter term, forecasts and advisories tailored to specific value chain actors enable day-to-day decision-making to prevent climate-related damage or loss. Longer term, climate projections can indicate the need to develop more substantial, climate-resilient infrastructure. They can also highlight the need for more efficient use of renewable energy and natural resources, such as water and land, for food storage, processing and packaging, refrigeration, transportation and markets, in order to decrease vulnerability and enhance the adaptive capacity of actors along the agrifood value chain. This increases the environmental, social and economic value of agrifood products, boosting market opportunities and revenues for producers and non-producers alike.

Different agribusiness actors use different types of climate-related information depending on their needs and their role in the agrifood value chain. Common requests, however, pertain to the accuracy and accessibility of information. USAID (2018a, pp.12) identifies three types of actors by their decision-making capacity, relationship with farmers and sustainability practitioners, and investment needs for climate-smart practices. These include "direct service providers to smallholder farmers", "collaborators with service providers" and "catalysts, those working at global, sector or policy level on climate issues with a light touch at the farm level". "Direct service providers" are more closely related to smallholder farmers, so need the most detailed information at farm level, including weather forecasts, climate impacts along the agrifood value chain and advice on suitable agricultural practices for adaptation to climate hazards. "Collaborators" work at a higher level and are in closest contact with direct service providers, to generate climate maps for wider areas and provide climate information through participatory co-production processes. "Catalysts" are those actors that approach the issue from a wider angle to define broader policies, programmes and strategies (USAID, 2018a).

The delivery of climate services tailored to different users, therefore, would enhance collaboration and knowledge transfer opportunities between actors along the chain. They would be of particular benefit to vulnerable groups, supporting the development of technology and Internet facilities so they could access, use and share climate information appropriately. Moreover, the development of climate services would facilitate stronger links between public institutions and private actors with a view to improving information sharing, investment and support, capacity-building, governance and participatory management approaches, overcoming maladaptive processes primarily focused on sector-specific and small-scale interventions and practices (IFAD, 2015).

Figure 7. Spatio-temporal scale of climate products and agricultural advisories for agrifood value chains



Source: Modified from FAO (2021c).

5

CLIMATE RISKS AND SERVICES AT KEY STEPS OF THE AGRIFOOD VALUE CHAIN

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Climate services and climate-informed advisory services for the agriculture sector are often targeted at ministries or extension services and tailored to support agricultural production. For example, mid- to long-term projections of climate and its impacts on agricultural systems can support governments in developing evidence-based plans and policies. Seasonal forecasts from extension workers can provide farmers with the knowledge to underpin decisions on planting times and cultivar choice. Likewise, alerts about the likelihood of specific pest and disease outbreaks will assist farmers in making decisions on treatments to reduce and prevent crop damage. However, as outlined in chapter 3, climate risks have impacts on the entire agrifood value chain, not just production. Identifying the climate risks and potential impacts at each step of a given value chain and offering tailored climate services presents an opportunity to increase actors' capacity to make climate-informed decisions at every step. Climate and other information can be analyzed in the context of each value chain stage to develop advice that will allow value chain actors to make decisions based on timely early warnings that are most relevant to their role in the agrifood value chain.

Therefore, key steps in a climate-sensitive agrifood value chain analysis include:

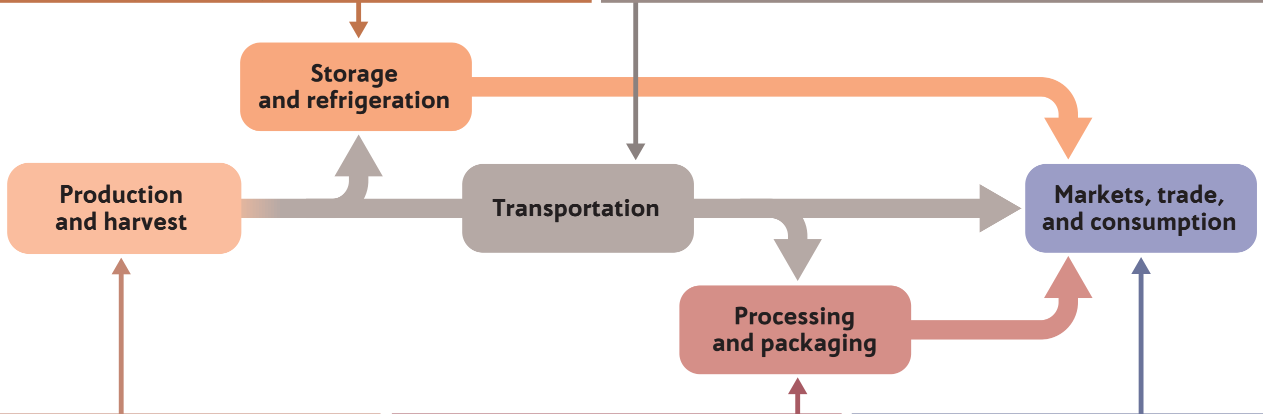
- **Detailed mapping of the agrifood value chain**, with an analysis of the food commodity in question, the actors and activities involved and key external stakeholders, including public and private institutional arrangements and agreements to provide financial, social and climate services.
- A **climate risk assessment** that analyzes climate hazards, the exposure of actors and infrastructure, socioeconomic and infrastructural vulnerabilities, and climate adaptation capacity.
- **Analysis of climate services development at institutional level**, including access, allocation, affordability and the use of climate and weather information products and services among targeted actors, as well as the availability of Internet and digital communication tools and the involvement of hydrometeorological experts in policy and decision-making.
- **Provision of tailored recommendations to value chain actors and stakeholders**, enhancing horizontal and vertical public–private partnerships to ensure coordination on delivering climate services.

With an understanding of climate risks, climate services can promote proactive and preventative risk management actions to reduce food loss, waste and damage at every stage of the value chain. Figure 8 outlines a few examples of the climate risks and services potentially relevant to agrifood production and harvest, storage and refrigeration, processing and packaging, transportation, and market/trade/consumption. It provides a brief outline of the steps in an agricultural value chain and how climate effects can translate into necessary climate services. These are analyzed further in the following chapters and tailored to the local contexts and specific value chains.

Figure 8. Examples of climate hazards, potential climate services and climate-resilient measures across the agrifood chain

Climate hazards	Climate services	Climate-resilient practices
Heavy rains and flooding	Flood advisory	• Storing on wood pallets, maintaining distance to walls • Sustainable structural requirements and standards • Rainwater collection systems
Relative humidity	Daily relative humidity forecast	• Mechanical drying techniques • Large or small packaging, containers, aseptic packaging • Preserving techniques • Dry and package food right after harvesting • ICTs such as temperature and humidity sensor systems

Climate hazards	Climate services	Climate-resilient practices
Heavy precipitation	Extreme rainfall advisory	• Climate-proof drainage systems and infrastructure • Ship products when external conditions are less critical • Reduce transport speed; • Efficient planning of transport routes; • Food storage technologies inside vehicles.
Extreme heat	Heat warnings	• Insulation of refrigerated trucks; • Safe, efficient routes for transportation of fresh, perishable food
Fog, dust and snow	Dense fog, dust and snow advisories	• Light-emitting diode (LED) panels, appropriate lighting and road planning

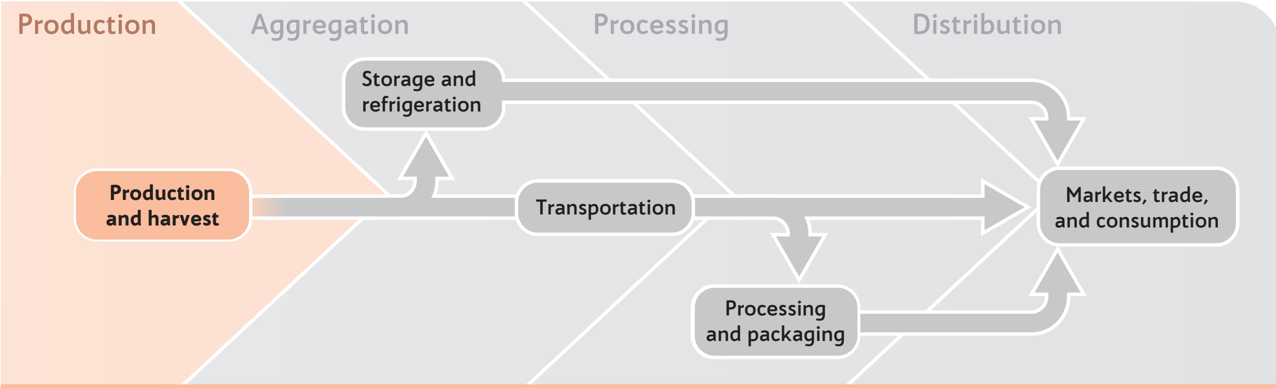


Climate hazards	Climate services	Climate-resilient practices
Flooding and Drought	Real-time weather forecasts	• Appropriate harvest equipment • Training on harvesting methods and best timing
Pests and diseases	Pest and disease alerts	• Earlier harvest • Work hygiene and sanitation practices • Immediate drying techniques

Climate hazards	Climate services	Climate-resilient practices
Relative humidity	Daily relative humidity forecast	• Fan systems for ventilation • Dehumidifiers, roof ventilators and wall air vents • Vapor heat treatment/hot water treatment • Crates to conserve food products • ICTs such as temperature and humidity sensors
Extreme heat	Extreme heat advisory	• Cold rooms • ICTs such as temperature and humidity sensors • Reduce time of storage

Climate hazards	Climate services	Climate-resilient practices
Heavy precipitation	Extreme rainfall advisory	• Efficient rainwater collection systems • ICTs to enhance communication and information sharing among value-chain actors
Changes in temperature and rainfall patterns	Seasonal forecasts	• Seasonal advice on climate impacts on yields and changes in food availability at national and international level

Source: Modified from FAO (2021e).



5.1 Agrifood production and harvest

5.1.1 Climate risks to agrifood production

An extensive body of literature outlines climate risks and their impacts on agrifood production and harvesting (Mbow *et al.*, 2019; FAO, IFAD, UNICEF, WFP and WHO, 2019). In brief, shifts in temperature and precipitation patterns, the occurrence of flooding and drought events (FAO, 2018) and impacts on soil quality, groundwater levels and freshwater systems can damage crop yields, reduce livestock productivity and alter agricultural systems.

Extreme weather events, heat-stress effects, floods, droughts and the spread of pests and diseases have substantial impacts on **crop** yields, causing agricultural losses of up to 60–80 percent in developing countries (FAO, 2018; Yang and Navi, 2005; Parker and Warmund, 2011; Gramaje *et al.*, 2016). The spread of pests and diseases in new geographical areas due to changing climate conditions and international trade is causing ever more damage to crops globally and contributing to significant food losses, undermining social and ecological systems. Extreme weather events, strong winds and storms are jeopardizing agricultural ecosystems by damaging tree and flower growth, fruit formation and crop plants' capacity to weather pests and weeds (Marvin *et al.*, 2013).

Extreme temperatures, changes in rainfall patterns and a greater concentration of carbon dioxide (CO_2) are the main causes of decreased **livestock** productivity, as they affect water availability, cause heat and drought stress conditions for animals that cannot dissipate the energy stored during the day and spread animal diseases (see case study 5.1.1) (Mbow *et al.*, 2019).

Forestry systems are affected by climate change, primarily by the spread of pests and diseases, extreme weather events such as wildfires, triggered by extreme heat and low relative humidity, and exacerbated by slow-onset climatological hazards such as droughts.

Climate impacts on **fisheries** include rising sea-surface temperatures and shifting fish catchment areas. Aquaculture infrastructure and dependent communities are often exposed and highly vulnerable to extreme weather events (such as floods, particularly in coastal regions), the reduced availability of fresh water and the spread of pests, diseases, algae and parasites (Mbow *et al.*, 2019).

5.1.2 Climate risks to food harvests

Substantial food losses can occur due to climatic constraints and extreme weather events, such as strong winds, storms and floods, particularly if these coincide with the harvest (Orge *et al.*, 2020). For example, if mature paddy rice grain gets wet or soaked by typhoons, heavy rains or flooding while still in the field, it will deteriorate quickly, requiring immediate intervention to avoid a poor-quality harvest, if not total loss. Without early warnings and preventative measures, farmers would not be able to prepare for such extreme weather events.

The risk associated with climate hazards is exacerbated by the high vulnerability and low adaptive capacity of farmers and agricultural communities to change practices, as well as a lack of technical knowledge and economic support to take timely climate-informed action (as outlined in Figure 5, section 2.4).

Producers may lack daily or seasonal advisory services on weather-related effects, or early warning systems to enable anticipatory action to prevent losses during production or harvest. Furthermore, inadequate harvest equipment and knowledge of climate-resilient practices may result in losses at the harvest stage.

5.1.3 Climate services for agrifood production and harvest

Climate services must be tailored to specific agricultural systems and management practices, accounting for specific geographical contexts, crop characteristics and socioeconomic factors For example, the type of information relevant to a rice producer in a lowland area will differ from that relevant to a pastoralist in mountainous terrain. As seen with digital financial services, climate services may prove more effective where mobile networks and cellular subscriptions are well established and where there is a certain level of education and literacy in the population, fuelling trust in such services (Lonie *et al.,* 2018). In addition, due to existing socio-economic disparities in accessing natural and technological resources, women in Africa make lower use of climate services compared to men (IPCC, 2022) (see case study 5.1.2).

Digital mobile technologies providing platforms for weather-informed agricultural advisories can prompt farmers and other decision makers along the agrifood value chain to combine weather and price forecasts and use this information in making decisions on crop insurance schemes, on adopting climate-resilient practices for production, on harvest calendars and in communication with agricultural extension services and input providers (see case study 5.1.3). Mobile networks can consequently improve knowledge and information sharing between all actors along the value chain, improving logistics and product traceability for food storage and processing, transportation, market access and payments along the chain (Lonie *et al.,* 2018).

Crop-related weather information is mainly requested when planning the crop season and making strategic decisions on sowing periods, crop varieties, field operation strategies and irrigation management plans. However, daily and decadal weather forecasts and early warning systems can also be highly relevant to decisions on harvest times, to prevent impacts from flooding or extreme heat events that could hinder farmers' access to fields and/or cause substantial food spoilage and losses (Njuguna *et al.,* 2021). Agrometeorological information can also be used in conjunction with pest and disease information to develop alerts and advisories for managing pest outbreaks and reducing infestation damage (see case study 5.1.4).

Early harvesting may be a good strategy when it comes to preventing or reducing the risk of insect attacks, especially when combined with other techniques, such as the use of packaging to conserve the products until they reach maturity. A key climate information product for determining the time to harvest can be to forecast the distribution of rainfall during crop maturation stages (FAO, IFAD, UNICEF, WFP and WHO, 2019). Soil moisture information can be useful in establishing the most appropriate date for harvesting. For instance, Trnka et al (2014) state that the optimal time for wheat harvest is when there are fewer than three days during the harvest window with a top-layer soil moisture level of less than 85 percent, with less than 0.05 mm of rain on the day in question and rain of 5 mm or less the preceding day. In extremely hot periods, heat advisories and early warnings would give indications as to proper harvest times, combined with appropriate methods and infrastructural interventions to preserve the produce right after harvest. This could include advice on managing the labour supply according to harvesting times and needs (Furuholt and Matotay, 2011).

CASE STUDY 5.1.1
CLIMATE RISKS TO LIVESTOCK PRODUCTION

Background

The livestock sector, including meat and dairy production, is highly vulnerable to climate impacts, such as heat stress, droughts, flooding, strong winds and extreme weather events. The fat and protein content in meat and milk can be altered by such hazards. According to a study by Hill and Wall (2014) on dairy cattle in Scotland, while temperature and humidity have the greatest influence on milk yields and fat content, wind speed and the number of hours of sunshine per day affect protein content. In addition, moderating wind speed helps to reduce heat stress on cattle. These observations are helpful in determining the economic impact of climate change on dairy productivity. Analyzing climate projections and weather forecasts in conjunction with historical and present yield data can be useful to policymakers and extension services in monitoring production (Hill and Wall, 2014). In addition, climate and weather services can shape decisions on the best time to artificially inseminate cattle (FAO, 2013).

Example of climate risk to agrifood production: heat stress – United States of America

The United States Department of Agriculture (USDA) is leading research into climate adaptation in the agriculture sector by creating regional hubs for risk adaptation and mitigation to climate change, with a view to assisting farmers in adapting to climate change and developing partnerships with public and private stakeholders (USDA, 2014).

The USDA conducted an analysis of dairy farms in a range of different US climate zones, from arid in the south-west to warm and cold climates in the north-east, to decipher the relationship between milk productivity and heat-stress conditions in cattle.

Its estimates suggest that an increase in average heat stress, based on the Temperature Humidity Index, of one Celsius degree per hour could cause up to a 0.38 percent decrease in milk production. Currently, heat stress is estimated to affect milk production to the tune of USD 1.2 billion per year (USDA, 2014).

The results of the analysis' four climate models are being used to project future losses in milk production due to global warming and increased heat stress. According to USDA's projections, by 2030, milk production will have decreased 0.60–1.35 percent, on average, from 2010 levels and by as much as 2 percent in the southern US states, if no climate-resilient action is taken (this could involve the use of technology, the adaptation of breeding varieties or locations depending on changes in climatic conditions, or the implementation of further climate policies). Combined with market dynamics, the cost of the increase in heat stress caused by climate change is likely to reach USD 106–269 million annually by 2030. By the end of the century, the impacts on productivity and costs are likely to increase even further due to more extreme temperatures, although the analysis does not quantify these.

CASE STUDY: Climate risks to livestock production *(continued)*

Lessons learned

The USDA study identifies heat stress as a major driver of losses in milk productivity and economic profitability, on top of anthropogenic drivers such as market input and output prices and policy effectiveness.

Example of climate, weather and water information services tailored to Australia's livestock industry

In Australia, the Bureau of Meteorology collaborates with extension services to co-produce, deliver and monitor forecast services (Brown and Hawksford, 2018). While global climate models are used to produce higher-level climate information, with appropriate model calibration techniques, state offices apply local knowledge and information to produce forecasting products across the country, such as the Australian Digital Forecast Database (http://www.bom.gov.au/australia/meteye/). This strategy is embedded in the national Agriculture Programme, which aims to produce and deliver bespoke services to the agriculture sector, including all food value chain actors, from production to processing, transportation, trade and markets, service providers and researchers.

Numerous climate, weather and water data services are tailored to the livestock industry, for example, to identify and prevent climate and weather impacts on animal conditions. Key indicators include temperature, precipitation, relative humidity, wind speed, soil moisture and solar radiation. These are used to predict heat and drought stress on livestock and to select suitable adaptation strategies, such as silvopastoral systems, moving cattle to cooler areas or introducing heat- or drought-resistant species. Brown and Hawksford (2018) conducted a detailed analysis of a wide number of complex datasets and information sources, including the Australian Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), that can be used to tailor services for livestock-sector researchers and developers, including climate data (historical observations, seasonal forecasts, decadal forecasts and climate projections), weather data (observation and weather forecasts) and water data (observations and seasonal forecasts).

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CASE STUDY 5.1.2
CLIMATE SERVICES FOR WOMEN ALONG AGRIFOOD VALUE CHAINS

Background

Climate services pertinent to production and harvest differ significantly for men and women. According to Fanzo et al. (2018), in developing countries, men usually prioritize forecasts on the start of rainy periods, as they need to prepare fields and manage livestock, while women usually require information on the end of rainy seasons and on dry periods, so they can manage harvesting activities. However, differences in informational priorities usually coincide with differences in opportunity to access information, largely due to the socioeconomic determinants of activities along the value chain. Indeed, lower levels of access to agricultural services have been observed among women in LDCs due to numerous limitations, such as a lack of transportation, time constraints (the need to combine household chores with farm work), lower levels education and a lack of technological access. This has led extension service providers to focus on men rather than women with regard to communication and information sharing with farmers, processors and traders (Gumucio *et al.*, 2020).

Major challenges

Gumucio et al. (2020) provide an overview of the key barriers to women accessing and using climate services for agricultural activities and suggest strategies for climate service development to overcome gender inequality.

Overall, women in rural areas are viewed as having limited access to information and communication technologies. Their need and capacity to make decisions based on climate and weather conditions is also driven by their social and work-related positions and their involvement in institutional networks.

Policy recommendations and investment opportunities

Women play a central role in a number of agricultural activities, although due to income and technology gaps in the most vulnerable countries worldwide, they are subject to greater climate change risks (IPCC, 2022). Increasing their access to information and means of communication would enhance farm productivity and advance their community role. It would also reduce their working hours, temper the risks involved and increase their decision-making capacity and ability to engage in numerous value-adding activities along the agrifood value chain (FAO, 2016).

Women should be more involved in inclusive communication networks and channels, to enable the identification of information and communication tools, and climate and weather information and advice that meet their needs. Further research is needed on communication strategies to enhance women's climate-related decision-making capacity through the use of climate services in their households and rural activities (Gumucio *et al.*, 2020).

CASE STUDY 5.1.3

LOCAL TECHNICAL AGROCLIMATIC COMMITTEES – LATIN AMERICA

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Background

Farmers in Latin America lack access to the information they need to make the best decisions possible and to manage different types of risk. With regard to climate, in particular, farmers have limited access to weather and climate information when preparing their crops. When they do have access to such information, they struggle to understand it and use it in making decisions to reduce the risks associated with climate change and variability.

The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) is part of the CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS). In Colombia, CIAT is using climatic information from the National Meteorological and Hydrological Services of Colombia (IDEAM) to provide advice to rice farmers on three main topics: (i) whether a farmer in a particular location should plant or not; (ii) if the farmer should plant, when they should do so; and (iii) which crop variety they should plant based on the seasonal weather forecast.

In total, 300 000 farmers are benefiting from user-tailored climate services co-produced and delivered by local partners such as the Colombian National Federation of Rice Growers (FEDEARROZ), Agronet and local technical agroclimatic committees (LTACs). The LTAC approach was co-developed in 2014 by CCAFS, led by CIAT.

Benefits of using climate services

The LTACs build capacity at different levels in areas such as climate forecasting, crop modelling, using climate forecast information, crop management in light of agroclimatic forecasts, formulating recommendations based on best management options, composing agroclimatic bulletins, giving participatory feedback on past weather forecasts and making recommendations (CGIAR, 2020). The LTACs have supported farmers in improving their farming practices through a continuous process of adaptation to climate change, enabling them to reduce losses and, in certain cases, improve profitability.

The LTACs have a central and a local component. The former generates meteorological information and translates it into targeted agroclimatic information on a regular basis. The latter brings together local stakeholders (for example, representatives of trade unions, producer organizations, community organizations, decentralized government, non-governmental organizations (NGOs), academia, agricultural research institutes and agricultural banking) to discuss agroclimatic forecasts or basic scientific information in a participatory manner and to merge these data with observations and local knowledge. Thanks to this dialogue process, recommendations are generated for specific crops and areas, collated in bulletins and disseminated to the largest possible number of producers.

The first two LTACs were established in 2014 in the departments of Cauca and Córdoba in Colombia. They proved a success and, two years later, the Government included the development of 15 LTACs in its NDCs, with a view to reaching one million producers

CASE STUDY: Local Technical Agroclimatic Committees – Latin America *(continued)*

To comply with the country's NDCs, in 2017, the Ministry of Agriculture and Rural Development of Colombia signed a cooperation agreement with FAO on the implementation of the "Programme for strengthening the agricultural sector in Colombia through the generation and dissemination of agroclimatic information and tools for comprehensive risk management agriculture and livestock" (known as the PFSA). As of May 2019, this had facilitated the expansion of 8 LTACs, covering 10 departments, 36 crops and 631 000 producers.

Based on Colombia's experience, LTACs were recognized across Latin America as an outstanding and replicable solution for the provision of agroclimatic information for producer use. In January 2019, the Ministry of Agriculture and Rural Development, with the support of CIAT and FAO, initiated, under the PFSA programme, a South–South exchange among Latin American countries. This enabled the launch of LTACs in Peru and Paraguay, under the leadership of their respective ministries of agriculture. At the same time, CIAT made progress on replicating the system in Honduras (one LTAC), Nicaragua (two LTACs) and Guatemala (one LTAC). As in Colombia, in Honduras, the LTACs developed into a functioning state policy, thanks to public resources. Reliable local information on climate is now being delivered in a timely and demand-oriented manner through more than 50 LTACs in 11 Latin American countries, strengthening the capacity of more than 350 public and private institutions and, ultimately, increasing the resilience and food security of an estimated 250 000 farmers.

Major challenges

Crucially, while the process does not generally involve complex changes to typical production process, any proposed modifications to traditional practices (for example, sowing dates or the order of rotations) can be viewed as a risk. This is also a challenge that can fuel resistance to change.

Recommendations and investment opportunities

To resolve these issues, the methodology uses two complementary strategies. The first is to ensure that the quality of information remains high and responds specifically to the needs of the farmer (contextualized, timely, etc.). It should also be fit for purpose (so that the farmer understands the recommendations) and come from a reliable source. In other words, it must be the product of a participatory process involving actors in the direct sphere of the producers (their representatives, agricultural extension workers, researchers and others). The second strategy is to strengthen agroclimatic literacy, or increase the knowledge of LTAC participants to optimize their contribution in terms of framing recommendations and becoming agents of multiplicative change. In particular, it seeks to advance the qualifications of extension workers to support producers in implementing recommendations.

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CASE STUDY 5.1.4

THE CLIMANDES COFFEE VALUE CHAIN PROJECT – PERU

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Benefits of using climate services

The CLIMANDES project is an example of climate services delivery to coffee producers, conducted by the national weather services of Peru and Switzerland – the National Meteorology and Hydrology Service of Peru (SENAMHI) and Meteo Swiss – and developed under the Global Framework for Climate Services of the WMO. Some of the key outcomes of this pilot study were to identify user requirements for climate-related information, in order to provide them with effective, user-tailored agrometeorological information. Requested climate services included monthly and seasonal forecasts for precipitation, agricultural drought, floods, frosts and extreme temperatures. Producers requested information on weather-driven biotic factors, such as pests and diseases (i.e., coffee rust), as well as climate services that could warn and trigger action against disease outbreaks.

The average yearly value of climate services in the coffee sector was estimated at USD 21 per hectare and USD 8.2 million for Peru as a whole (Lechthaler and Vinogradova, 2017).

The study concluded that farmers showed significant willingness to pay for enhanced climate services, particularly if the service was effective (immediate impact on the economic product) and had high geographical resolution. Overall, the CLIMANDES project emphasized the importance of strengthening the communication links between climate services producers and users to enable tailored access to climate information relevant to the agriculture sector. This would provide coffee producers in Peru with numerous socio-economic benefits which consequently drive the increase in public investments in the development and maintenance of climate services.

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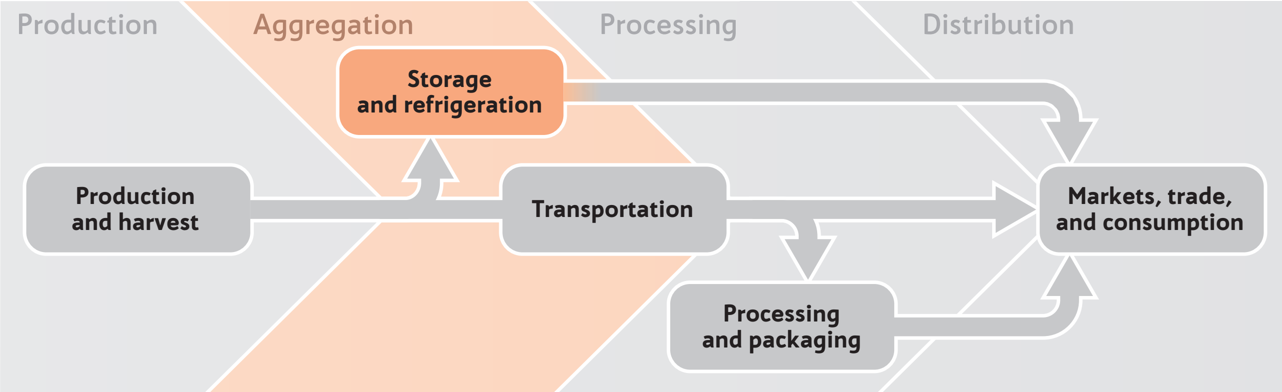
Table 2. Climate risks, services and resilience measures for food harvesting

STAGE OF THE VALUE CHAIN	CLIMATE RISK	CLIMATE SERVICES	CLIMATE-RESILIENT MEASURES
HARVEST	Flooding and drought	Real-time weather forecasts	• Use proper harvest equipment and conduct training on harvesting methods and the best timing to minimize losses caused by falling fruit and food spoilage. • Strengthen early warning systems to prevent and reduce climate impacts on crop yields. • Build climate-proof warehouses that meet sustainable structural requirements and standards.
	Extreme heat	Extreme heat advisory	• Use proper harvest equipment to minimize losses caused by falling fruit and food spoilage. • Cover perishables to preserve them until they reach maturity. • Implement cold chains and ice cooling to remove heat from fresh fruit and vegetables quickly after harvest, reducing food losses • Conduct training on optimum temperature ranges to preserve products, tailored to local production. • Use ICT, such as temperature and humidity sensors, to prevent food loss from heat or humidity.
	Storm/wind	Storm or strong wind advisory	• Use proper harvest equipment and conductv training on harvesting methods and best timing. • Strengthen early warning systems to prepare for storm and wind impacts on crop yields and to minimize losses caused by falling fruit and food spoilage.
	Pests and diseases	Pest and disease alert	• Weather-informed agricultural advisories on when to apply pesticides and fungicides to avoid misuse and losses into the environment. • Practice earlier harvests and conduct training on best harvest timing. • Ensure appropriate work hygiene and sanitation practices. • Use immediate drying techniques, such as sun drying or heated air-drying, to prevent the spread of pests and disease. • Strengthen early warning systems to reduce the impacts on crop yields of pests and rodent attacks, as well as the spread of plant pathogens.
	Relative humidity	Daily relative humidity forecast	• Use immediate drying techniques, such as sun drying, heated air-drying, to reduce food moisture.

Source: FAO (2021e).



5.2 Aggregation: Agrifood storage and refrigeration

Post-harvest loss is a key contributor to food insecurity worldwide. Losses after harvest are exacerbated, in particular, by climate risks such as pests and diseases, high humidity during storage, heavy rains and flooding events. Effective storage, which can last from a few hours to several months, allows suppliers and consumers to optimize the timing of marketing and consumption decisions. Storage provides stability for producers by helping to prevent losses (FAO, IFAD, UNICEF, WFP and WHO, 2019).

5.2.1 Climate risks to agrifood storage and refrigeration

Once harvested and brought to storage, fruits and vegetables, fresh meat, dairy products, eggs and fish are highly perishable and subject to substantial losses due to climate hazards. Changes in temperature, precipitation frequency and intensity can lead to food contamination and exposure to pests and diseases, with negative economic consequences in term of the quantity and quality of food available for sale (FAO, 2020a; FAO, IFAD, UNICEF, WFP and WHO, 2021). Climate hazards can exacerbate post-harvest agrifood product losses, particularly in very hot periods, where the quality of perishable agrifood products – and selling opportunities – can diminish rapidly. The shelf-life of perishable items can decline by as much as a day for every hour's delay between harvesting and storage (IoME, 2014). In Zambia, 35 percent of grain losses and almost 50 percent of vegetable losses occur at the storage stage (Verhage *et al.*, 2018). In North Africa, between 15 percent and 40 percent of potato losses are caused by inadequate storage facilities amid rising temperatures.

Other food losses are caused by a lack of maintenance of storage infrastructure and equipment, something that results in 10-15 percent of perishable food losses in China (Bhattacharya and Fayezi, 2021).

The lack of infrastructure for sustainable storage and refrigeration of agricultural products after harvest contributes to the low adaptive capacity of smallholder farmers, resulting in greater climate risk and food losses at this stage of the agrifood value chain. Adequate post-harvest food storage is fundamental to ensuring shelf-life, so that produce can reach its final market and consumers. This is frequently hindered, however, by a lack of coordination between value chain actors on the best timing and equipment for warehousing and worsened by climate hazards, which increase the need for immediate and effective decision-making.

In the absence of cold-chain facilities and practices, the high moisture content in temperate/warm and humid climates heightens the risk of food damage, as it increases the spread of mould and fruit stem rots. Food products can thus be contaminated by mycotoxins, bacteria and diseases through the proliferation of microorganisms, particularly in aquatic food chains and areas subject to flooding events (see case study 5.2.1) (Misiou and Koutsoumanis, 2021; Mbow *et al.*, 2019).

Extreme weather events could cause faults in the electricity grid resulting in power shortages in cold storage systems. This would particularly damage fresh, perishable goods, and compromise the food's nutritional quality (IPCC, 2022).

A key prerequisite to ensuring a working cold storage and refrigeration facility is consistent and stable access to energy, which remains elusive in many rural communities in developing countries. This has a direct impact on the ability to build cold storage infrastructure in these areas and results in both direct and indirect economic losses for farmers.

Direct economic losses occur as a result of food losses, while indirect economic losses occur due to the fact that, in the absence of proper cold storage, farmers are often forced to sell their produce at low prices soon after harvest to avoid the complete loss of produce. For example, in sub-Saharan Africa, while livestock and dairy production are fundamental food commodities for smallholders' income and well-being, refrigeration facilities are almost non-existent and storage infrastructure is basic and made of unsuitable material, such as wood. This increases the probability of pest infestation and exposure to flooding events and exacerbates the impacts of extreme heat and high relative humidity on biological deterioration, resulting in quantitative and qualitative food losses (FAO, IFAD, UNICEF, WFP and WHO, 2020). This inevitably leads to the deterioration of a substantial amount of produce, generating food losses and the waste of natural resources to produce them. At the same time, developing countries in the Global South possess significant potential to deploy local renewable energy solutions, such as solar panels and biofuel, to power cold storage and milling stations. However, it is imperative to assess which renewable energy technologies are techno-economically effective in a given context, based on the local geographical, environmental and climatic conditions (see case study 5.2.2) (Puri, 2014).

Climate change is projected to exacerbate the spread of pathogens and mycotoxins in food products that require storage and refrigeration facilities, increasing the need for proper cold storage infrastructure and techniques, not only in buildings, but also in food transportation vehicles, to prevent further spoilage and losses (Fanzo *et al.*, 2018). The lack of cold storage facilities is already a leading cause of food loss, directly affecting local food availability (Verhage *et al.*, 2018).

It is estimated that around a quarter of all food losses and waste in developing countries could be avoided by introducing the same level of cold-chain equipment available in developed economies (IoME, 2014). Storage infrastructure in LDCs is also frequently subject to extreme climate events, leaving them submerged or damaged by floods or hurricanes.

According to Adekomaya (2018), shifts in seasonal patterns affect food spoilage and contamination, with higher impact during summers rather than in winters. Lack of knowledge on optimum temperature ranges and techniques for storing and refrigerating increases the existing vulnerability of the storage sector to climate risks. Future changes in average temperatures due to climate change can further exacerbate food losses and ability to store food, undermining food availability in times of extreme weather events (Furuholt and Matotay, 2011).

5.2.2 Climate services for agrifood storage and refrigeration

Suitable temperatures and relative humidity conditions are fundamental to ensuring the preservation of stored perishable food. Producers without adequate storage infrastructure and temperature monitoring systems often need to sell their product right after harvest, leaving them unable to wait for the most profitable selling periods and best market prices. Climate and weather constraints mean they may not be able to properly maintain the quantity and quality of their fresh food product (FAO, IFAD, UNICEF, WFP and WHO, 2021). While most countries understand the need for post-harvest infrastructure, many find it difficult to identify which technologies are suitable.

Many food products require storage temperatures that are far lower than ambient temperatures, so require refrigeration. Freezing and refrigeration are among the most common methods of food preservation and need specific thermal conditions for optimal conservation (Potter and Hotchkiss, 1995). While fresh meat, poultry, dairy and fish need to be stored and refrigerated at an internal temperature of 5 °C, eggs are stored at 7 °C and canned and/or dry food are stored 10 °C to 21 °C.

Consequently, and depending on the type of product, different climatic parameters and their associated heat and moisture risks need to be considered to avoid food deterioration (TIS, 2020).

Lastly, some food products require specific air-exchange conditions, such as ventilation, reduced humidity and temperature of the storage environment. Proper refrigeration is imperative to preserve the quality of food, its nutritional value and microbiological safety, which can be easily undermined at various stages in the cold chain – be it in storage, transportation, market or consumption – thus increasing the risk of bacterial growth (Rovňaníková, 2017).

Cooling and refrigeration technologies and infrastructures require high levels of investment in materials and energy, however, they are still very limited in the most remote areas and LDCs, contributing to lower food quantity and quality and increasing food contamination and health issues (Puri, 2016). While farmers may be able to follow advice on harvest timing and equipment to avoid food loss, access to common storage facilities can be a challenge amid rising temperatures and the consequent spike in demand for cooling structures. A lack of coordination and communication between various food-chain actors can significantly undermine effective agrifood management (Despoudi, 2021).

Climate services that can inform policymakers about future changes in climatic factors and extremes in a given region can enable the planning and deployment of context-specific cold storage and processing infrastructure. Incorporating climate services into the planning phase of post-harvest infrastructure development can future proof the infrastructure against future climatic events. This can increase community resilience to climate change by ensuring the availability of food throughout the year, including in extreme weather events, such as drought (see case study 5.2.3).

Access to mobile phones also helps farmers to communicate with the owners of warehouses in surrounding villages and to negotiate prices and book storage space for their crops.

In addition, during harvest, mobile technologies can support farmers in receiving advice from agricultural extension officers on the most suitable food storage methods (Furuholt and Matotay, 2011).

Information on storage conditions, relative humidity, ultraviolet light (UV) exposure and possible contamination from pollutants or biotic stressors can be provided using Internet of Things sensors that constantly monitor environmental and infrastructural parameters. They relay regular updates to users, with alarms and warnings as to potential risks and safety breaches. This type of advanced technology provides swifter alerts and prevents food damage and loss at crucial stages of the agrifood value chain. The quality and safety of the product can then be certified. However, devices such as these come at a significant financial cost, so there are substantial economic barriers to such technology in developing countries.

More affordable measures are available to ensure climate-smart value chains. Climate and environmental assessments can support the deployment of cost-efficient, safe energy, the construction of infrastructure suited to specific environments, and the allocation of storage slots in shared warehouses, though this will depend on the availability and accuracy of information on the quantity of harvested products to be managed (Furuholt and Matotay, 2011). These could include buildings located in areas not subject to flooding risk, retrofitted to reduce the impact of heavy rains and extreme temperatures, or the promotion of value chain actors' knowledge and management capacity to implement climate-resilient practices and technologies through investments in agricultural and disaster risk insurance and early warning systems (Puri, 2014; FAO, 2021f; IFAD, 2015). Climate services can inform storage and processing managers on the most suitable climatic conditions and options for storing water efficiently or using alternative sources of energy, such as biomass and solar panels, more affordably. The development of climate-smart solutions for LDCs is imperative and urgent to reduce substantial food losses, enhance the efficient use of energy and natural resources and to diversify and increase value chain actors' income and livelihoods through the development of post-harvest value-adding activities.

CASE STUDY 5.2.1

CLIMATE SERVICES FOR COFFEE STORAGE

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Background

After coffee beans are harvested, they need to be dried in the sun or by drying machinery, generally with a view to reaching a moisture content of 12 percent. The amount of time coffee beans can spend in storage before roasting depends on the temperature and humidity of the storage facility. The main climate impacts affecting coffee beans in storage are high relative humidity and weather related pests and diseases attacks, which can cause mould and mycotoxins to spread. Food losses along the coffee value chain occur primarily in storage, largely due to ochratoxin A (OTA) contamination.

Major challenges

Coffee requires proper storage infrastructure and facilities, which tend to be lacking, particularly in LDCs, where changing climatic conditions, such as higher humidity and temperatures, have the greatest impact. In addition, stored coffee is highly susceptible to heavy rainfall and flooding events, which can disrupt or damage infrastructure and re-wet dried coffee beans. The issue is exacerbated by weak facilities that do not allow the safe storage of coffee against climate impacts (for example, where beans are not sufficiently far away from walls or the floor, or where ventilation is poor, causing stagnant humidity). Small-scale producers often use simple structures to store their products, which are often poorly ventilated without fans or humidity controls.

Benefits of using climate services

Measures and technology to ensure the quality of the product and the surrounding environment are, therefore, crucial to avoid food loss and spoilage. Temperature and relative humidity conditions need to be constantly monitored, both within the product and in the broader storage structure, to avoid fungal and bacterial attacks. Climate services at this stage could provide information estimating maximum storage time based on measured climatic parameters. Recommended temperatures for coffee storage vary from as low as 4.4 °C to 10–21 °C. Humidity recommendations range from 50 percent to 70 percent relative humidity right after coffee is harvested, to 12 percent after the drying process (Palacios *et al.*, 2004).

Example of climate services for agrifood storage – Côte d'Ivoire

A study in Côte d'Ivoire – as part of the global coffee project "Enhancement of Coffee Quality Through the Prevention of Mould Formation" – found that moisture levels rose from about 12 percent to almost 18 percent within four months of storage (FAO, 2006). In this case, it was revealed that coffee storage management practices can enable producers to monitor changing temperature and humidity levels in the ambient and stored coffee. In addition, food losses can be reduced by reducing the time of storage and, consequently, its exposure to heavy rains. Effective water drainage systems and climate-proof infrastructure can be built to reduce flooding risks (FAO, 2006). Climate information services can support the development of guidance on storage time based on the local conditions and promote shorter storage times to reduce moisture accumulation.


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CASE STUDY 5.2.2

MARKET POTENTIAL FOR DECENTRALIZED SOLAR COLD STORAGE – RWANDA

Background

Horticulture crops are a key source of domestic food supply and export revenue in Rwanda. In 2018, the country produced 5.9 million tonnes of horticultural products. The 2018 national agriculture policy aims to export 46 314 tonnes of those crops by 2024.

Major challenges

The horticultural value chain is rudimentary and dominated by small-scale producers and traders. Fruit and vegetables are prone to biological degradation and require cold storage so they do not rot. Most fruits and vegetables are sold and consumed fresh, and losses of horticultural crops are high. Around 56 percent of all tomatoes produced in Rwanda are lost, for example (USAID, 2018b). The lack of cold storage is a major impediment to loss reduction, but a major challenge in deploying cold storage to rural parts of the country is the lack of reliable electricity access. In Rwanda, only 23 percent of the rural population had access to electricity as of 2018 (World Bank Data, 2021).

Benefits of using climate services to identify suitable renewable energy solutions

The use of climate services – climate projections, seasonal forecasts, information and advisory services – on the availability of natural resources, including water, land and renewable energy sources, is key to identifying the most suitable and profitable long-term infrastructural interventions for powering food storage and refrigeration. This would help make the agrifood value chain both climate-resilient and sustainable and bolster the overall energy system on which so many depend for their livelihoods.

In this case, local assessments of the feasibility of renewable energy deployment, based on geographical characteristics and socioeconomic conditions at national and local level, enabled researchers to identify solar energy as the most effective renewable solution for developing cold storage in the area. Indeed, Rwanda has substantial potential to use solar-based energy, due to the country's location two degrees below the equator. Both geographical and political enabling factors are making a positive contribution to the development of large-scale solar-powered electricity at national level, along with the promotion of sustainable and resilient agrifood value chains (Puri, Rincon, and Maltsoglou, 2021).

Recommendations and investment opportunities

Decentralized solar-powered cold storage is a solution. It can be deployed in rural areas that are not connected to the grid. It provides rural farmers with much-needed cold storage capacity, while minimizing GHG emissions. A recent assessment conducted by FAO in Rwanda estimated the market potential of various solar energy technologies across all of Rwanda's food value chains, including the market potential for deploying solar cold storage across the horticulture value chain. The assessment focused on the Government of Rwanda's export target of 46 314 tonnes of horticultural products by 2024.

The results showed that if the target were met, the market potential for solar cold storage could be as high as USD 6 105 000, with a 75 percent adoption rate of solar cold storage for horticultural products for export (Puri, Rincon, and Maltsoglou, 2021). The deployment of solar cold storage could solve the dual challenge of remedying the lack of cold storage capacity while at the same time limiting GHG emissions rural cold storage expansion.

CASE STUDY 5.2.3

CLIMATE-INFORMED ADVISORY SERVICES FOR FOOD COLD CHAINS

Background and major challenges

India is a key food-producing country and global exporter, although a substantial portion of the food it produces gets lost along the agrifood value chain, particularly due to a lack of refrigeration facilities (FAO, 2018). According to Koegelenberg (2021), the main barriers to accessing cold chains are the lack of investments in post-harvest infrastructure, electricity and technology. All this is exacerbated by limited producer funds and technical capacity to implement cold-chain practices and awareness of the benefits of purchasing high-cost equipment.

Example of climate services for food cold chains – India

The Basel Agency for Sustainable Energy and the Swiss Federal Laboratories for Materials Science and Technology joined forces to create Your Virtual Cold-Chain Assistant, a mobile app that provides smallholder farmers in India with key information, advice on and access to cold-chain practices. The app has made a substantial contribution to cutting food losses and enhancing market opportunities.

Benefits of using climate services

Primary data include climate and weather information in selected geographical areas, yield levels, sensory data on temperature and humidity conditions for cold storage, and estimates of final product expiry for monitoring food quality and shelf-life, all combined with market pricing information. Farmers are provided with cold-chain facilities and maintenance service contracts, as well as consultations on the optimum storage conditions to reduce food loss and resource waste.

This assistance and tailored advice enables farmers to make climate-smart decisions, from production to storage and market practices, and will help reduce poverty by enhancing value-adding opportunities within food cold-chain practices. It will also significantly decrease food losses in India (Koegelenberg, 2021).

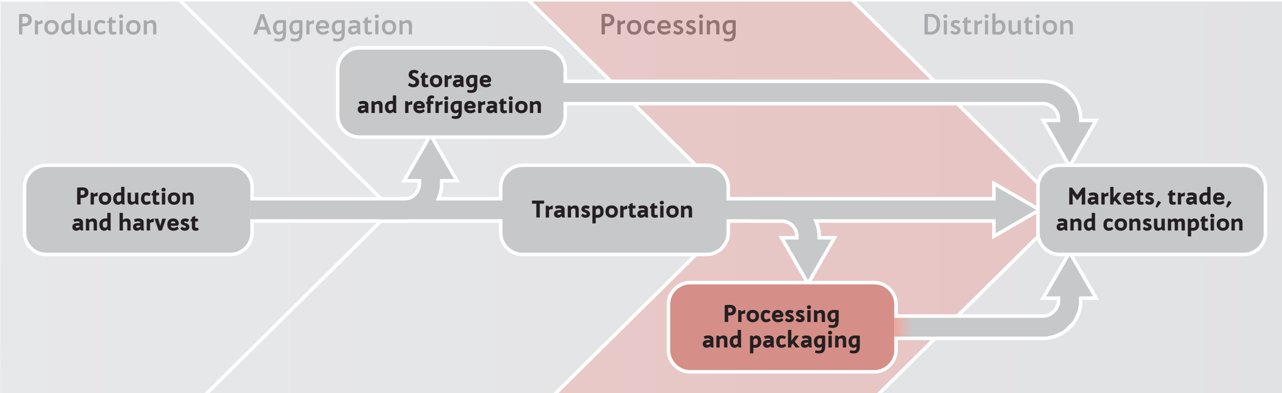
Table 3. Climate risks, services and resilience measures for food storage and refrigeration

<table>
<tr><th>STAGE OF THE VALUE CHAIN</th><th>CLIMATE RISK</th><th>CLIMATE SERVICES</th><th>CLIMATE-RESILIENT MEASURES</th></tr>
<tr><td rowspan="3">STORAGE</td><td>Extreme heat</td><td>Extreme heat advisory; seasonal climate advisory</td><td>• Strengthen early warning systems to prepare for and reduce food spoilage from extreme heat.
• Use cold rooms to prevent biological degradation.
• Install efficient energy infrastructures to support temperature-controlled storage and contribute to offsetting GHG emissions from fossil fuel-based sources of energy.
• Develop renewable energy technologies to reduce reliance on fossil fuels, offering mitigation benefits and increasing resilience.
• Use appropriate preserving techniques (such as drying, chilling and freezing, heating, salting, pickling, preserving in oil/honey/alcohol, smoking, irradiation and high-pressure processing).
• Use ICTs, such as temperature and humidity sensors, to prevent food losses from heat.
• Reduce storage time to reduce risks of food deterioration.</td></tr>
<tr><td>Flooding</td><td>Flood advisory</td><td>• Strengthen early warning systems to prevent flooding impacts on storage infrastructure and food products.
• Store on wood pallets, maintain distance to walls, and put in place hygiene practices to counter humidity and prevent the spread of mould.
• Build climate-proof warehouses that meet sustainable structural requirements and standards (such as appropriate location with respect to floodplains, appropriate dimensions, building type, slope of the roof, roof ledge and solid building foundations).
• Deploy rainwater collection systems, such as rainwater tanks, pumps and purifiers; use drying hangers and storm drain maintenance.</td></tr>
<tr><td>Storm/strong wind</td><td>Storm or wind advisory</td><td>• Strengthen early warning systems to prevent storm and wind impacts on storage infrastructure and food losses.
• Build climate-proof infrastructure such as an appropriate location, appropriate dimensions, brick and concrete buildings rather than wood infrastructure.</td></tr>
</table>

Table 3. *(Continued)*

STAGE OF THE VALUE CHAIN	CLIMATE RISK	CLIMATE SERVICES	CLIMATE-RESILIENT MEASURES
STORAGE	Pests and diseases	Pests and diseases alert	• Strengthen early warning systems to prevent impacts on food products from pests and rodent attacks, as well as the spread of mycotoxins. • Store in jute bags and wool blankets to let the air circulate, or hermetic bags to decrease food contamination and the spread of mould. • Increase food quality controls to comply with food safety standards. • Ensure appropriate work hygiene and sanitation practices.
	Relative humidity	Daily relative humidity forecast and monitoring	• Improve storage conditions, for example, with fan systems for ventilation in temperate climates or reduced moisture and temperature in warm, humid environments. • Use dehumidifiers, roof ventilators and wall air vents. • Implement vapour heat treatment/hot water treatment; use crates to conserve food products. • Use ICTs, such as temperature and humidity sensors.
REFRIGERATION	Extreme heat and relative humidity	Climatic parameters for appropriate temperature and moisture levels	• Build cold-chain infrastructures and technologies, such as ventilation, pre-cooling and air-conditioning. • Deploy accessible, efficient, affordable and renewable energy technologies, such as biogas production from the anaerobic digestion of organic waste, including spoiled food, to reduce food waste and GHG emissions. • Build sustainable energy infrastructure to support temperature-controlled storage.

Source: FAO (2021e).



5.3 Processing: Agrifood processing and packaging

Food processing implies the use of different scientific and technological practices to increase food preservation by delaying the process of food ripening and deterioration, with predicted and controlled effects on the nutritional quality of food products. Nutritious properties can be improved by tailored processing techniques, such as drying, fermentation, germination, smoking and roasting, which often do not require substantial technological or energy resources (Table 1; FAO, IFAD, UNICEF, WFP and WHO, 2020). At the same time, food processing can cause a reduction in food organoleptic and nutritional properties compared with fresh products (Guiné, 2018). For example, while UV light exposure is useful in treating fungal toxins, it can also impact the composition of food through protein digestion, vitamin loss, antioxidant damage, lipid oxidation and changes in colour, substance, flavour and odour (Csapò *et al.*, 2019). Food processing can also involve the transformation of raw foods into other food products and by-products, increasing opportunities for producers to sell different varieties of the same agrifood and giving consumers greater choice (FAO, 2004).

Ineffective traditional techniques for processing and packing products and the absence of adequate infrastructure result in high food and value losses, as the high moisture content of temperate/warm and humid climates damages food products by speeding the spread of mould (Puri, 2014). Many disruptive events in LDCs also occur due to processing and packaging infrastructure being submerged or damaged by extreme flood events or hurricanes. In addition, frequent transport of produce to countries other than the country of origin for processing and trading makes it difficult to track the movements of products. This also increases the opportunity to deliver climate services tailored to specific users in the intermediate stages of the value chain.

5.3.1. Climate risks to agrifood processing and packaging

In many cases, processing and post-harvest treatments rely on weather conditions when minimal infrastructure is in place (Puri, 2014). There are advantages and disadvantages to each processing method, all dependent on specific climatic conditions, such as the duration of the drying process, the loss of nutritional properties, a decrease in storage life when air moisture levels are too high at the time of packaging, and the arrival of insects and microorganisms if temperatures and relative humidity are high.

The packaging stage of the agrifood value chain is less affected by weather hazards compared to other stages of the agrifood value chain. It is more vulnerable to indoor ambient conditions, as well as the technologies and equipment used to pack agrifood products. This will also have implications for the preservation of product quality on long journeys (see case study 5.3.1) (Piacentini and Mujumdar, 2009; Xiao and Mujumdar, 2019; Orge *et al.*, 2020).

In many developing countries, storage, processing and packaging infrastructure and practices are often limited and underdeveloped, reliant on conventional and unsustainable energy, the inefficient use of natural resources and lack of information that could present opportunities to reduce food losses by practising harvest and post-harvest techniques or reduce food contamination, spoilage, and losses through food processing (Puri, 2014). Climatic constraints are more impactful in developing countries, which are highly vulnerable to climate change due to geographical and environmental characteristics that leave them significantly exposed to climatic impacts. Another major challenge in developing countries is the lack of appropriate and reliable infrastructure and facilities, energy services and technologies to buffer shocks to agricultural producers and actors. The lack of infrastructure for processing foods immediately after harvest significantly reduces the adaptive capacity of farmers and increases the likelihood of losses (Rezaei and Liu, 2017).

The processing and packaging phase is also highly susceptible to downstream activities and associated climate impacts along the entire value chain (see case studies 5.3.2 and 5.3.3). For example, climate variability in Rwanda has negative impacts on the tea and coffee processing industry and, therefore, on business opportunities. Longer dry seasons damage tea bushes, delay the flowering of coffee plants and the ripening of coffee beans, reducing the quantity and quality of products delivered to storage and processing facilities. At the same time, shorter harvesting periods condense the availability of raw tea and coffee products into a shorter period, overloading processing facilities, resulting in food spoilage and economic losses. Lastly, prolonged droughts, extreme temperatures and flooding events impact the availability and cost of energy systems to dry tea in what is an energy-intensive process (Climate Expert, 2017).

A common method for processing and preserving foods is drying. The traditional and most affordable techniques in the fisheries, grain, fruit, vegetable and meat production sectors rely on weather conditions for the drying process, including solar and sun drying. Sun-dried products are exposed to direct solar radiation and the wind to extract water and moisture. Solar-dried products, in contrast, are dried out in an enclosed space, such as a solar greenhouse, and are directly in contact with the air, but not sunlight. There are disadvantages and risks associated with the sun-drying technique: the product is exposed to changing weather conditions and relative humidity, as well as contamination sources, such as rodents, insects and birds, which can compromise quality and, indeed, the entire drying process (Guiné, 2018). Consequently, more advanced indoor techniques have been developed, including "hot air drying, spray drying, lyophilization, infrared, microwave or radio frequency drying, osmotic dehydration or combined processes" (Guiné, 2018, p.93).

The success of fish-drying techniques, as well as the well-being of communities and economies involved in fish processing and trading, is subject to changes in temperature, rainfall patterns and cloudy weather, as well as extreme weather events, such as storms, heavy rains and flooding. Where there are suboptimal conditions, the cost of processing fish may increase, with direct consequences for fishers' profits, product quality and market availability, as well as consumers' purchasing capacity and nutritional intake (Monirul Islam *et al.*, 2014; Mitu *et al.*, 2021; FAO, 2021f).

Cereals also require drying to prevent spoilage. Due to a lack of storage, drying infrastructure and technology in developing countries, grains can be left in the field until they mature to dry under the sun. This can mean greater exposure to pests and rodent infestations, extreme weather events such as heavy rains, leading to spoilage and quantitative losses from mould and/or aflatoxin contamination during the drying process, compromising the entire agrifood value chain (Puri, 2016).

5.3.2 Climate services for agrifood processing and packaging

Where crops are sun-dried, climate services can offer temperature, relative humidity and precipitation forecasts, on a daily to monthly basis, tailored to specific contexts and crops. This can reduce food loss and product damage caused by unfavourable or extreme weather events and pest outbreaks, even in areas where storage infrastructure is not available.

Climate services would, thus, improve farmers' capacity to choose the most appropriate timing and drying methods for the climate and weather in question. Indeed, while sun drying is suited to warm and dry climates, in areas where the weather is more unpredictable or changeable, or where there is a humid climate or cold temperatures, other methods must be identified. Solar drying is an option, though it requires the development of additional infrastructure and energy technologies, as well as environmental and socioeconomic assessments to identify the suitability of renewable energy deployment to support sustainable value chain interventions (Puri, 2014).

Advisory services on how and when to dry products based on weather conditions should also be tailored to each crop. For example, a cereal drying process needs to be monitored, so that the crop can be harvested when fully dried. Legumes, in contrast, need to be stored and dried on a mat rather than in the field. Tubers must be dried and processed directly after harvesting to prolong their storage period (Njuguna *et al.*, 2021).

Information and advice on optimal humidity conditions, UV light exposure, temperature and airflow are examples of climate services that are very useful to the food processing and packaging stages. Climate services can also include educational services to raise awareness of the benefits and risks associated with food processing and packaging practices. They can further incorporate technical training on the most effective storage, refrigeration, processing and packaging methods and technologies to preserve nutritional qualities, prevent food losses and overall damage to infrastructure due to extreme weather events, pests and diseases (Fanzo *et al.*, 2018). In addition, capacity-building campaigns on methods and opportunities to process perishable foods will add value to products and encourage producers to engage in new activities that create by-products, thereby also increasing market opportunities and producers' income (FAO, 2018).

Lastly, mid- to long-term climate projections support the development of climate-proof infrastructure and facilities to enhance value chain resilience in the future.

CASE STUDY 5.3.1

DEVELOPMENT OF INNOVATIVE FOOD PACKAGING – ITALY

©Pexels/Cindy Amimer

Background

To prevent early food spoilage and ensure the successful preservation of food products without affecting food quality and safety, packaging is crucial. The determining factors in food loss and waste are primarily oxygen and bacteria, which promote the development of odours and, most importantly, the loss of nutrients (FAO, IFAD, UNICEF, WFP and WHO, 2019).

Example of innovative food packaging with antioxidant activity

Knowing that the interaction between food and packaging is as important as the interaction between packaging and the environment, the University of Camerino and Italian coatings manufacturer Elettrogalvanica Settimi srl recently applied for a patent on a new type of food packaging, a functionalized polyethylene terephthalate (PET) with an antioxidant activity (Alessandroni *et al.*, 2022). The invention overcomes the drawbacks of antioxidant film production by treating the surface of the material, making it easily recyclable and particularly suitable for use in food packaging.

Example of active food packaging against food waste

Food waste is a big problem globally. According to FAO data, about 14 percent of all food is lost and wasted (FAO, IFAD, UNICEF, WFP and WHO, 2020). Reducing that percentage would make the global agrifood system far more resilient. To this end, another joint venture, this time between the University of Camerino and the packaging company EsseO4, have patented innovative packaging that can extend the shelf-life of fresh food (meat, fish, cheese, etc.) by up to 50 percent. The patent is for packaging with a natural active ingredient (rosemary extract, which can slow the proliferation of bacteria responsible for the development of bad odours and loss of nutrients), supported by a recyclable film. The company is preparing to market this active packaging, and has received positive feedback from customers (Sirocchi *et al.*, 2013; Sirocchi *et al.*, 2017).

CASE STUDY 5.3.2

CLIMATE RISK TO THE DAIRY VALUE CHAIN – KENYA AND UGANDA

Background

A study of the dairy value chain in Kenya (Mwongera *et al.*, 2019) identifies the extent to which climate hazards impact each step of the livestock value chain, drawing on stakeholder participation and discussions to glean knowledge on how climate impacts are perceived. Drought, extreme temperatures, heavy rains and flooding have consistently affected those involved in livestock production, processing and transportation. There is strong awareness of climate impacts due to the underlying socioeconomic vulnerability (poverty) of value chain actors, amid weak infrastructure and limited services and regulation, which has forced producers to cope with climate hazards using inadequate adaptation practices, such as pastoral migration. Climate-resilient practices along the livestock value chain, therefore, have great potential to reduce climate effects on dairy processing. These include strengthening research and development of innovative and energy-efficient technologies for cooling animal housing, improving animal nutrition and the integration of heat-tolerant breeds.

Example of drought and flooding in Kenya and Uganda

In Kenya, drought is a major driver of dairy value chain losses, from input supply and breeding to higher feed costs and lower quantity and quality of fodder. At the production level, drought significantly affects dairy cattle, which suffer in hot and dry conditions, reducing their resistance to pests and diseases. The storage and processing stages are also affected by drought, which causes milk spoilage and increases the costs of collection and bulking. All of this has a market impact, due to the reduced quantity and quality of the final product (Mwongera *et al.*, 2019). Drought has historically also had a negative impact on the livestock value chain in Uganda, causing water and forage shortages in the production stages, and reducing market availability (Carabine *et al.*, 2017).

Flooding events are another major driver of food losses along the dairy value chain, from input supply to processing, transportation, market and consumption (Mwongera *et al.*, 2019). Heavy rainfall causes disruption to roads, storage and market infrastructure, increasing the cost of inputs, milk production and collection, and impeding access to storage, processing and market facilities. The effects are, therefore, very much felt by producers, processing and transportation actors, as well as final consumers. Climate change will continue to negatively impact livestock and dairy value chains in Kenya and Uganda unless the effects of the changing climate are addressed properly. However, there may be new opportunities for value chain actors and stakeholders to develop new products and services to support the transition to sustainable, inclusive and resilient value chains. This, in turn, will boost social well-being and economic growth in the form of domestic and international market opportunities, job creation and stronger national income (Carabine *et al.*, 2017).

Policy recommendations and investment opportunities

The research study conducted by the Overseas Development Institute, Makerere University and the Karamoja Development Forum (Carabine *et al.*, 2017), makes recommendations on strengthening climate-resilient livestock value chains in Uganda. These range from the implementation of market-based instruments and financial services to infrastructural interventions, technical deployments and market advisory based on climate and weather information, which would benefit actors along the value chain, particularly pastoralists, who are frequently the most vulnerable. Overall, the study says that integrating the private sector – including those in processing and transport – with the institutional sector is key to strengthening market opportunities (Carabine *et al.*, 2017).

CASE STUDY 5.3.3

RED PEPPER PROCESSING – NORTH MACEDONIA

Background

The Rural Development Network of North Macedonia under the Flexible Multi-Partner Mechanism project "Sustainable productivity in agriculture – in the context of climate-smart agriculture (CSA) and agroecology" (FAO, 2021g) prepared a report assessing the need for climate impact services in the red pepper value chain. The fruit and vegetable processing and preserving industry is a key sector in North Macedonia. The Rural Development Network surveyed 43 smallholder companies – the most common type of enterprise, due to the seasonality of fruit and vegetable production and employment opportunities – working in vegetable and fruit processing, including food preservation by canning, drying and freezing.

Lessons learned and investment opportunities

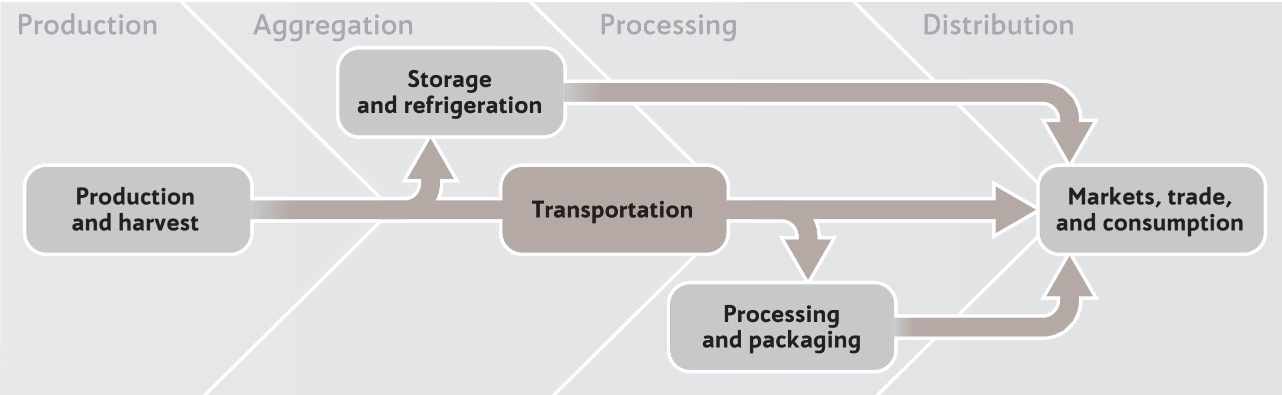
Processing enterprises observed that climate and weather hazards were more of an issue for input suppliers and transportation actors than for other actors along the value chain. This is largely due to the fact that climate services in the red pepper value chain are mainly provided at the production stage by the National Hydrometeorology Directorate of the Ministry of Agriculture, Forestry and Water Economy. These are then used in making weather-informed decisions on inputs (such as seeds and fertilizers). Climate services are mostly provided through television and radio, so are not specific to the needs of different stakeholders along the agrifood value chain, particularly processors, as they mainly concern information on temperature and precipitation.

These basic climate services are not supplemented with tailored advisory services on climate adaptation or mitigation opportunities. There is, therefore, a gap in the research on and empirical application of bespoke climate services to deal with specific hazards and reduce vulnerability along the entire agrifood value chain. This translates into an opportunity for future research into methods of participatory stakeholder engagement, as well as the development of tools and tailored interventions to benefit red pepper processing actors.

Table 4. Climate risks, services and resilience measures for food processing and packaging

STAGE OF THE VALUE CHAIN	CLIMATE RISK	CLIMATE SERVICES	CLIMATE-RESILIENT MEASURES
PROCESSING AND PACKAGING	UV light	UV index forecast	• Use UV lamps to preserve food quality and safety. • Switch from sun-drying to solar-drying techniques (such as using solar cabinet dryer technologies).
	Relative humidity	Daily relative humidity forecast and monitoring	• Use mechanical dryer techniques, such as heated air-drying. • Provide advice on modern processing techniques, such as optimum thermal processing conditions, the creation of by-products and the use of food dehydrators. • Use large or small packaging, containers, aseptic packaging, packaging that is impermeable to moisture and oxygen bags. • Implement modified atmosphere packaging technology and pulsed electric field techniques. • Dry and package food right after harvesting to prevent food spoilage. • Install sustainable, safe, energy-efficient machines (for instance, for milling, drying and grating) to increase productivity, save time and boost the cost effectiveness of labour and operations. • Use ICTs, such as temperature and humidity sensor systems.

Source: FAO (2021e).



5.4 Distribution: Agrifood transportation

Agrifood transportation is a key step in the agrifood value chain, aimed at ensuring the safe delivery of agrifood products to market and for final consumption. It is a wide sector encompassing multiple fields, including infrastructure development, logistics and international driving regulations and standards. Agrifood transport can occur at more than one stage of the value chain, for example, to farms and other facilities, to storage and processing facilities, and to national and international markets. Different modes of transport are also used in the agrifood sector, from bicycles to trucks, ships and airplanes, depending on the food commodity being transported, the state of the socioeconomic system, infrastructural development and the sophistication of markets and other agrifood value chain facilities and services, both in and across countries. These also involve different timelines, so require deadlines and standards to ensure that the quality and quantity of the product are not undermined during transportation (FAO, 2021f).

Numerous factors affect food losses at the transport stage, including damage to vehicles, road accidents, a lack of cold storage technologies in vehicles and disruptions to road, port, rail and air infrastructure. Climate and weather hazards are key stressors in all of these areas.

5.4.1 Climate risks to agrifood transportation

Climate hazards, such as extreme temperatures, heavy rain, storms and rising sea levels, combined with geophysical hazards, such as landslides, all pose fundamental challenges to agrifood transport, impeding passage by roads, rail, air or sea in the short term and substantially damaging road infrastructure, particularly in the long term (Fanzo *et al.*, 2018; IPCC, 2022). The impacts differ according to the mode of transport. In the case of road transport, accidents frequently occur due to the effects of weather on road safety and driving conditions. In the rail sector, extreme weather and flooding events can stymie operating efficiency, damage rail and station infrastructure and, thus, the safe movement of freight and people. When it comes to sea transport, weather can impact the stability and time of the journey, the safety of the loads and vessels, fuel supply and fuel efficiency (Pilli-Sihvola *et al.*, 2016).

Consequently, the effects of extreme weather on the broader transport sector have consequences for agrifood transport, requiring appropriate time and journey management to minimize food spoilage and waste. Moreover, extreme weather events, combined with weak road and logistics infrastructure, can hinder access to farms, warehouses and markets, with further effects on agricultural productivity and food security for the most vulnerable.

Extreme heat during transport affects the quantity and quality of delivered agrifood products, particularly if they are transported right after being harvested, without first being processed and packed, or transported in vehicles that lack appropriate temperature and humidity controls. Heavy rain, strong winds and low visibility due to fog, dust or snow are perilous to drivers, particularly when road infrastructure and vehicles are precarious, and driver facilities, such as parking and rest areas, are not available.

5.4.2 Climate services for agrifood transportation

The homogenization of climate services for the transport of food commodities remains a challenge. Each mode of transportation (air, sea and land) has a different way of dealing with the consequences of high-impact weather events on the safety, efficiency and continuity of their operations (WMO, 2016). The primary areas availing of climate services in the transport sector include inland marine transport, road transport, rail transport and ports and harbours (McGuirk *et al.*, 2009). However, while climate services are effectively embedded in the transportation sector to reduce road and marine incidents resulting from extreme weather events and natural disasters (see case study 5.4.1), the use of bespoke climate services for the transport of perishable food is scantly analyzed in the body of available literature.

Overall, investments in climate services, climate-resilient infrastructure and agrifood transport practices are not properly mainstreamed into agrifood value chain activities, particularly in LDCs, where the cost of such interventions is high. However, these activities provide substantial economic returns in terms of increased income for agrifood value chain actors and healthier diets for local communities and international consumers (FAO, IFAD, UNICEF, WFP and WHO, 2020). Transportation is one of the most important steps in the agrifood value chain; markets and retailers and, therefore, consumers depend on it.

Climate and weather information services, including weather forecasts and early warning systems, using appropriate information and communication tools, have the potential to improve agrifood transportation logistics by providing detailed daily or hourly information to drivers and food transport operators on weather conditions for road transport or navigation services (see case study 5.4.2).

It is, therefore, crucial to emphasize the potential of climate and weather information to enhance transport operators' decision-making capacity to adapt to climate and weather hazards.

However, information on the most effective routes and timely updates on appropriate driving conditions are not always readily available, particularly in LDCs.

Climate-resilient practices tailored to agrifood transport include managing transport logistics from farm to storage and deciding on the quantity and timing of deliveries to hauliers and traders according to the availability and price of storage, so as to take advantage of the best market deals (FAO, 2021f). Such interventions are particularly relevant at harvest time and for selling to market, so require consistent, useful information and communication strategies and technologies for all actors. For example, farmers can organize transport for their products over the Internet using mobile phones or connect with transport services to deal with any road accidents. This reduces the risks brought about by weather extremes that directly affect road infrastructure and drivers, substantially reducing the time spent, costs involved and potential for food and economic losses (Furuholt and Matotay, 2011).

Practices should be combined with rapid interventions, such early warning systems, to reduce short-term impacts, or strengthening communication with transport actors to ensure the consistent provision of weather information throughout a journey. Such interventions make agrifood transportation more efficient and reduce the potential costs involved in recovering from disruptions caused by extreme weather events (FAO, IFAD, UNICEF, WFP and WHO, 2020). It is crucial that climate experts recognize the need to tailor climate information and related advisory services to transportation stakeholders' needs and level of understanding of climate risks. Clear communication is key to reaching the actors involved (Quinn *et al.*, 2018). The diverse modes of transport mean a different approach is needed to that for other actors in the agrifood value chain that deal with agrifood products more closely.

5.4.3. Climate services for policy and interventions on roads and other infrastructure

As the transportation sector is highly vulnerable to climate change, climate adaptation measures should be designed to deliver long-term infrastructural interventions on roads, in vehicles and at ports that will reduce exposure in a lasting way, particularly in areas limited by social, economic and environmental constraints. Measures could address poor-quality road infrastructure and vehicles, ineffective fuel and vehicle technologies for storing perishable food, and a lack of public and private investment in infrastructure interventions, roadside assistance and insurance schemes (see case study 5.4.3).

The installation of cold storage technologies inside vehicles is an intervention that could increase the quantity and maintain the quality of post-harvest food in transport, protecting it against extreme temperatures and humid conditions. This should be combined with the consistent management and maintenance of road, rail and navigation infrastructure, as well as transport logistics. Transport actors are more akin to external stakeholders in the infrastructural, logistics and energy sectors. Therefore, information on the risks affecting road infrastructure and vehicles must be clear and tailored to users' perceptions of those risks, which may differ between developed and developing countries, depending on the infrastructure and means of communication available. This can be achieved through stakeholder consultations, enhancing communication, sharing information between climate experts and transportation actors, and upscaling decision-making capacity across the entire transportation network.

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CASE STUDY 5.4.1

DEVELOPMENT OF WEATHER SERVICES FOR THE TRANSPORTATION SECTOR – EUROPE

Background

Pilli-Sihvola et al. (2016) demonstrate the effectiveness of weather services development to reduce sensitivity and vulnerability to weather and climate changes in the transportation sector. The study is based on a theoretical framework for climate change adaptation and the evaluation of weather and climate services. It conducts an analysis of the weather service chain to understand drivers' decision-making processes before and during a trip in challenging weather conditions, as well as to identify potential tailored measures and information tools to improve users' access to and use of hydro-meteorological information. The work focuses on road transportation, the most exposed transport sector in terms of accidents, losses and costs caused by extreme weather events. It is also one of the sectors in which the use of climate and weather information services could most increase the adaptive capacity of actors to climate change.

To obtain a representative sample of the actors involved and a comprehensive overview of the development and use of climate services in the transport sector, 12 interviews were conducted with a variety of road transporters, stakeholders and service providers, such as European Union hydrometeorological services, experts on weather observation technologies and a road maintenance company.

Policy recommendations and investment opportunities

The results of the consultation reveal the need for greater cooperation between actors in developing tailored climate information, infrastructure and technologies that reach public and private stakeholders and improving climate-smart transportation systems. The co-production of services by public institutions could make a difference here, particularly collaborations between national hydrometeorological services and the private sector, such as the automotive industry, infrastructure engineering companies and weather information services, delivered through appropriate channels, such as radio, smartphone apps and satellite navigation devices.

The research outcomes show the importance of developing and implementing climate services, weather forecasts and early warning systems for the transport sector and setting up tailored information and communication channels to reduce its vulnerability to short-term weather variability and extreme weather and long-term climate change risks

CASE STUDY 5.4.2

THE FOOD MODERNIZATION ACT – UNITED STATES OF AMERICA

Background

The United States Food and Drug Administration established the Food Safety Modernization Act in 2011 (U.S. Food and Drug Administration, 2017) to monitor the safe transport of food products between companies in the food industry. Companies need to meet numerous standards and requirements and put in place surveillance systems and plans to ensure food quality and prevent the spread of disease.

Recommendations and investment opportunities

Food-industry control plans must be preventative, to detect potential physical, biological and chemical hazards to food safety. They must be tailored to specific steps along the supply chain and seek to identify those points in the chain most vulnerable to external impacts (such as storage, packaging and transport, particularly in the process of transferring food into vehicles and during rail transport, due to an overall absence of control systems). They must also have strategies to prevent and reduce risks, including soil, temperature and moisture monitoring systems, packaging and hygiene standards, and appropriate vehicle-based storage to prevent food cross-contamination.

Adequate transportation vehicles and equipment are vital to ensuring food safety. Motor vehicles or railcars are identified as the most suitable vehicles, while transportation equipment, such as bulk or non-bulk containers, must meet specific hygienic requirements to prevent food from being contaminated and affected by pests and diseases.

Inspections, training on sanitary transportation practices and contamination risks, and coordination between actors, especially transport actors, must be ensured throughout the value chain.

Temperature monitoring is crucial throughout the cold value chain, particularly for the transport of highly perishable food. This requires the use of tools for temperature data collection and information sharing through tailored communication instruments, such as smartphone apps, to transport actors, as well as food producers, warehouses, traders, suppliers, markets, supermarkets and restaurants.

CASE STUDY 5.4.3

THE RESEARCH FOR COMMUNITY ACCESS PARTNERSHIP (RECAP)

Background and major challenges

Climate change exacerbates rural communities' infrastructural, social and economic challenges in accessing road networks, markets and services, particularly in remote areas of Africa and Asia. In Africa, disconnected roads are a fundamental barrier, with fewer than 40 percent of rural communities located within two km of a well-maintained road. Extreme weather events, such as storms, flooding and drought, accelerate road deterioration, hampering people's access to the main villages and city centres for the exchange of agrifood products and services. While agricultural development is being increasingly promoted among small-scale farmers and communities worldwide, however, scant attention is paid to improving road networks and equipment for transporting agrifood inputs and products to storage warehouses or markets in these areas. Limited investment is being channelled into rural road development, raising the cost of acquiring agricultural inputs and transporting/selling harvested products.

Little attention is paid, too, to promoting the use of suitable vehicles – trucks rather than motorcycles, for instance – which are even more vulnerable to rough road surfaces and unpredictable weather extremes.

This inevitably leads to food loss and waste across the value chain, with detrimental consequences for food security and the socioeconomic sustainability of rural communities (ReCAP PMU and Scriptoria, 2020).

Example of climate adaptation measures for rural transportation

ReCAP, funded by the Government of the United Kingdom of Great Britain and Northern Ireland, supports infrastructural and non-infrastructural interventions in developing countries to increase rural transport efficiency and accessibility. The partnership aims to improve the access of rural communities in Africa and Asia to economic opportunities and public goods and services by improving road infrastructure and transport services.

Projects also include short-term and long-term climate adaptation measures, the former on developing hi-tech road solutions, such as climate risk assessments, the implementation of web-based systems, monitoring and advice for drivers on road conditions. ReCAP conducted a study to identify high-tech solutions for road-condition and resource assessments to combat weather extremes in Ghana, Kenya, the United Republic of Tanzania, Uganda and Zambia, to increase accessibility to remote areas, tools and operational practices (ReCAP PMU and Scriptoria, 2020).

CASE STUDY: The research for community access partnership (RECAP) *(continued)*

Its Climate Adaptation Handbook and guidelines on Change Management; Climate Risk and Vulnerability Assessment; Engineering Adaptation; and Visual Assessment provide guidance and recommendations on strengthening adaptation to climate change and weather extremes by implementing climate-resilient practices, technologies and infrastructure in the transportation sector. This comprehensive framework is a useful guide for decision-makers to enhance their adaptive capacity and develop climate-proof infrastructure in the transportation sector (ReCAP PMU and Scriptoria, 2020).

Benefits of improving road transportation

ReCAP conducted a cost-benefit analysis of improvements to agrifood producers' access to farms and markets in the United Republic of Tanzania and Kenya. Key investment opportunities to reduce transport costs and increase farmers' income targeted severely damaged roads that were accessible only during the dry season and by four-wheel drive. The road networks needed to be accessible regardless of seasonal factors and potential weather events and be built as close as possible to farming centres and rural villages. National and local governments, in collaboration with rural communities, play a key role in ensuring sufficient investment in and subsidization of resources and technical services for the reconstruction and maintenance of climate-proof rural roads (ReCAP PMU and Scriptoria, 2020).

Example of climate risk assessment – Bangladesh

Marine coastal areas in countries such as Bangladesh are particularly exposed to climate hazards, such as flooding, that affect the viability of road networks, as well as physical and chemical infrastructure erosion caused by increased CO_2 concentrations and seawater salinity. ReCAP, together with the local government engineering department, undertook research in Bangladesh with a view to improving the sustainability and resistance of concrete materials used to build roads and bridges in coastal regions prone to marine flooding. The results of the durability testing were crucial to identifying the most resilient concrete mix, prompting the partnership to invest USD 600 million in replacing the concrete in 380 000 metres of the most damaged and flood-exposed bridges. Another

200 000 metres of durable bridges are forecast to be built over the next ten years in Bangladesh, helping to reduce the vulnerability of millions of people to extreme weather events in coastal areas. The project provides a useful template for other areas at risk of coastal flooding worldwide (ReCAP PMU and Scriptoria, 2020).


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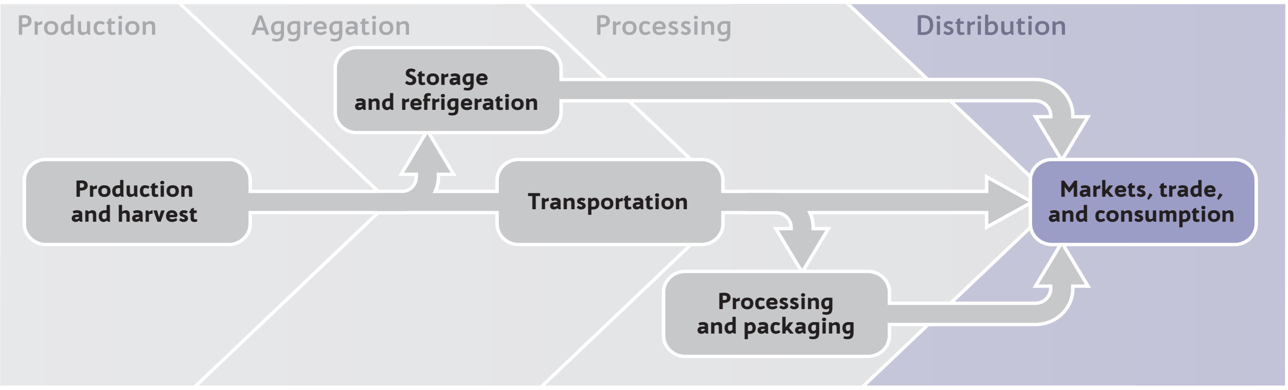
Table 5. Climate risks, services and resilience measures for food transportation

STAGE OF THE VALUE CHAIN	CLIMATE RISK	CLIMATE SERVICES	CLIMATE-RESILIENT MEASURES
TRANSPORTATION	Heavy precipitation	Extreme rainfall advisory	• Strengthen early warning systems to prevent impacts on road infrastructure and reduce food losses from heavy rainfall events. • Build resilient drainage systems and infrastructure. • Elevate roads and bridges above flood levels. • Ship products when external conditions are less critical. • Reduce transport speed and implement more efficient planning of transport routes. • Promote safe, efficient routes for transporting fresh, perishable food to reduce transport time, food losses and energy use. • Provide training and advice on food-storage manufacturing techniques to reduce losses during transportation.
	Thunderstorm	Thunderstorm advisory	• Strengthen early warning systems to prevent impacts on road infrastructure and reduce food losses from storms. • Conduct road-network vulnerability assessments tailored to specific means of transport. • Reduce transport speeds and implement more efficient planning of transport routes.
	Strong wind	Wind advisory	• Strengthen early warning systems to prevent impacts on roads and vehicles and to reduce food losses from strong winds. • Reduce road traffic when external driving conditions are critical. • Install embankment protection infrastructure.
	Dense fog, dust and snow	Fog, dust and snow advisories	• Use LED panels and appropriate lighting and planning to reduce road accidents.
	Extreme sea conditions	Coastal and offshore warnings	• Strengthen early warning systems to avoid shipments of products when external conditions are critical. • Promote the use of navigational equipment. • Use colour-coded warnings to inform on the best times to ship products.
	Extreme heat	Heat warnings	• Strengthen early warning systems to avoid shipments of produce when external driving conditions are critical. • Improve the insulation of refrigerated trucks while reducing the energy consumption of vehicles. • Promote safe, efficient routes for transporting fresh, perishable food, to reduce transport time, food losses and energy use.

Source: FAO (2021e).



5.5 Distribution: Agrifood markets, trade and consumption

Climate change greatly impacts the market and retail sector by affecting the price at which food is sold relative to international market trends, its nutritional value and, consequently, undermine domestic and international trade and consumer choices (IPCC, 2022). All this has an effect on access to safe, healthy food, undermining consumers' chances of having a healthy and balanced diet, particularly in LDCs and the most vulnerable communities worldwide (Fanzo *et al.*, 2018).

5.5.1 Climate risks to agrifood markets

Retailers' incomes are hit when lower quantities and quality of food are available for sale. The risk of food spoilage and contamination also rises when agrifood products are stored in markets beyond their shelf lives (FAO, 2018). The interconnected nature of agrifood value chains means that climate impacts at all stages of the chain ultimately affect markets, trade and consumption. Heavy rainfall and extreme temperatures can hinder access to market infrastructure, especially in the most vulnerable areas of LDCs and SIDS. Rural areas are affected, in particular, by weak and unsuitable retail infrastructure, with scant access to freshwater systems or cold storage, affecting food quality and safety and leading to food spoilage and waste (Fanzo *et al.*, 2018). For instance, in 2019, Hurricane Dorian and flooding events in the Bahamas disrupted supermarkets, warehouses, local tuna supply-chain infrastructure and drinking water facilities. Food markets in LDCs usually lack adequate, safe infrastructure that can prevent additional food spoilage and waste, necessary to meet health and safety standards and reduce impacts by extreme weather events (Fanzo *et al.*, 2018).

Liverpool-Tasie et al. (2020) explored the direct and indirect climate effects on the maize and poultry trade in Nigeria. It concluded that above-optimal temperatures, flooding events during production periods, high relative humidity, mould contamination during storage and weather extremes disrupting transportation may affect the final quantity and quality of food available in markets, thus increasing costs and prices. In addition, damage to energy systems and infrastructure caused by flooding can directly affect markets and logistics.

5.5.2 Climate risks to the agrifood trade

Aflatoxin contamination, which primarily occurs in the post-harvest stages, is a significant factor when it comes to climate change impacts on the agrifood trade. Unpredictable weather conditions have increased levels of such mycotoxins, especially in grains and groundnuts in sub-Saharan Africa, leading to food and economic losses as crops are rejected for export due to their non-compliance with food security standards. In reality, agrifood products contaminated by aflatoxin and rejected for global trade are usually consumed at lower prices in producing African countries, where regulations and standards are more lenient, with the risk of acute poisoning for consumers (Leslie *et al.*, 2008; Wu, 2015).

The impacts of climate change, climate variability and extreme weather on the availability of natural resources, crop yields and food stability have combined to affect the price at which agrifood products are traded throughout the agrifood chain and sold at markets.

This has, in turn, prompted a decline in domestic agricultural productivity, boosting the need to import food (see case study 5.5.1) (FAO, IFAD, UNICEF, WFP and WHO. 2021). These dynamics can be seen from the local to the national and international level, affecting countries' import and export systems and national income (IPCC, 2022). According to Anbumozhi (2020), developing countries are more susceptible to changes in food availability on local due to climate change-related impacts on the local and neighbouring environments than to changes in international market prices, making production unsustainable, particularly for smallholders (see case study 5.5.2).

An example of such dynamics can be found in Tunisia's cereal sector. Durum wheat is the country's most important cereal crop, both in terms of production and consumption, sustaining the human and livestock populations. It is, therefore, heavily subsidized. Cereal production in Tunisia is now seeing yield and price fluctuations, however, due to climate impacts, with negative effects on producer income and consumer purchasing power. Amid trade barriers - to imports, in particular - and incentives for domestic production and consumption, the market is likely to become unsustainable if production is affected by weather shocks that reduce producer competitiveness and consumer availability (Laajimi *et al.,* 2016).

Negative weather shocks in Central Asia are believed to be having profound effects on commodity prices. For example, low temperatures and precipitation, leading to erratic water supply for irrigation, are directly affecting wheat and potato prices, due to limited wheat yields, stocks and supply shortfalls (Mirzabaev and Tsegai, 2012).

5.5.3 Climate risks to food consumption

Climate impacts throughout the agrifood value chain have compounded effects on the quantity and nutritional quality of food available for consumption, on freshwater availability and sanitation, on health risks and on the spread of diseases, affecting food availability, access, utilization and stability (FAO, IFAD, UNICEF, WFP and WHO. 2021). Indeed, climate impacts on agrifood production and the use of water and energy resources along the value chain increase the cost of delivering value-adding activities such as food processing. This raises the market price for consumers, reducing their purchasing power and their dietary diversity, increasing the risk of food insecurity and consequently malnutrition or undernourishment (Mbow *et al.,* 2019).

Weather has an immediate impact on consumer behaviour in the food market and retail sector. Depending on the weather, the volume of customers can increase or decrease, as weather has been shown to affect human behaviour and mood. The latter can have a significant impact on total demand, as well as the purchase of specific agrifood products (Bujisic *et al.,* 2016). Changes in temperature, for example, have a substantial impact on consumer choice in restaurants. Different weather factors can influence sales, as some items are more affected by weather than others. Warmer temperatures, for instance, tend to increase beverage sales (WeatherAds, 2021). They can also prompt retailers to offer consumers better deals on perishable food that might otherwise remain unsold in stores and be wasted. Agrifood value chains in Greece, for instance, have been undergoing marketing challenges in a bid to get consumers to buy peaches throughout the year. Greece's climate is now seeing alternating prolonged periods of hot and cold weather. While supply for peaches is plentiful throughout the year, the demand for peaches is high only in warm periods, causing substantial food losses in periods of low demand. Thus, weather-induced changes in consumer needs and purchasing decisions present significant obstacles to which farmers and traders need to adapt in order to limit food waste and economic losses (Despoudi, 2021).

5.5.4 Climate services for the agrifood trade

Digital technologies and ICT offer new opportunities to enhance communication and collaboration between producers and markets, thus boosting their capacity to make climate-smart and resilient decisions. Exporter countries could, therefore, benefit from seasonal advisory services on climate effects on yield and national and international trends in food availability (Anbumozhi, 2020). This would enable them to set more suitable, transparent and competitive prices and increase their decision-making and management capacity to collaborate with intermediaries and end markets (see case study 5.5.3) (FAO, 2018). In addition, farmers could be advised on the most appropriate timing for harvesting and selling their products based on local and national price trends (Njuguna *et al.*, 2021).

Combined with weather-based market information, agricultural price and weather insurance schemes could help protect farmers and food traders against extreme weather events that affect crop productivity and final food availability, both on local and international markets (Fu *et al.*, 2018). Weather risk-based price insurance could ensure consistent revenues for value chain actors, minimize price volatility and maintain adequate levels of investment in agrifood production and trade in the face of extreme weather events and climate change (Mirzabaev and Tsegai, 2012).

5.5.5 Climate services for agrifood markets

Markets and supermarkets would benefit from greater awareness of the relationship between consumer demand and food supply, ensuring appropriate stocks of agrifood products in stores and retail outlets, guaranteeing freshness and avoiding food waste. With sales forecasting thus related to climate impacts along the food supply chain, advisory services could assist producers, processors, transporters and suppliers in managing stocks, as well as reducing costs due to damaged agrifood products (Wang *et al.*, 2018). Climate services can also enable producers, agrifood storage actors and retailers to improve shelf-life when post-harvest facilities and technologies are harder to come by. This can be achieved by introducing more resistant, durable varieties that are better suited to local weather conditions, reducing food waste at the retail stage (see case study 5.5.4).

However, disconnections between activities along the value chain caused by the geographical fragmentation of farms, roads, villages, electricity and Internet infrastructure hinder the transformation of smallholder agriculture into market-based production and sustainable rural development (Okello *et al.*, 2013). In the final stages of the agrifood value chain, actors are usually more aware of climate and economic risks, so they should use their expertise to encourage actors at earlier stages of the value chain to reduce climate impacts and food losses (Liverpool-Tasie *et al.*, 2020). However, this is a real challenge, particularly in developing countries, where smallholder farmers are not directly involved in post-harvest activities, so do not really know how to deal with climate hazards, use climate-resilient and value-adding practices to reduce food losses and enhance the quality of their products, or engage in marketing and trading (Okello *et al.*, 2013). Because of a lack of electricity, storage and processing facilities, financial resources to buy equipment and labour, as well as information and communication, farmers frequently need to accept prices set by traders to sell their food right after harvest, which may not be the best option in terms of profit.

The vulnerability of the market/retail sector to climate change is exacerbated by a lack of collaboration among agrifood value chain actors, which reduces the quantity and quality of food available to sell and distribute. This lack of communication and exchange of information is commonplace among actors along the value chain in LDCs and can act as a major barrier to sustainable agrifood value chains. This lack of information sharing can reduce opportunities to enhance partnerships among key stakeholders and to deliver effective climate services tailored to users at every step of the value chain. Therefore, further integration of stakeholder values and needs along the value chain would help to improve the agrifood system, the collaboration between small farmers and large retailers, and provide opportunities for climate services to reach users and communicate useful information in a more synergistic way.

The use of tailored information and communication tools, such as mobile phones, to receive up-to-date weather information is critical to reducing food producers' vulnerability. These allow producers to deal and negotiate with traders and ensure transparent product pricing, so they can base their decisions on production and trade, in line with seasonal forecasts, and respond more effectively to weather shocks to prevent food and economic losses along the value chain (Furuholt and Matotay, 2011).

5.5.6 Climate services for food consumption

Weather marketing is an innovative form of marketing strategy that analyzes the relationship between weather conditions and consumer demand for different products (WeatherAds, 2021). Temperature forecasting, live weather data and weather-driven demand analysis allow supermarkets, restaurants and advertisers to select the most suitable ingredients, menus, promotions and pricing strategies according to changes in consumer demand due to different weather conditions, thus maximizing sales and reducing food waste (Bujisic *et al.*, 2016). Supermarkets in the United Kingdom of Great Britain and Northern Ireland and in the United States of America, for instance, are attuned to the positive effects on sales of fresh, chilled food and beverages when temperatures rise above 18°C and on the consumption of warm foods and soups as temperatures drop (WeatherAds, 2021).

In addition, a study by Lim-Camacho et al. (2017) on food product choices to support climate adaptation in Australia, showed that information provided to consumers on adaptation strategies along the agrifood value chain was key to increasing their awareness of climate risks and their consequent preference for climate-resilient food products. This further underlines the importance of disseminating information on climate hazards and impacts that can cause food insecurity by undermining food quality, quantity and safety, as well as opportunities for climate services and climate adaptation practices among value chain actors to reduce such risks, not just for local actors, but also for international consumers.

Warning systems, such as the Rapid Alert System for Food and Feed (RASFF) implemented by the European Union, are powerful instruments aimed at preserving food safety, controlling risk and rapidly sharing information to coordinate action to deal with health and safety risks to food sales and consumption. Information is exchanged in a systematic, rapid and transparent way online. For example, when a threat to human health or food security is detected in food or feed, the RASFF network immediately transmits the information to the European Commission, which then communicates it with all network members through a rapid notification system. Member states then notify the Commission of any measures they take to block the sale and consumption of affected products, to remove the product from shelves and communicate the warning to food operators and consumers (RASFF, 2016).

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CASE STUDY 5.5.1

THE IMPACT OF DROUGHTS IN BRAZIL ON GLOBAL COFFEE PRICES

Background

Brazil is a key coffee producer and international exporter. Climate impacts on coffee production have cascading effects on the sale of coffee worldwide. Brazil's 2021 coffee crops suffered from a prolonged period of drought late in the growing season, particularly in the country's leading agricultural region of Minas Gerais. This has already caused wholesale prices to increase and led to a substantial reduction in world coffee supply. The impact is likely to affect the 2022 harvest as well, as the drought caused premature flowering and hampered trees' ability to recover before the onset of the rainy season in September (Daniel, 2021).

Persistently low soil moisture levels are evident in Brazil's Drought Index and precipitation monitor (Gro Intelligence, 2021).

Moreover, the drought was followed by frost, the impact of which primarily hit next year's crop. The price of arabica coffee rose 60 percent from 2020 (Figure 9). Combined with a cyclical reduction of ten percent in Brazilian output every two years, the drop in yields has been exacerbated by a reduction in supply due to the COVID-19 pandemic, which increased equipment and food transportation costs, causing disruptions both to supply and demand worldwide.

Overall, a stronger access among coffee producers in the country to international market information on changes in global demand and prices would enable farmers to increase their decision-making capacities to preventively shift towards more climate-resilient varieties and adapt to climate and market changes.

Figure 9. Price change of arabica coffee beans between 2020 and 2021

Source: Evans, P. 2021. *Record Brazilian drought causes coffee prices to spike to highest level in years.* CBC [online]. [Cited 2 August 2021]. www.cbc.ca/news/business/brazil-coffee-drought-1.6096120

CASE STUDY 5.5.2

CLIMATE CHANGE AND IMPACTS ON THE FOOD TRADE IN SOUTHEAST ASIA

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Background

Food price stability, particularly in developing countries, is frequently driven by the effects of climate and weather variability on crop yields, rather than changes in international market prices due to, say, financial shocks (Anbumozhi, 2020). Climate hazards and impacts on food prices (including weather extremes, changes in temperature and precipitation patterns, as well as the effects of CO_2 on crop productivity) in key producing areas globally have been detected since the IPCC AR4 report (IPCC, 2007), reflecting the correlation between climate change and food value chain performance, particularly food market trends. However, detailed economic impacts on food purchasing power have yet to be quantified systematically (Porter *et al.*, 2014).

Anbumozhi (2020) quantifies the short-term impact of weather hazards and international price changes on local commodity markets in numerous developing countries.

The study shows how climate is a major driver in local prices change, with implications for the development of public policies targeting agrifood system improvements, particularly among the most vulnerable communities. It underlines the importance of continuing to strengthen weather information components of public-sector interventions (Figure 10).

Food markets are highly influenced not only by national production capacity, but also by import and export decisions and opportunities. Indeed, climate change impacts on food availability in neighbouring countries will affect food prices and increase market opportunities in other producer countries. This has been the case in China and India, amid increased demand for rice in Association of Southeast Asian Nations (ASEAN) countries. Climate impacts on crop productivity suggest around a 30 percent increase rice price, a 80–100 percent increase in wheat price, a 60–90 percent increase in corn price and a 15–50 percent increase in soybean price by 2050 compared with a no-climate-change scenario (Anbumozhi, 2020).

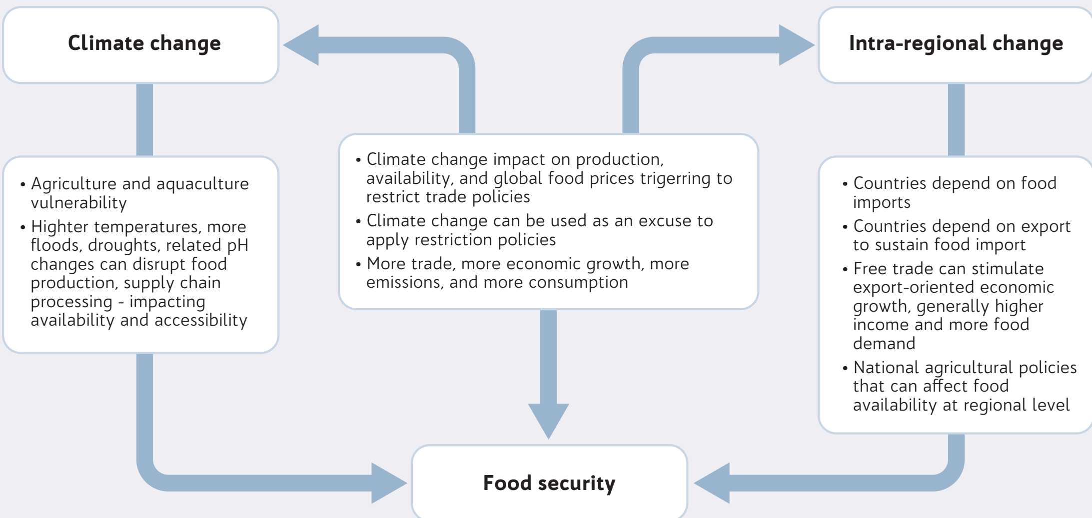
CASE STUDY: Climate change and impacts on the food trade in Southeast Asia *(continued)*

Recommendations and investment opportunities

This implies the need to better assess the impacts of climate and weather hazards on food stability, markets and consumption, particularly in developing countries and the most vulnerable communities.

To date, these have received less attention than analysis of international trade impacts on food stability. To this end, information on food price changes should be combined with remote-sensing data on crop conditions and weather forecasts to understand their relationships with local market disruption, food availability and stability.

Figure 10. Climate change, trade and food-security linkages



Source: Anbumozhi (2020).

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CASE STUDY 5.5.3

EL NIÑO/LA NIÑA IMPACTS ON THE GLOBAL WHEAT MARKET

Background

Wheat is a key staple food providing vegetable proteins and calories to human diets worldwide, with a leading presence in the global market alongside maize and rice (Gutierrez, 2017).

Gutierrez (2017) identifies crucial elements of the impacts of the El Niño-Southern Oscillation (ENSO) phenomenon on wheat yields, export prices and stocks, its effects on wheat availability in the most vulnerable countries and communities worldwide and its implications for national governments.

ENSO is a cyclical ocean-atmospheric phenomenon formed in the tropical Pacific by two opposing weather events, dubbed El Niño and La Niña. The former leads to increasing ocean surface temperatures in the eastern equatorial Pacific Ocean, as well as heavy rains in South and North America and eastern Africa, simultaneously causing droughts in Australia, India and Indonesia. The latter causes decreasing ocean surface temperatures in the equatorial Pacific, heavy rains in the western Pacific and Australia and cooler temperatures in North America (Gutierrez, 2017; WMO, 2014).

ENSO has a large influence on global temperature and precipitation trends. Negative El Niño impacts have been observed on wheat yields, particularly in Australia, but positive effects have been seen in Argentina and the European Union. La Niña, in contrast, has greater negative effects overall, other than in the United States of America. Researchers have observed correlations between the occurrence of ENSO and soybean and vegetable oil prices, for instance, which increase during El Niño events and decrease during La Niña.

Benefits of using climate services, recommendations and investment opportunities

Gutierrez (2017), therefore, proposes a global dynamic model, an instrument capable of forecasting ENSO impacts on precipitation and temperature to support projections of wheat yields and export prices, so that governments can set the most appropriate quantities and prices for imports and exports, minimizing food losses and maximizing economic opportunities for suppliers and consumers.

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CASE STUDY 5.5.4

INTRODUCING RESISTANT TOMATO VARIETIES TO BOOST SMALLHOLDER FARMERS' MARKET ACCESS IN INDIA

Background and major challenges

Crop breeding offers opportunities to improve food security and reduce the environmental impact of food value chains. For example, crop breeding can support the development of highly productive varieties, drought and heat tolerant as well as more resistant to pests and diseases or have characteristics that improve product shelf-life.

Through a study conducted by Bayer AG (2021), an improved crop variety (Bayer's Ayushman tomato breed) was introduced in India with a view to significantly improve tomato yields. It proved successful. The variety was vulnerable in post-harvest chains, however, as it had a limited shelf-life, reducing sales and consumption opportunities, and was subject to higher post-harvest losses, especially during transport to remote markets - all of which outweighed the benefits of a higher yield.

Benefits of introducing a resilient variety

Another new tomato variety was therefore developed and introduced to the Indian market. It has demonstrated a better shelf-life, making it better able to overcome the challenging conditions of low-tech post-harvest chains frequently found in rural areas of developing countries.

As a result of this work, food availability has increased, as more produce per unit of production area (up 25 percent) is deliverable to the market.

The reduction in food waste and food losses calculated by analyzing the product lifecycle through the Agro-chain GHG emissions (ACE) calculator (2021), showed a 20 percent to 30 percent reduction in GHG emissions per unit of food sold to consumers.

The enhanced tomato variety proved successful in improving food security and contributing to mitigation of climate change. However, the higher value of the product only benefits actors in the post-harvest stage of the value chain, especially traders and market sellers (almost women) in rural markets. Cultivating the improved strain involves higher production costs, which fall on seed producers and farmers.

Recommendations and investment opportunities

In India, crop breeding has proved an effective means of increasing the resilience of the food value chain to climate change. Still, it involves additional costs, which need to be offset, for actors at the beginning of the value chain. Crop breeding needs to be combined with the development of appropriate business models, therefore, in which actors early in the value chain are compensated for their higher production costs.

Table 6. Climate risks, services and resilience measures for food markets, trade and consumption

STAGE OF THE VALUE CHAIN	CLIMATE RISK	CLIMATE SERVICES	CLIMATE-RESILIENT MEASURES
MARKETS, TRADE AND CONSUMPTION	Extreme heat	Heat index values and warnings	• Enhance availability of water-rich food products and beverages.
	Pests and diseases, food contamination	Alert systems for food contamination	• Promote appropriate work hygiene and sanitation practices. • Provide warnings on identified risks to consumers' health at market level after complaints or illnesses linked to product-specific consumption. • Ensure immediate removal of the product from markets, stopping further distribution and inform all other actors along the value chain of its non-compliance with health and safety requirements
	Changes in temperature and rainfall patterns	Seasonal forecasts	• Provide seasonal advisory services for climate impacts on yields and changes in food availability in national and international production to enable value chain actors to set transparent and competitive food prices for both domestic markets and export.
	Heavy precipitation	Extreme rainfall advisory	• Develop efficient rainwater collection systems, such as rainwater tanks, pumps and purifiers. • Use ICTs to enhance communication and information sharing between actors along the value chain.
	Flooding	Flood advisory	• Strengthen early warning systems to enhance flood preparedness and reduce disaster risk. • Develop flood-proofing practices, such as storage on wood pallets, maintaining distance to walls and hygiene. • Build flood-proof infrastructure that meets sustainable structural requirements and standards (in appropriate locations with regard to floodplains, of suitable dimensions and type, with the right roof slope and ledge and solid building foundations). • Promote rainwater collection systems such as rainwater tanks, pumps and purifiers; use drying hangers and maintain storm drains.

Source: FAO (2021e).


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6

CROSS-CUTTING CLIMATE SERVICES FOR AGRIFOOD VALUE CHAINS

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This report provides a preliminary systematic approach to identify climate risk at certain stages of the agrifood value chain. Climate services tailored to the needs of specific actors have great potential to improve the climate resilience of the value chain as a whole. To this end, climate services must be integrated and function as a unique and coordinated system across the entire agrifood value chain, so as to highlight the interlinkages and trade-offs between actors and activities in achieving climate resilience. The collaboration of all actors at all levels is fundamental to consistent climate action along the agrifood value chain that goes beyond interventions focused solely on individual steps.

At a macro level, cross-cutting climate services enable policy- and decision-makers to align climate-resilient activities and partnerships between agrifood value chain actors in a synergistic way, to enhance systemic adaptation capacity to climate change (see case study 6.1). Climate risk assessment of long-term business strategies and large-scale national policymaking strategies, for instance, can help evaluate the overall socioeconomic vulnerability and adaptive capacity of targeted value chain actors. This can support the implementation of climate risk management practices by providing tailored recommendations throughout agrifood value chains (see case study 6.2). To achieve this, public institutions must collaborate with extension services to build users' capacity to use climate services properly and make climate-informed decisions. This will involve the provision of participatory technical training to actors along the entire value chain (see case study 6.3). Educational training will also raise awareness of the risks and associated consequences of the four pillars of food security: availability, accessibility, stability and utilization. It will also bolster synergy and networking opportunities among all actors in the value chain (O'Grady *et al.*, 2020; FAO, 2021b).

Building resilience to climate change for small producers implies increasing their access to financial services and incentivizing investment in their products by the private sector. Public and private stakeholders can improve climate-informed financial services by providing insurance against extreme weather events and improving access to credit and funding for value chain actors that make decisions based on climate services. This will support the costs of implementing climate-resilient interventions and enhancing the profitability of their food products from production to market (see case study 6.4). Lastly, combining climate services with financial, market-based and general advisory and information services on, say, price fluctuations, health and pandemics would improve the chain's ability to face compounded climate and socioeconomic risks, enhance resilience and meet development objectives by investing in adaptation action (see case study 6.5).

CASE STUDY 6.1

PUBLIC–PRIVATE PARTNERSHIPS TO ENHANCE CLIMATE RESILIENCE IN THE COCOA VALUE CHAIN

Background

The global cocoa supply chain centres on the production of cocoa by smallholder farmers in West Africa, particularly in Ghana. The country is significantly exposed to climate change and variability, with substantial impacts on the performance of the value chain. A project implemented under CCAFS, in collaboration with the International Center for Tropical Agriculture (CIAT) and the International Institute of Tropical Agriculture (IITA), therefore, focused on mobilizing private-sector partners, including financial institutions, agricultural and climate experts and certification entities, to mainstream climate action into Ghana's cocoa value chain (CCAFS, 2015).

The aim of the project was to transform climate information into practical guidance and strategies to support farmers and other actors in the agrifood value chain such as agri-businesses, traders, certification bodies and financial institutions, by embedding climate science and climate-smart agriculture practices into the Rainforest Alliance's voluntary certification scheme and investment risk assessments for food value chain interventions (CCAFS, 2015).

Lessons learned

Project results suggest that national and multinational private-sector partners need further information on climate change and its impacts on the cocoa value chain, for example, through the use of exposure maps (CCAFS, 2015).

One of the outcomes of discussions with cocoa value chain actors was that drought impacts every activity along the chain. At the production stage, drought directly affects farmers by reducing yields.

Input suppliers, processors, transporters and licence buyers are impacted indirectly by a reduction in input demand (for example, for fertilizers, harvest and storage equipment), as well as lower sales of final product and higher prices for value-adding activities such as processing. Access to early warning information and knowledge of practices to deal with drought is limited among coffee value chain actors, with input suppliers and transporters among the most exposed and least informed and farmers mostly having access to informal information. Therefore, the use of early warning systems may be helpful for multiple stakeholders to monitor activities and strengthen their capacity to prevent the economic impacts of a climate hazard such as drought (Joerin *et al.*, 2018).

According to a study from the Swiss Federal Institute of Technology, the development of drought early warning systems, combined with weather and agriculture-based insurance protection, is crucial to ensure consistent pre-harvest cocoa production and stable post-harvest activities and prices – also on the international markets – for stakeholders in Ghana, thus enhancing their climate resilience (Monastyrnaya *et al.*, 2016).

Results from a stakeholder workshop for the Swiss research study show that the main tools used to spread information on disruptions and emergencies are radio and television, though farmers and rural workers rely mostly on informal communication channels. Overall, early warning systems, communication networks, the distribution of agricultural officers and economic and human resources and modes of transportation are inefficient, despite growing requests from farmers for extension services to increase their productivity (Monastyrnaya *et al.*, 2016).

CASE STUDY 6.2

TAILORED FINANCIAL SERVICES AND CLIMATE RISK MANAGEMENT RECOMMENDATIONS FOR POLICYMAKERS TO LINK SMALL FARMERS TO MARKETS IN THE ROOTS AND TUBERS SECTOR

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Background

Roots and tubers account for 20 percent of calories consumed in Africa. Crops such as cassava, yam and potatoes are not only important for food security, but also increasingly for income generation for farmers and small businesses, particularly for women.

Against this backdrop, by collaborating with the European Union and the African Caribbean and Pacific Group of States (ACP), between 2015 and 2019, FAO supported the development of the cassava and potato value chains in seven African countries – Benin, Cameroon, Côte d'Ivoire, Ghana, Malawi, Rwanda and Uganda – under the African Roots and Tubers (ART) project. To implement the project, FAO followed a comprehensive approach aimed at increasing production and improving the quality of food products.

Major challenges

From 2015, the project built the capacity of smallholder farmers, processors and traders to meet increasing market demand and developed inclusive business models that strengthened value chain links and increased access to markets. However, despite positive results on market linkages and on sustainable production intensification for the roots and tubers produced and commercialized by small actors, the project concluded that building capacity and facilitating relationships might not be enough to enable farmers to move beyond subsistence farming.

Indeed, despite root and tuber crops, such as cassava, being increasingly studied for their higher tolerance to poor soils and drought compared with other crops in Africa, production is still not immune to the negative effects of climate variability and change, as well as natural hazard-induced disasters.

CASE STUDY: Tailored financial services and climate risk management recommendations for policymakers to link small farmers to markets in the roots and tubers sector *(continued)*

Benefits of using climate services

In Malawi, in collaboration with the World Food Programme (WFP) and the National Department of Climate Change and Meteorological Services, the ART project strengthened the capacity of extension officers and cassava farmers' leaders on participatory tools to develop and improve cassava and other crops according to weather conditions, livestock and livelihood options best suited to individual farmers' circumstances. In Uganda, the project developed climate change adaptation curricula specific to the Irish potato sector in local languages, including meteorological terminology, with guidelines for simple understanding and location-specific climate risk management strategies (CRM) for potato farmers.

Lessons learned, policy recommendations and investment opportunities

By analyzing the impact of climate variability on root and tuber production, particularly cassava, in selected African countries, the project developed, in collaboration with the national meteorological agencies of the seven countries, a set of policy recommendations and CRM strategies for actors at various levels, which could alleviate the scale of climate-related losses for smallholder farmers. Designing new or strengthening existing CRM measures for these sectors – whose crops, in some cases, are more resilient than crops in other sectors – could have positive catalytic effects in the effort to fight food insecurity in vulnerable African countries.

Some of the recommendations for policymakers developed as part of the project include:

- integrating CRM into agricultural development policies and planning to anticipate, prevent or more effectively manage production crises;
- developing an inclusive strategy for climate services that combines investments to improve climate information systems at central and local levels;
- building the capacity of agricultural units at all levels on climate modelling, risk assessment and management tools;
- encouraging the role of the private sector in CRM; and
- organizing regular dialogue between key root and tuber value chain leaders, NMAs, formal and informal financial institutions and insurance companies to develop insurance schemes tailored to the needs of small farmers and processors in the root and tuber value chains.


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CASE STUDY 6.3

CLIMATE-RESILIENT AGRIBUSINESS FOR TOMORROW'S EAST AFRICA (CRAFT EAST AFRICA)

Background

The CRAFT project has been implemented by CGIAR in Kenya, the United Republic of Tanzania and Uganda since June 2018, through a private-sector approach (CRAFT, 2020).

The overarching goal of the project is to promote the development of inclusive climate-resilient agrifood systems by considering all phases of the value chain, from pre-planting to post-harvest handling. So far, the project has focused on seven crops and their related value chains: the common bean, green gram, potato, sesame, sorghum, soybean and sunflower.

The specific objectives of the project are:

- to increase the adoption of climate-smart agriculture (CSA) practices and technologies among farmers and agricultural enterprises;
- to increase investment and business growth in CSA value chains; and
- to create an enabling environment to ensure the large-scale roll out of market-driven CSA.

The initiative seeks to achieve climate-resilient food production practices on a total of 600 000 hectares (at least 200 000 hectares per country).

Project intervention involves contract farming between agri-businesses and smallholder farmers to revitalize and facilitate access to climate-smart services, technologies and inputs along the value chain and to secure markets for climate-smart products.

Benefits of using climate services

Project climate services include climate risk assessments (CRAs) encompassing trends, impacts, projections and knowledge on the implications of climate change on selected value chains, implemented by agribusiness partners and their contracted farmers, with affirmative bias towards women and youth (SNV, 2019).

CRA is the entry point for identifying suitable adaptation practices for changes in climate and weather conditions. Climate services include generating livelihood-specific climate information (temperature and rainfall) used in local decision-making and index-based insurance for the value chain and country. CRA results are then tailored to business development advisories for farming contracts through climate and business-based narratives. Such strategies have the potential to benefit input service providers, producers, aggregators, processors and marketers at each stage of the value chain.

CASE STUDY: Climate-resilient Agribusiness for Tomorrow's East Africa (CRAFT East Africa) *(continued)*

Targeted stakeholders are mainly farmers' cooperatives and agribusiness SMEs, as well as their contracted smallholder farmers in each value chain, including service providers and policymakers. The project targets about 50 agribusiness SMEs and 30 farmer cooperatives, serving 300 000 smallholder farmers with innovative climate-smart solutions. The approach aims to climate-proof production systems and value chains through inclusive business initiatives.

The project, which started in June 2018 and will continue to May 2023, has so far covered 36 agri-businesses (29 SMEs and 7 cooperatives), contracting 237 250 smallholder farmers in the target countries.

The contracted agribusiness partner value chains are sunflower (10), soybean (9), potato (5), sorghum (6), common bean (3), sesame (2) and green gram (1). Across the value chains, farmers are already adopting climate-smart practices and technologies learned from training and exchange visits.

Some 41 290 smallholder farmers have been trained on CSA, while climate information services have reached 60 084 farmers (49 percent of them female). CSA is being practised on 29 060 ha of farmland.

The dissemination of weather information to 60 000 smallholder farmers is ongoing in collaboration with national meteorological agencies.

Lessons learned

The major strengths of the project include pooling diverse consortium expertise and experience, leveraging private-sector participation and investment, policy influencing and the operationalization of climate plans. Weaknesses include poor links with the public sector and a lengthy process to identify suitable agri-businesses with viable business proposals.

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CASE STUDY 6.4

THE AGRICULTURE AND CLIMATE RISK ENTERPRISE (ACRE) IN SUB-SAHARAN AFRICA

Background

ACRE is a weather index-based insurance programme developed in sub-Saharan Africa through the collaboration of multiple public and private partners, including insurance actors, agri-businesses, microfinance institutions, NGOs and input suppliers (FAO, 2020a; Agriculture and Climate Risk Enterprise, 2020). It is the first and largest programme worldwide to deliver weather-based insurance products to smallholders through tailored distribution channels and mobile phone technologies, including mobile banking.

ACRE offers different products, including:

- Insurance on investments and loans for the provision of agricultural inputs from microfinance institutions. The programme also includes training for farmers by microfinance specialists on agronomic practices.
- A second insurance product involves a process whereby seeds are bought from seed companies and registered with a specific code sent by SMS to ACRE. If the seeds are affected by a drought within two weeks of planting, the company guarantees replanting within the same season, to ensure farmers do not lose out on that crop season.
- A hybrid index and multi-peril crop insurance product combines yield-based and weather index-based insurance and covers the entire crop cycle from germination, presenting a value-added component that supports farmers more comprehensively than traditional insurance approaches.

Benefits of using climate services

A 2012 study revealed that farmers covered by insurance invested 19 percent more than farmers not covered by insurance, with corresponding economic benefits: incomes increased by 16 percent. As of 2018, almost USD 200 million had been invested in Kenya, Rwanda and Tanzania to insure around two million farmers against weather hazards.

An alternative form of insurance, often unaffordable to smallholder farmers, is a smart contract that reduces agricultural insurance costs. Insurance based on weather information from observation stations, satellites and remote sensors, combined with blockchain technology, for instance, enables companies to make climate-smart decisions that ensure farmers are paid a timely manner against specific and properly measured climate risks.

Consequently, ACRE Africa has also collaborated with The Lab, Sprout Insure and Etherisc to create Blockchain Climate Risk Crop Insurance to reach smallholder farmers in Africa. The insurance product is indexed to local weather and activated automatically after the occurrence of an extreme weather event, which improves the efficiency and transparency of insurance payments based on weather factors, as well as the costs for insurers, with economic benefits for both farmers and insurance companies.

CASE STUDY 6.5

CLIMATE SERVICES DURING THE COVID-19 PANDEMIC

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Background

The COVID-19 pandemic has been a key stressor of agrifood value chains and food security worldwide. Connections between value chain actors have been disrupted by national mobility restrictions and this has substantially affected food transportation and market networks, with significant negative effects on food security in the most vulnerable areas. In addition, climate and weather hazards coinciding with the COVID-19 pandemic, national and international restrictions and economic crises have compounded the impacts, particularly in low-income and net-food-importing countries (Figure 11) (FAO, 2020b).

Restrictions on the movement of people and goods have caused challenges in dealing with the effects of climate and weather on food availability, access, utilization and stability globally. They have curtailed the extension services provided to farmers and other value chain actors with regard to information on weather forecasts, early warnings of extreme weather events and agricultural advisories, hindering value chain actors from communicating and dealing with climate hazards.

This has affected the quantity and quality of food produced and available for consumption (WMO, 2020). The COVID-19 pandemic, therefore, has exacerbated already high levels of food insecurity, malnutrition and food-based illnesses, in tandem with climate impacts, risky socioeconomic conditions and international conflicts (FAO, 2021f).

Major challenges to the delivery of climate services across agrifood value chains

While weather observation systems around the world are largely automatized, the COVID-19 pandemic hindered logistical repairs, maintenance, supply work and redeployments, disrupting the production and communication of climate and weather information between observation networks. This led to a reduction in the extension-service delivery of fundamental climate and market information to farmers and other value chain actors, as well as agricultural advisory services on tackling pests and diseases (WMO, 2020). This has limited actors' capacity to make climate-informed and market-based decisions to reduce food losses, prevent resource waste and increase market opportunities.

Example of climate services development across agrifood value chains in Ethiopia

In Ethiopia, the traditional radio network has played a key role in ensuring that farmers and value chain actors receive and use tailored information to make climate-smart decisions. Seid et al. (2020) conducted a study aimed at strengthening the Ethiopian climate services value chain and delivering tailored seasonal climate forecasts, including alerts on extreme weather events. This information was translated into agro-climate advisories and delivered to smallholder farmers, decision-makers and value chain actors, combined with updates and alerts on the spread of COVID-19, to increase decision-making capacity in the midst of the pandemic.

CASE STUDY: Climate services during the COVID-19 pandemic *(continued)*

In addition, to strengthen communication and collaboration between value chain actors and stakeholders, the service included advisory services and information on plans and updates from the Ministry of Agriculture.

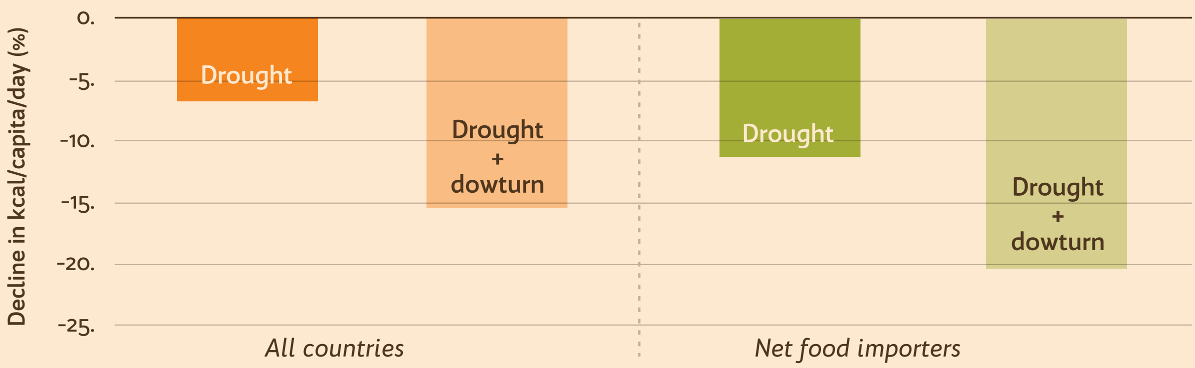
The most suitable and effective means of communication proved to be the traditional radio network. Seid et al.(2020) demonstrate the importance of delivering climate information tailored to different users' needs and priorities in the most effective and inclusive way, by using appropriate communications means and connecting different actors to create a climate-smart networking community.

Policy recommendations and investment opportunities

The operating systems of agricultural extension and advisory services, as well as information and communication networks, equipment and services, need to be developed significantly to address climate risks in the swiftest, most innovative and effective way during emergency situations and when social-distancing restrictions are in place (FAO, 2020b).

The role of agricultural extension and advisory services was crucial to ensuring climate, weather and market-based information and knowledge-sharing during the pandemic. In addition to tailored services, inputs, access to storage and processing facilities, transport and logistics, financial support, market access and supply-chain functioning, collaboration with multiple actors from governments to small-scale farmers, and strengthening linkages to social protection services and social insurance schemes (FAO, 2020b). Policy strategies to strengthen food security and the resilient functioning of agrifood value chains should, therefore, aim to systematically counteract risks caused by both the COVID-19 pandemic and climate and weather hazards to prevent and reduce future economic impacts (FAO, 2020c).

Figure 11. Comparison between drought impacts on food supply and compounded drought and economic recession impacts



Notes: The figure shows the average percentage change ini food supply in countries affected by a drought and countries affected by a drought in the context of a global economic downturn. The negative changes are measured relatively to countries not affected by a drought and their differences are statistically significant at 5 percent level.

Source: FAO (2020d).

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BARRIERS TO CLIMATE SERVICES DEVELOPMENT AND IMPLEMENTATION

Climate change presents multifaceted risks at every stage of the agrifood value chain, with the frequency and intensity of impacts driven by numerous factors, such as the type of food commodity, geographical area and the prevailing environmental social and economic conditions. Climate services provide a way for agrifood actors to increase the resilience and adaptive capacity of value-adding activities along the value chain and to reduce socioeconomic vulnerability through informed planning and value chain development. Climate services also hold great potential for national and international public institutions to make targeted, climate-informed investments in resilient agrifood value chains worldwide (Furuholt and Matotay, 2011; FAO, 2020d). However, the development of climate services fuelled by public and private institutions and tailored to agrifood value chains globally, needs to tackle multiple challenges, as outlined below.

1. Need for reliable data

The development of climate services requires a consistent flow of timely and reliable climate and weather data tailored to users' needs and socioeconomic characteristics. This is particularly challenging in developing countries where, due to limited investment in data collection, storage and dissemination facilities, raw data (for example, national historical climate databases) are not always available or properly stored in common databases. Policies and technical capacity to implement reliable and accurate climate services from the national to local levels are also frequently underdeveloped. For example, the cost of implementing climate services, especially at the start of activities, can be a major barrier to scaling up or replicating interventions, due to the need to train personnel and calibrate models. This cost varies significantly depending on existing national capacity to produce high-resolution climate and agroclimatic data.

2. Technology and innovation barriers

Increased access to energy, ICT, the Internet and safe and sustainable infrastructure is essential, especially in developing countries. There are a number of barriers that can impede development at scale.

These include limited human, social and natural capital to invest; inconsistent planning and incompatible technologies; and investments in innovative products that are not tailored to user needs, and so end up unused. In addition, smallholder actors frequently do not receive the support they need to invest in implementing resilient practices and technologies, for example, insurance schemes and certification that could ensure a substantial return on investment.

3. Challenges in addressing heterogeneous agrifood value chains through tailored interventions

Value chains differ depending on the type of production, geographical characteristics, climate zone, political environment and economic state of development of a given country. Challenges arise when it comes to identifying a common pathway for assessing broad socioecological systems and the numerous variations in these variables. Rather, these need to be specific to the environmental, social and economic context of the agrifood value chain, with a keen understanding of climate hazards, exposure and vulnerability. The heterogeneity of the actors involved in the same agrifood value chain is also a challenge when it comes to bespoke climate services, as well as to ensuring that services reach different users, between whom communication is frequently lacking, due to different needs as well as information and communication tools used across the value chain

4. Lack of communication and capacity-building

The main barriers to enhancing climate-resilient agrifood value chains include limited financial incentive and technical capacity to assess local climate risks and the decision-making ability to manage those risks. These are primarily due to technical limitations on accessing and utilizing climate projections and weather forecast data tailored to different users' needs and socioecological contexts (Dazé and Deckens, 2016). Another key barrier to the development of efficient and climate-resilient agrifood value chains is the limited communication between value chain actors, as well as a lack of leadership among public institutions.

These challenges hamper opportunities for collaboration to build capacity to use climate- and weather-based ICTs among smallholder farmers, to boost vertical and horizontal networking and sharing of information, to enhance public–private partnerships and to implement participatory climate risk management practices (Hernandez *et al.*, 2017). Mapping the agrifood value chain – the actors involved, climate risks affecting the chain and governance relationships between actors and stakeholders – is vital to identifying key channels for communication between actors (Okello *et al.*, 2013). Through mapping exercises, opportunities can be pinpointed for value chain actors to connect and develop synergistic agrifood value chains and ensure effective use and sharing of climate products and outputs.

Different actors and institutions, from farmers to governments, research institutions and NGOs, should therefore increase their networking opportunities to become familiar with the tools, resources and investment priorities of other value chain actors, the potential for climate services to enhance agrifood value chains' development against climate risks, and capitalize on the opportunity to collaborate to achieve positive outcomes globally (USAID, 2018a).

5. Limited financing initiatives

While both public and private investments in climate adaptation are fundamental and urgent in light of current trends and future climate scenarios, they fall short compared with investments in mitigation. The recent blueprint for digital climate-informed advisory services prepared by the Global Commission on Adaptation and the World Resources Institute (Ferdinand *et al.*, 2021) highlights that a substantial investment of USD 7 billion will be needed by 2030 to build the resilience of 300 million small-scale agricultural producers through climate services.

The necessary investments include upfront and maintenance costs of services, which vary according to the state of infrastructure development, the enabling environment for adaptive capacity and the type of service in question. However, the blueprint targets investments for small-scale agricultural producers, ignoring the investment needs of other value chain actors. The interventions proposed in this research – targeting post-harvest activities, in particular – require even greater investment.

In addition, climate assessments and methodologies justifying climate finance for adaptation often focus on the impacts of climate change on yields and production. Greater understanding of the climate risks to the post-harvest agrifood value chain, and methodologies for assessing their impacts, are needed. This will ensure recognition and finance from targeted funding initiatives for projects and interventions focusing on post-harvest agricultural value chains.

6. Limited policy support

The lack of consistent public and private financing initiatives for climate adaptation projects and strategies specifically targeting agrifood value chains in the post-harvest stages is a major challenge. This is despite the increasing vulnerability of countries and communities to climate change, and requests from developing countries for greater consideration of adaptation issues at global climate summits (Bianco, 2020). Of the 163 NDC submissions analyzed by Wieben (2019), only 48 countries reported adaptation strategies and plans of action to enhance the resilience of agrifood value chains to climate change through climate risk management interventions.


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POLICY RECOMMENDATIONS AND INVESTMENT OPPORTUNITIES

1. Identify climate risks to agrifood value chains and the potential for solutions through climate services in NDCs and NAPs.

Climate services and climate-resilient interventions to support agrifood value chains must be incorporated into NDCs and, from there, into local policy strategies and national climate adaptation action plans (Wieben, 2019). They must emphasize the role of private actors, such as national and local businesses, SMEs, investment funds and companies, in supporting the implementation of climate-resilient strategies, as well as the benefits they would derive from doing so. There is a widely recognized need to integrate CRAs into policy strategies when it comes to planning climate-proof infrastructure and climate-resilient technologies (IFAD, 2015; FAO, 2021e). In addition, by mainstreaming the development of the climate services framework, from data collection and monitoring, and the co-production of climate and weather information to communications tailored to different users along the agrifood value chain (FAO, 2021b), climate services would enhance collaboration and knowledge transfer between actors along the chain, with particular benefit for the most vulnerable groups. Governments, agricultural extension and financial services must support this process by providing climate-integrated investment opportunities at every stage of the value chain, as well as evidence-based information on climate projections, weather forecasts through climate services and sufficient knowledge, technical and economic resources to enhance local management and decision-making capacity. The potential of climate services to stimulate social inclusion particularly among under-represented groups, women and youth, should also be emphasized within local and national policy strategies.

2. Scale up access to information and communication tools

While diverse challenges and levels of development are also evident in agrifood value chains, climate services can optimize logistics and connections, traceability and coordination through improved digitalization and access to updated information. This strengthens the adaptive capacity of actors to prevent and minimize climate impacts where they occur, with direct and indirect benefits for the rest of the chain (FAO, IFAD, UNICEF, WFP and WHO, 2019).

Investment in large-scale network systems enables the digitalization of information and information systems accessed by value chain actors, supports the systematization of mobile networks and facilitates the upscaling of relevant ICTs. Climate-proofing infrastructural interventions where they are needed, including energy and access to electricity, could simultaneously support the development of technological and Internet facilities, so that value chain actors can access, use and share climate information.

Digitalization must be supported in a consistent and inclusive way to bridge the technological and knowledge gaps in the agriculture sector. Ensuring that relevant technologies and communication tools are used along agrifood value chains requires investment in infrastructure, while services must take into account costs, literacy rates, digital skills, regulations and access to the Internet. Only in this way will interventions overcome the widespread, chronic lack of access to new technologies and digital innovation in developing countries and, in particular, rural communities (FAO, 2019b).

Data sharing and tailoring advisory services to the needs of value chain actors can lead to the creation of a business model for national hydrological and meteorological services and their interaction with policymakers and agrifood value chain actors (FAO, 2020d; USAID, 2018a). Ideally, all data for a target value chain should be aggregated in a common database and data-sharing system to ensure that climate data can be put in the right context and create actionable and user-driven products. For example, sector-specific data (such as information on transport routes, collection points and market destinations) should complement climate data for transport stakeholders. To overcome barriers to communication and improve the decision-making capacity of value chain actors, Hernandez et al. (2017) propose measures and practices aimed at selecting the most appropriate means of communication for given agrifood value chain structures, matching value chain actors' needs and interests, and boosting communication and information sharing between actors.

The ICTs chosen should be uniform throughout the agrifood chain and be replicable for each actor and stakeholder, to ensure consistency from production to trade, as well as the long-term transparent, effective delivery of bespoke climate information. This requires careful analysis of the most suitable communication methods through climate risk-based stakeholder consultations.

3. Build the capacity of value chain actors to use climate services and communication tools

Developing climate services throughout the agrifood value chain and improving access to and the use of climate-based information and communication has the potential to enhance the adaptive and decision-making capacity of all value chain actors, especially the most vulnerable and marginalized. Farmers, processors, drivers and traders require participatory training and capacity-building on the interpretation and use of climate information and application of climate resilience measures that could help minimize climate impacts on production, harvest, and post-harvest stages (Feed the Future, 2018).

Analysis of the most suitable information and communication tools across agrifood value chains should thus be followed by participatory training schemes. These should be led by climate and value chain experts, who bring actors together to share best practices and knowledge, foster opportunities for further collaboration and enhance decision-making capacity. Capacity-building and technical assistance are required for extension service providers, input providers, the private sector and other actors, so that they can systematically tailor and communicate climate services in a cost and time-effective manner to different actors along the agrifood value chain. There also needs to be participatory training and technical support for users, to enable them to effectively use the information and services they receive. The strategy should be supported by a structured national government regulatory system.

4. Integrate climate risk assessments into project design and business plans for agrifood value chains

Investment recommendations for projects and programmes of action on climate services development must be informed by climate, environmental, economic and social assessments, as well as cost-benefit analyzes for each step of the agrifood value chain. Assessments should consider the targeted geographical area and take into account priorities for climate information by identifying the most vulnerable areas and value chain steps and the specific role each actor has both in the value chain and with regard to climate-resilient interventions (Sloan *et al.,* 2019; Ferdinand *et al.,* 2021).

The same approach should be followed when integrating climate risk management into agrifood value chain investments and business plans. To properly engage with the private sector and align proposals with their priorities, the economic rationale for investing in climate services and climate-resilient agrifood value chains needs to be clear and transparent. The business case, including both short- and long-term productivity, income benefits and return on investment compared with business-as-usual scenarios, should be clearly set out for proposed climate risk management interventions (Sloan *et al.,* 2019; Dazé and Deckens, 2016). Private stakeholders must recognize the value-added benefits of such interventions to properly incorporate climate risk management into value chain activities.

To increase the resilience of agrifood value chains to climate change, it is imperative to ensure that actors have the necessary information and sufficient financial and technological resources to make smart, resilient, climate-informed decisions. Preventative action and early response must be supported by the accurate identification and evaluation of climate risk, followed by enhanced adaptive capacity and strategies for the integrated management of natural resources. Climate services should ensure that all actors and stakeholders in the agrifood value chain have greater coordination and technical capacity to deal with climate risks.

A value chain approach that fosters the provision and use of climate services for agrifood production would tackle climate risks and consequent food losses and damages in a more comprehensive, synergistic and integrated way.

5. Strengthen social protection systems and foster climate-resilient certification schemes to underscore the return on investment.

By boosting investment in the implementation of climate-proof technologies and infrastructure, climate services should increase the safety of farmers and other actors against disaster risks, reduce food losses and resource waste. This entails shoring up early warning systems, agroclimatic advisory services and appropriate food storage facilities to prevent or reduce losses from extreme weather events at every stage of the agrifood value chain. Such measures must be combined with long-term adaptation planning and investment in technologies and infrastructure to climate-proof every step of the agrifood value chain. Investment in the long-term transition of small producers from conventional to climate-smart practices is something that rarely happens and is an area that should receive more attention. Such investments should be profitable and drive further demand for information and communication technologies and climate services to build climate-resilient agrifood value chains, significantly enhancing the value of agrifood products and raising value chain revenues (Global Commission on Adaptation, 2019).

The return on investment in social protection systems and climate-resilient certification schemes will come from avoiding the substantial costs of repairing and recovering from disasters, as well as from increased trading opportunities, particularly in developing countries where adaptive capacity is low compared with high-income countries. To build climate resilience and provide environmental, economic and social benefits along the agrifood value chain, climate services should be complemented by climate-informed financial services, input supply, insurance schemes tailored to specific value chains and climate-informed market information.

In addition, agrifood value chains are embedded in global trade, so must comply with international standards and regulations. Further support and legislation will, therefore, be required to adapt value chains to international climate hazards and socioeconomic risks. Investments in adaptation in developing countries cannot originate solely from within national borders but should be driven by greater international financial support from innovative multi-stakeholder partnerships and economic development models (Ferdinand *et al.*, 2021).

6. Mainstream climate change discussions, including climate services, into multi-stakeholder forums to address sustainability and the development of agrifood value chains.

While the actors and activities of agrifood value chains are diverse, enhancing vertical and horizontal collaboration between public and private actors will strengthen social and economic support, boost the integration of information, reduce inconsistencies in regulation and management practices, increase access to resources and technologies, and climate change awareness (Hernandez et al, 2017).

Public–private partnerships will be fundamental to integrating climate risks into investment plans, as well as to delivering training and information on opportunities for climate-resilient business strategies. They would enable numerous public and private actors to bring higher-level climate research and products down to a scale relevant to local decision-making on the agrifood value chain (Dazé and Deckens, 2016). Due to limited availability, the market potential for energy and cooling infrastructure is high in developing countries. If supportive policies are put in place, the private sector could take the lead on developing decentralized cold storage solutions. This could reduce losses, increase farmers' income and increase the resilience of agrifood chains to extreme weather events.

Here, the role of the national public sector should be emphasized, given its financial and logistical capacity to incentivize production in certain sectors.

Engagement also creates an enabling environment for the private sector to invest in climate adaptation measures, such as climate-proofed infrastructure and climate-based agricultural and social insurance, resulting in a substantial return on investment (Ferdinand *et al.*, 2021). Private-sector investment, meanwhile, is deemed crucial to supplement limited public resources for climate adaptation and to close the adaptation finance gap (World Bank, 2021). National and international development organizations can also play a key role in systematically engaging with local stakeholders and mainstreaming climate and market-based information systems along agrifood value chains (Dazé and Deckens, 2016).

Investment needs

Table 7 outlines investment needs and value of challenges at each step of the agrifood value chain.

Table 7. Overview of challenges and investment needs across the agrifood value chain

STAGE IN THE AGRIFOOD VALUE CHAIN	CHALLENGES	INVESTMENT NEEDS
Production and harvest	· Limited access to climate-resilient technologies and practices · Lack of connection with markets and market information for price setting and marketing strategies · Limited collaboration with other agrifood value chain actors · Inequitable access to climate services for women	· Invest in efficient harvest equipment and technologies. · Enhance ICTs for temperature and humidity monitoring at harvest. · Develop participatory training material and link to community engagement and outreach. · Investment in mobile, Internet networks. · Invest in services tailored to the needs and activities of women and youth, considering the barriers for these groups. · Support equitable access to climate services, including through a more robust understanding of the communication channels and means used by women, youth and underrepresented groups.
Storage and refrigeration	· Lack of climate-resilient infrastructure for effective and climate-controlled storage · Lack of information on how/where to invest in storage facilities based on projected climate risks · Lack of capital at farm level to invest in storage · Limited collaboration with other agrifood value chain actors to optimize post-harvest efficiency	· Enhance quality of climate projections and risk assessments targeting impacts on post-harvest activities. · Invest in the development of cold storage facilities or agricultural cooperatives that can support facilities for a region or community where climate risks are most severe. · Support efficient and renewable energy, infrastructure and materials based on technical and economically feasible technologies in each context. · Invest in ICTs for temperature and humidity monitoring. · Capacity development for government to develop climate-resilient infrastructure and technologies · Support the development of communication platforms between storage facilities and producers · Invest in mobile, Internet networks. · Invest in education services - technical training, capacity-building campaigns on the benefits of correct food storage for food safety and security.

Table 7. *(Continued)*

STAGE IN THE AGRIFOOD VALUE CHAIN	CHALLENGES	INVESTMENT NEEDS
Processing and packaging	· Lack of knowledge and training on most appropriate and cost-effective processing and packaging options · Lack of investment in climate-proofed infrastructure, equipment for processing and packaging · Limited collaboration with other value chain actors	· Invest in the development of processing facilities or agricultural cooperatives that can support facilities for a region or community. · Support agricultural cooperatives and NGOs in incorporating climate information into their services for farmers. · Support the development of and research into efficient processing technologies. · Invest in efficient and renewable energy infrastructure. · Support the development of communication platforms between agrifood value chain actors. · Develop business plans for processing value-adding activities. · Invest in education services - technical training, capacity-building campaigns on innovative processing methods.
Transportation	· Limited collaboration with other agrifood value chain actors · Lack of accurate and real-time weather information · Lack of climate information services tailored to the transport of agricultural products · Lack of refrigeration or proper storage capacity in transport vehicles	· Invest in the development of climate services tailored to food transport actors linked to existing climate information in the transport sector. · Enhance food transportation logistics (connection with other transport actors and services). · Develop fresh food corridors. · Enhance early warning systems for the transport sector. · Develop detailed CRAs for road and other infrastructure development. · Increase research and climate projections for infrastructure policy planning. · Invest in up-to-date weather information delivery. · Develop communication platforms between transportation actors and other value chain actors.
Markets, trade and consumption	· Limited collaboration with other agrifood value chain actors · Limited connection between climate, weather and market information · Limited use of research on the impacts of climate on consumer behaviour	· Enhance seasonal advisory combined with domestic and international market information. · Link early warning systems to market information to ensure effective use of services. · Develop communication platforms linked to market information and value chain actors. · Invest in weather-based sales forecasting and price insurance. · Invest in effective weather marketing for markets and consumption. · Assist countries in accessing climate-resilient food certification and standards.

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GLOSSARY

Agrifood system	An agrifood system is characterized by complex social and ecological interactions, as well as the numerous actors and stakeholders involved in value chain activities from the production to consumption of products originating in agriculture, forestry, livestock and fishery systems (FAO, IFAD, UNICEF, WFP and WHO, 2021; Mbow et al. 2019).
Agrifood value chain	An agrifood value chain can be defined as a set of actors and activities involved in bringing an agricultural product from production to final consumption, with value addition at each stage. Agrifood value chains comprise four core functions – production (production and harvest), aggregation (storage and refrigeration), processing (processing and packaging) and distribution (markets, trade and consumption) – with transportation occurring throughout the chain and various, interrelated actors involved at every step (FAO, 2014; Wieben, 2019).
Climate change	Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (FAO, IFAD, UNICEF, WFP and WHO, 2021).
Climate variability	Refers to variations in the mean state and other statistics (standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability) (FAO, IFAD, UNICEF, WFP and WHO, 2021).
Weather extremes	The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (FAO, IFAD, UNICEF, WFP and WHO, 2021).
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2018).
Mitigation	A human intervention to reduce emissions or enhance the sinks of greenhouse gases. In climate policy, mitigation measures are technologies, processes or practices that contribute to mitigation, for example, renewable energy (RE) technologies, waste minimization processes and public transport commuting practices (IPCC, 2018).
Climate resilience	An approach to building and/or strengthening the ability of individuals, households, communities, cities, institutions, systems and societies to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively current or expected climate variability and changing average climate conditions, while maintaining an acceptable level of functioning and without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all (FAO, IFAD, UNICEF, WFP and WHO, 2021).

Climate services	Climate services involve the production, translation, transfer and use of climate knowledge and information in climate-informed decision-making and climate-smart policy and planning. Climate services should be provided in a comprehensive and user-friendly way that enhances early action and risk management capacity in the agriculture, water, energy, health, and disaster risk reduction sectors. Climate services aim to enable targeted actors to base decision-making on strong evidence, supporting adaptation and mitigation of climate change from the short to medium term to the long term by ensuring interventions and investments are informed by climate information (Climate Services Partnership, 2022; WMO, 2021).
Food security	A situation that exists when all people, always have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food-security dimensions can be identified: food availability, economic and physical access to food, food utilization and stability over time. The concept of food security is evolving to recognize the centrality of agency and sustainability (FAO, IFAD, UNICEF, WFP and WHO, 2021).
Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs and balances social, economic and environmental concerns. The 17 global goals for development for all countries established by the United Nations through a participatory process and elaborated in the 2030 Agenda for Sustainable Development, including ending poverty and hunger; ensuring health and well-being, education, gender equality, clean water and energy, and decent work; building and ensuring resilient and sustainable infrastructure, cities and consumption; reducing inequalities; protecting land and water ecosystems; promoting peace, justice and partnerships; and taking urgent action on climate change (IPCC, 2018).

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