REGIONAL DEVELOPMENTS

CLIMATE CHANGE IS A TRULY GLOBAL THREAT, BUT ITS IMPACTS DIFFER AROUND the world. Regions and countries urgently need to identify and implement policy responses that reflect local needs and opportunities. This section examines the effects of climate change on national and regional food systems in Africa, the Middle East and North Africa, Central Asia, South Asia, East and Southeast Asia, and Latin America and the Caribbean. For each major region, promising innovations and policy directions to promote the resilience and sustainability of food systems are considered:

- Scaling up social protection programs in Africa south of the Sahara
- Strengthening the focus on climate adaptation in Africa
- Rethinking water use in the Middle East and North Africa
- Promoting climate-smart practices and crop diversification in Central Asia
- Reforming agricultural support policies in South Asia
- Improving financing for climate change mitigation and adaptation in East and Southeast Asia
- Supporting global food security and sustainability in Latin America and the Caribbean

AFRICA

JEMIMAH NJUKI, SAMUEL BENIN, WIM MARIVOET, JOHN ULIMWENGU, AND CAROLINE MWONGERA

Jemimah Njuki is former director for Africa, **Samuel Benin** is deputy division director, **Wim Marivoet** is a research fellow, and **John Ulimwengu** is a senior research fellow, Africa office, International Food Policy Research Institute. **Caroline Mwongera** is a senior scientist with the Alliance of Bioversity International and CIAT.

Africa's food systems are evolving rapidly, driven by the rise of an African middle class, growing urbanization, shifts in the labor force from farming to nonfarm jobs, and increased availability of digital technologies. As a result, the entire food system is changing, marked by rising food import bills as the gap between Africa's food production and consumption widens, by growing consumer demand for more diverse, higher-quality and safer foods, and by new preferences regarding packaging, shopping outlets, and financial and electronic payment services.[1] Despite growing demand and competition for African farmland, low-input, rainfed production systems with low yields[2] still predominate, and the entire food value chain is led by smallholders and small and medium enterprises (SMEs),[3] with women playing critical roles in the production, processing, retailing, preparation, and waste management of food.[4]

With more than 50 percent of Africa's population depending on rainfed agrifood systems for their livelihoods, the impact of climate change on Africa's food security and other outcomes will be enormous. However, differences across the continent in food systems and their transformation will shape those outcomes. For example, although northern and southern Africa are projected to experience the largest increases in temperature and decreases in rainfall, the negative impact of rising temperatures on GDP is projected to be greatest in western and eastern Africa.[5] For the coastal and island countries, the projected rise in sea levels, leading to coastal degradation and erosion, will compound the other negative effects of climate change.[6] Similarly, other crises such as the recent COVID-19 pandemic and locust and fall armyworm infestations that have exposed the fragility of Africa's food systems have also had different effects across the continent. For example, COVID-19's impact has varied across the continent, with Egypt, Morocco, South Africa, and Tunisia alone accounting for about 68 percent of Africa's reported deaths.[7] And while the locust infestation was concentrated in eastern Africa,[8] the fall armyworm has invaded most of sub-Saharan Africa.[9] In addition, although food insecurity, hunger, and undernourishment have worsened all across Africa, the prevalence of undernourishment, for example, is highest in eastern (28.1 percent) and central (31.8 percent) Africa, and lower in the western (18.7 percent), southern (10.1 percent), and northern (7.1 percent) regions.[10] The COVID-19 pandemic has further exacerbated the situation, resulting in production losses, lower household incomes, and declining nutrition levels among the most vulnerable.[11] As with these other crises, the most vulnerable populations disproportionately bear the burden of climate change, as shown in a recent assessment of the climate resilience of pastoralists and agro-pastoralists in sub-Saharan Africa.[12]

COMMITMENT TO ADAPTATION AND BUILDING RESILIENCE TO CLIMATE CHANGE

Responses to climate change in Africa must focus on adaptation, given the region's vulnerability to impacts in agriculture and throughout its food systems, and the region's relatively small contribution to global greenhouse gas (GHG) emissions.

AFRICAN COMMITMENTS AND PROGRESS

As part of the 2014 Malabo Declaration, African heads of state and governments committed to building a climate-resilient African food system, including preparedness to respond to present and future climate variabilities and shocks, and providing social protection provisions for rural and vulnerable groups.[13] The specific commitments and targets to reach by 2025 are: 1) improving the resilience capacity of at least 30 percent of farmer, pastoral, and fishing households by equipping them to mitigate, adapt to, and recover from shocks and stresses; 2) having 30 percent of agricultural land under sustainable land and water management or climate-smart agriculture practices; and 3) creating investment and an enabling environment for resilience initiatives, especially for disaster preparedness plans, early warning and response systems, social safety nets, and weather-based index insurance.[14]

According to the second biennial review of progress on the Comprehensive Africa Agriculture Development Programme (CAADP), conducted in 2019, 11 African countries (Burundi, Cabo Verde, Ghana, Ethiopia, Mali, Mauritania, Morocco, Rwanda, Seychelles, Tunisia, and Uganda) are on track to meet these commitments,[15,16] up from just 7 countries in 2017.[17] With respect to individual indicators, only 25 countries were on track for households' resilience to climate-related shocks, 12 for share of agricultural land under sustainable management practices, and just 1 for existence of government budget spending lines dedicated to resilience-building initiatives. However, the lack of good quality data hampers accurate assessment of countries' progress. For example, 30 countries lack data on households' climate resilience, and 22 countries lack data on use of sustainable management practices in agriculture.

To meet international commitments, many countries are working to keep their national GHG emissions within the required range through reporting their Nationally Determined Contributions (NDCs) and developing and implementing their National Adaptation Plans (NAPs) in line with the UN Framework Convention for Climate Change (UNFCCC). Fifty-three countries have submitted their first NDCs and are now submitting revised versions.[18] However, integrating these goals with the overall national development priorities of individual countries and the continent will be challenging as the bulk of the NDC targets set by African countries are conditional on external support.

FINANCING FOR ADAPTATION AND RESILIENCE

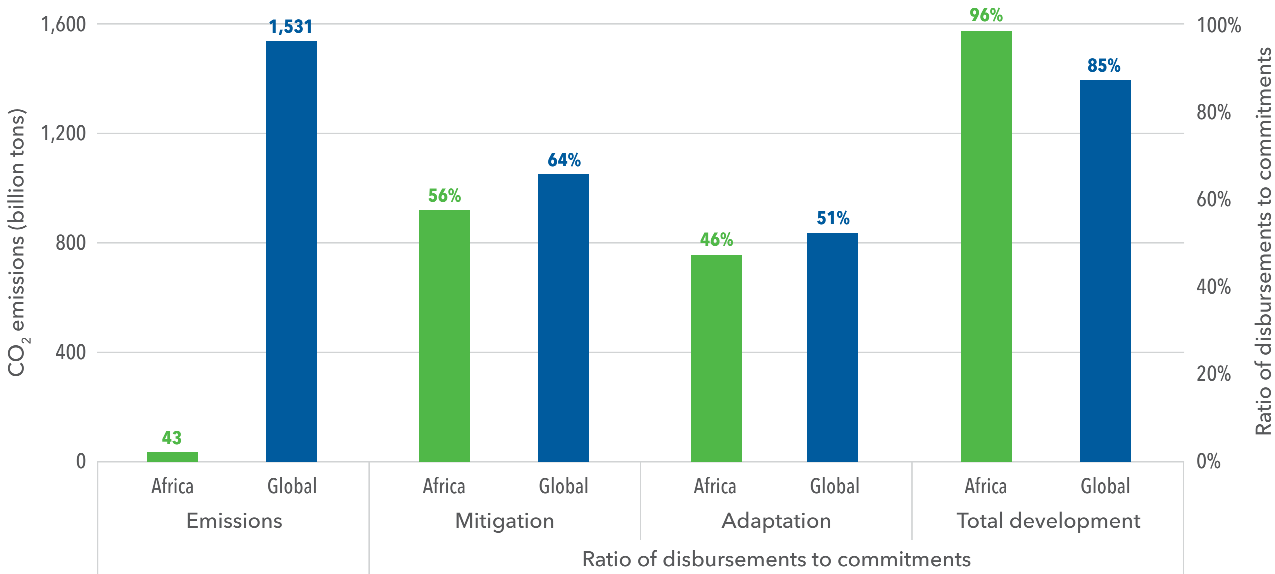
While funding needs for adaptation are large, tracking development finance going to Africa reveals that adaptation funding is only half the amount of the overall mitigation budget, that disbursement ratios are lower for adaptation (46 percent) than for mitigation-related projects (56 percent), and that most adaptation programs offer loans as opposed to grants (Figure 1).[19] Given Africa's relatively low contribution to GHG emissions compared to other global regions (about 3 percent),[20] it seems that the investments in Africa for mitigation are disproportionate relative to its GHG contribution, and that the focus should be on adaptation. Furthermore, although developed countries pledged to mobilize US$100 billion annually to address climate change in developing countries through 2025, that commitment has not been met (see Chapter 5).

Nevertheless, important investments are being made at the country and continental levels. In Kenya, for example, CGIAR is supporting the development and implementation of the Kenya Climate Smart Agriculture Implementation Framework (KCSAIF), with monitoring and evaluation frameworks at the county and subnational levels for measuring progress in increasing agricultural productivity and building the climate change resilience of agrifood systems and value chain actors.[21] At the continental level, the African Development Bank, under the African Financial Alliance on Climate Change, has committed to mobilize $25 billion for low-income African countries. It has also established the Africa NDC Hub to serve as a resource pool for its member countries, with a focus on fostering long-term climate action, mobilizing resources for implementation, and coordinating other NDC-support activities on the continent.[22]

PROMISING INNOVATIONS

Many innovations for building resilience of food systems (discussed in other chapters of this report) hold great promise for Africa, but are largely unproven. These include innovations in agricultural insurance, precision agriculture, renewable energy, and monitoring and evaluation of climate policy. Social

FIGURE 1 African and global CO_2 emissions (1951–2017) and disbursements of public adaptation and mitigation funds (2014–2018)



Source: Based on data from: H. Ritchie, "Who Has Contributed Most to Global CO2 Emissions?" *Our World in Data*, October 1, 2019; G. Savvidou, A. Atteridge, K. Omari-Motsumi, and C.H. Trisos, "Quantifying International Public Finance for Climate Change Adaptation in Africa," *Climate Policy* 21, 8 (2021): 1020-1036. Reproduced with permission of the publisher.

protection, discussed in last year's Global Food Policy Report, must also play a critical role.[23] Availability and increased use of digital technologies and information can potentially help catalyze adoption of all these innovations (see Chapter 12).

Use of agricultural insurance remains low at the continental level, with only 3 to 6 percent of farmers being covered.[24] Since the early 2000s, various index-based agricultural insurance products, seen as more promising than traditional insurance products that rely on actual crop loss assessments, have been tested across the continent. Coverage of these, which ranges from a few hundred farmers in a single country to about 400,000 farmers across multiple countries, depends on the primary company and collaborating organizations, type of commodities covered, and number of products offered, among other things.[25] A major challenge hindering wide implementation of these products is reducing the basis risk, that is, the mismatch between the index triggering the insurance payout and the actual damage experienced by the farmers. Innovations to reduce spatial basis risk involve indexes that use remote-sensing data (such as soil moisture and vegetation) to better proxy rainfed yield,[26] such as index-based livestock insurance that is based on a normalized-difference vegetation index,[27] the Africa Risk Capacity drought insurance that is based on soil water availability, or a water requirements satisfaction index.[28] However, it may be difficult for farmers to understand how such remote-sensing data are correlated with weather variability and thus trigger payouts. Innovations toward this include ACRE-Africa's hybrid index and bundle for comprehensive coverage, which includes both different shocks (drought, storms, pests, and diseases) and different stages from planting to harvest.[29] These combine index-based insurance products with other technologies such as picture-based tools to assess actual damages, or bundle insurance products with credit for climate-smart practices and technologies.[30]

Efforts to address climate change must tap into renewable energy sources to build the resilience of African food systems. Over half of Africa's population has no access to modern electricity services.[31] Lack of access to reliable, affordable, and sustainable energy contributes to food loss and limits the efficient use and growth of food supply chains, which in turn affects food availability and access.[32] Moreover, 78 percent of the population relies on traditional biomass for cooking and heating, with implications not only for climate change but also for women's health and labor.[33] Many African countries have committed to transitioning to green energy which, together with increasing sustainable agricultural practices, is prioritized in more than 70 percent of the African NDCs and NAPs.[34] Several countries including South Africa, Ghana, and Nigeria are investing in electricity grids and off-grid technologies (especially mini-grids) to expand rural electrification and reduce dependence on forest products (see Chapter 9),[35] which has reduced the share of people in sub-Saharan Africa without access to electricity from 69 percent in 2010 to 57 percent in 2018.[36] A key challenge is the low demand for electricity, especially in rural areas, due primarily to poverty as well as unreliability of existing service provision, high costs, and a lack of policy support for clean energy sources.

KEY RECOMMENDATIONS

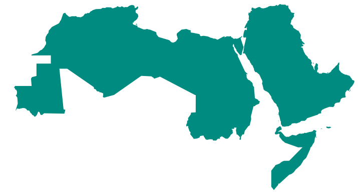
Innovations in Africa should prioritize climate change adaptation, and seek to capture "sweet spots" where adaptations can also deliver co-benefits to mitigation.[37] This includes exploring sustainable intensification as a climate-smart option to build resilience and increase crop yields while also contributing to mitigation through reduction of GHG emissions.[38] In addition, innovations should be seen as immediate and complementary means to accelerate economic recovery and inclusive development more broadly, as defined by national and sectoral masterplans.[39,40] As communities become healthier, wealthier, and more educated, they will be better placed to adapt to the negative consequences of climate change.

LOCALIZE INNOVATIONS. Because of the immense diversity across the continent, innovations that work well in one country or region might not work well in another. Any promising options for transforming African food systems should be locally assessed and based on local projected climate vulnerability and prevailing biophysical and socioeconomic conditions. More contextualized research, data, and information are needed to inform climate change adaptation. Research and analysis should consider the expected impacts on food system components and actors all along value chains.[41] It should support better assessment of trade-offs among competing options, in terms of both effectiveness and cost-efficiency, in meeting climate change goals along with other development goals (see Chapters 11 and 12). Although several platforms, models, and datasets have been developed in this direction, including the meta-dataset Evidence for Resilient Agriculture (ERA),[42] none of these initiatives focus on cost-efficiency at the continental level, which is critical information for resource-constrained African policymakers.

INCREASE AND IMPROVE INVESTMENT FOR RESILIENCE. Taking resilience-building innovations to scale will require increased finance flows to Africa. Public finance and foreign direct investment (FDI) for food systems development and climate change adaptation in Africa must be substantially increased by scaling up both commitments and disbursement ratios, as well as the quality of investments (see Chapter 5). To mobilize more resources that can speed up the implementation of Africa's national adaptation plans, procedures to access climate finance need to be simplified, harmonized, and mainstreamed across donors and funding vehicles.[43,44] Each national government should also involve and empower local and subnational actors and institutions in the design, monitoring, and evaluation of climate change adaptation projects, employing their local expertise.[45] This will require continued efforts to increase the participation, representation, and legitimacy of vulnerable and marginalized groups within national processes to address climate change along with other long-term challenges facing the continent.

While Africa's food systems are evolving rapidly in response to multiple factors, including changing demographics, growing urbanization, shifts in labor supply, and increased availability of digital technologies, more than 50 percent of the population depends on rainfed agrifood systems for their livelihoods. As a result, the impact of climate change on the continent's food security and other outcomes will be enormous. Considering the diversity in food systems and other factors across the continent, how African countries respond to climate change will be critical for food systems. Overall, the focus must be on adaptation and on investing in innovations, such as those in agricultural insurance, precision agriculture, renewable energy, and social protection, that can build the resilience of Africa's food systems.

MIDDLE EAST AND NORTH AFRICA



CLEMENS BREISINGER, AMGAD ELMAHDI, YUMNA KASSIM, AND NICOSTRATO PEREZ

Clemens Breisinger is a senior research fellow and program leader, Development Strategy and Governance Division, International Food Policy Research Institute (IFPRI), Nairobi. **Amgad Elmahdi** is water sector lead, Green Climate Fund, Songdo, Republic of Korea, and former director for MENA, International Water Management Institute (IWMI). **Yumna Kassim** is a senior research associate, Development Strategy and Governance Division, IFPRI, Cairo. **Nicostrato Perez** is a research fellow, Environment and Production Technology Division, IFPRI, Washington, DC.

In many countries of the Middle East and North Africa region (MENA), the COVID-19 pandemic has increased budget deficits, reduced economic growth, and raised poverty and unemployment levels.[1] Ongoing conflicts, political turbulence, and fragility in Sudan, Syria, Yemen, and elsewhere have hindered both the response to the pandemic and long-term economic reform and development processes. The Russian invasion of Ukraine has further exacerbated the recent rise in global food prices and created additional pressure for economies and populations in MENA countries that are net food and fuel importers, such as Morocco, Tunisia, and Egypt. For example, in Egypt and Yemen, wheat and wheat products represent between 35 and 46 percent of caloric intake per person. Egypt is the world's largest importer of wheat, with imports accounting for about 60 percent of total wheat use in the country, and Yemen's cereal import dependence ratio is estimated to be 97 percent. As such, the Russia-Ukraine war poses a serious food security threat for Egypt and threatens to further exacerbate undernourishment and reliance on external assistance in Yemen.[2]

Beyond these immediate crises, climate change, along with water scarcity, poses a short- and long-term challenge for food and water security, sustainability, and development. Climate change and variability threaten to destabilize agricultural production and further reduce water availability and accessibility in the region, with implications for the broader food system. Yields are projected to decline for most crops in MENA, while the global impacts of climate change may lead to substantial increases in consumer prices for the region's major food imports (Table 1). Consumption, nutrition, and food security are all likely to suffer,

TABLE 1 Impact of climate change on food security in MENA region by 2050 (percent change)

Indicators	Cereals	Fruits & Vegetables	Oilseed Crops	Pulses	Roots & Tubers	Meat Products
Yield	-4.18	-1.78	-6.86	-17.20	-0.17	–
Production	-5.67	1.53	0.78	-26.55	9.06	-1.22
Consumer prices	12.84	13.89	20.82	10.56	35.17	8.72
Consumption	-1.93	-2.23	-7.28	0.54	-9.84	-1.24

Source: IMPACT simulations.

Note: Values are percentage changes from a no-climate-change assumption. Climate change scenario is based on HadGEM general circulation model, SSP2 and RCP 8.5. "–" means not significant changes.

putting more people at risk of reduced water availability, hunger, and malnutrition.

In addition to these longer-term impacts of climate change, extreme climate events such as droughts, floods, and storms are already becoming more frequent and intense, costing lives and millions of dollars in lost revenue and damages.[3] In Egypt, for example, the costs of climate change impacts to the agriculture sector alone are estimated at US$1.84 billion per year over the next 30 years.[4] For the region as a whole, GDP could shrink by 6–14 percent by 2050 due to climate change and water scarcity.[5]

Conflicts over water are expected to become more frequent and severe with climate change, as rising temperatures and more volatile rainfall reduce water quality and quantity. Notably, about 60 percent of the region's water resources are transboundary water bodies, with every country sharing at least an aquifer with a neighboring country.[6] Increased competition over this scarce resource will be compounded by rapid population growth, economic development, and conflict-related migration in several MENA countries.[7] In addition, sea-level rise, coastal degradation, and water variability driven by climate change will threaten the viability of low-lying areas (particularly the Nile Delta in Egypt), harbors, and other critical food system infrastructure, and will potentially lead to loss of fertile land, social disruption, displacement, and migration.[8]

IMPLEMENTING "SHOVEL-READY" POLICIES, REFORMS, AND INNOVATIONS

To turn these threats into opportunities for development, existing "shovel-ready" policies and investments for climate change adaptation and mitigation need to be implemented by public institutions and the private sector, working in tandem, and capacities need to be built to adapt interventions to local contexts.

To mitigate the impacts of the war in Ukraine and address the vulnerabilities arising from high and increasing food import dependency, MENA countries should diversify their food import sources, utilize the potential for agricultural production remaining amid water shortages and climate change, endeavor to reduce food waste, diversify diets away from imported cereals toward locally grown staples, and increase the use of targeted cash transfers for the poor.

PARADIGM SHIFT ON WATER MANAGEMENT. A shift in approaches to water use that embraces the need to conserve water resources and develop new water sources has the potential to increase resilience to climate change. Better demand management — including greater water conservation, water efficiency, and water re-use and recycling — can reduce pressure on water supplies. This shift can also promote the use of new water supply sources, such as rainwater and desalinated water. Innovative pricing mechanisms, such as those established in Morocco and Tunisia for cost recovery for water, would allow the region's agricultural water sector to become financially sustainable and to meet its maintenance and operational costs while also promoting more efficient water use by end-users. In addition, these water pricing policies can deliver on financial goals (achieving full-cost recovery), social goals (ensuring access for all), and environmental goals (incentivizing sustainable use). Knowledge building, including data on existing water and uses, hydrology of regional water flows, and ecosystem services, as well as engagement with communities and the private sector for knowledge sharing can support these changes. Projects to promote water-saving technologies and improve irrigation management, such as those implemented in Jordan and Egypt, often benefit from co-designed interventions that involve partnerships among all key private and public market players rather than targeting end-users directly.[9] At the farm level, a number of technologies and services can improve water management and resilience.

INVESTING IN PROMISING FARM TECHNOLOGIES AND SERVICES. Investments in R&D and scaling-up of promising technologies should foremost include those focused on greater efficiency of water use, including irrigation and water management technologies. Solar photovoltaic water pumping stations along with water-saving drip irrigation kits can help to increase resilience of irrigated systems, reduce operational and maintenance costs, increase yields, and promote crop diversification.[10] Moreover, judicious use of groundwater and/or treated wastewater could reclaim and transform desert lands for agricultural use, which could further boost agriculture's resilience to climate change.

Mobile phone applications can provide farmers with geo-specific information customized to their plots, weather conditions, and crop types. These apps can make irrigation recommendations based on the crop type, irrigation system, farm size, planting time, types of water pumps, energy sources, and soil type (Figure 1). The IRWI APP, for delta areas in Egypt, and LARI-LEB, for Bekka Valley in Lebanon, have reduced the time and amount of irrigation by 30 percent on average.[11] Other promising technologies include improved seeds, greenhouses, hydroponics, optimized fertilizer application, improved groundwater management, and digital agricultural tools and services, particularly for extension and market performance (see Chapter 12).[12]

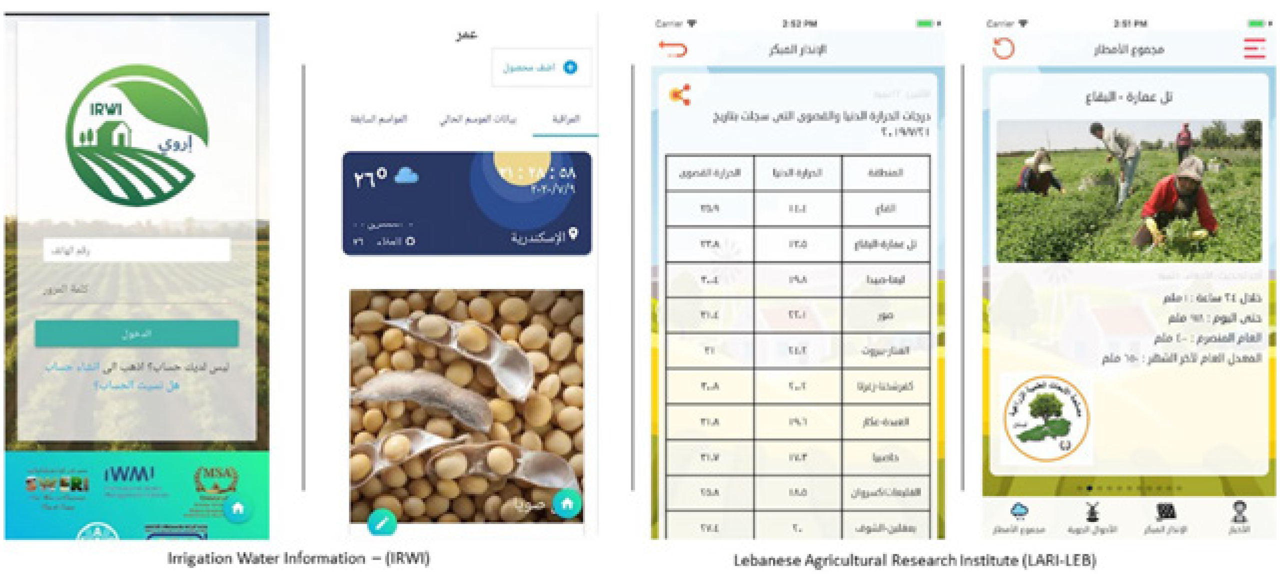
CREATING AN ENABLING ENVIRONMENT FOR CLIMATE-FRIENDLY FOOD SYSTEMS

Adopting these policy and technology changes will require an enabling environment of coherent policies, incentives, investments, and capacity building across all food system sectors. Creating an enabling business environment, fostering climate-smart trade, and expanding international cooperation will help MENA to meet country-level 2030 development agendas and international goals, including the UN Sustainable Development Goals.

ENABLING BUSINESS ENVIRONMENTS. More business-friendly environments with clear regulatory and enforcement frameworks will support all food system actors and make domestic markets more competitive. Examples include investments in food system infrastructure, promotion of food quality standards, frameworks to stimulate more efficient water use in the agriculture sector, disincentives for food and water waste, and encouragement of more sustainable practices. When combined with targeted, sector-specific public investments and social safety nets, macroeconomic and fiscal policies that phase out unsustainable energy and fertilizer subsidies and incentivize climate-smart investments have proven successful in countries like Egypt.[13] The private sector can help close the financial gap through public–private partnerships. These partnerships are new and rapidly evolving tools for funding in MENA, from the agro-industrial sector to food trade. In fragile and post-conflict areas, such as Iraq, public–private partnerships may also offer a strategy to resume construction, maintenance, and operation of abandoned projects.[14]

CLIMATE-SMART TRADE. Climate-smart trade policies and openness to trade will be critical for MENA, even though some policymakers may be inclined to promote self-sufficiency goals as a result of

FIGURE 1 Mobile applications that support agricultural production



Source: IRWI App (Irrigation Water Information Application) and LARI-LEB App (Lebanese Agricultural Research Institute).

the Russia-Ukraine war and related uncertainties around wheat imports. But net food imports are likely to further increase due to rising demand and limited potential for domestic wheat production. Vulnerabilities to production shocks from climate change and extreme climate events, as well as prolonged health emergencies and pandemics, are also likely to grow. Export crops will remain important as a source of income and foreign exchange, particularly where MENA countries have a comparative advantage, as in fruits and vegetables. Rather than focusing on unrealistic self-sufficiency goals for wheat, efforts to phase out water-intensive crops could facilitate further specialization in high-value agricultural products while addressing countries' food security concerns. Incentives to promote trade in "virtual water" — that is, water embodied in crops — could expand regional production of less water-intensive, more heat-tolerant, and high-value export crops like fruits and vegetables and increase imports of water-intensive crops like rice and wheat, with positive impacts on sustainability and resilience amid climate change.

INTERNATIONAL COOPERATION. Regional and international cooperation in climate change adaptation efforts can also improve production, lower food prices, and facilitate the import of strategic crops or food items.[15] Areas for cooperation may include R&D, financing, trade, technologies, innovations, digitalization, and management support, as well as capacity building. Regional collaboration and cooperation are also essential for conflict-resolution and problem-solving around water resource management. For example, the establishment of water allocation mechanisms where water resources are shared across borders can support more sustainable water use and reduce conflict.

LESSONS FROM OTHER SHOCKS FOR CLIMATE CHANGE

The pandemic and the invasion of Ukraine, in addition to imminent threats from climate change–induced extreme weather events, have clearly shown MENA countries that a well-functioning, resilient food system is critical and that "climate-proofing" the regional food system must be a priority. In several MENA countries, the negative impacts of COVID-19 were cushioned by keeping domestic and international food markets open; diversifying food imports; ensuring that food producers, traders, and retailers could operate within sensible enabling environments (including soft and hard institutions); and providing safety nets for the most vulnerable. These responses will also be crucial to dealing with the impacts from the war in Ukraine. Some of the same principles — coupled with a push to "green" MENA economies and investment in a new water paradigm, as well as tools and technologies for more sustainable agriculture — could support adaption to climate change and pave the way for greater prosperity.

CENTRAL ASIA

KAMILJON AKRAMOV, KAHRAMON DJUMABOEV, AND ROMAN ROMASHKIN

Kamiljon Akramov is a senior research fellow, Development Strategy and Governance Division, International Food Policy Research Institute, Washington, DC. **Kahramon Djumaboev** is a researcher in Water Management, International Water Management Institute, Central Asia Regional Office, Tashkent. **Roman Romashkin** is deputy director of the Eurasian Center for Food Security at Lomonosov Moscow State University, Moscow.

Increasing evidence shows that shifts in Central Asia's climate are already occurring at an accelerating rate, and the region's aridity is expected to increase, with consequences for agricultural production.[1] While this warming trend applies to all areas and seasons, regional and seasonal trends vary. Lowland areas have seen a greater warming trend than mid-altitude and upland regions. The average annual temperature in Tajikistan, where mountains cover 93 percent of the land area, has increased by 0.3°C–1.2°C since the 1950s. In contrast, in Turkmenistan, where 80 percent of the land area is flat desert, the average annual temperature increased by 1.1°C–2.4°C during the same period.[2] In Uzbekistan, the average minimum temperature rose by 2.0°C and average maximum temperatures by 1.6°C between 1950 and 2013. The warming was steepest in spring (0.39°C per decade) and more modest in winter (0.13°C per decade).[3] In contrast, Kazakhstan has seen the sharpest rise in winter temperatures (0.35°C per decade), with less warming in summer months (0.18°C per decade).[4] Unlike the clear warming trends, precipitation changes have shown no clear trend, with significant variations observed across the region.

The frequency and intensity of extreme climate events, notably heatwaves, droughts, and dust storms, have increased during recent decades throughout Central Asia. The probability of heatwaves is expected to rise further, especially in Tajikistan, Turkmenistan, and Uzbekistan, and Central Asia's arid climate and steadily high summer temperatures make the region particularly susceptible to drought.[5]

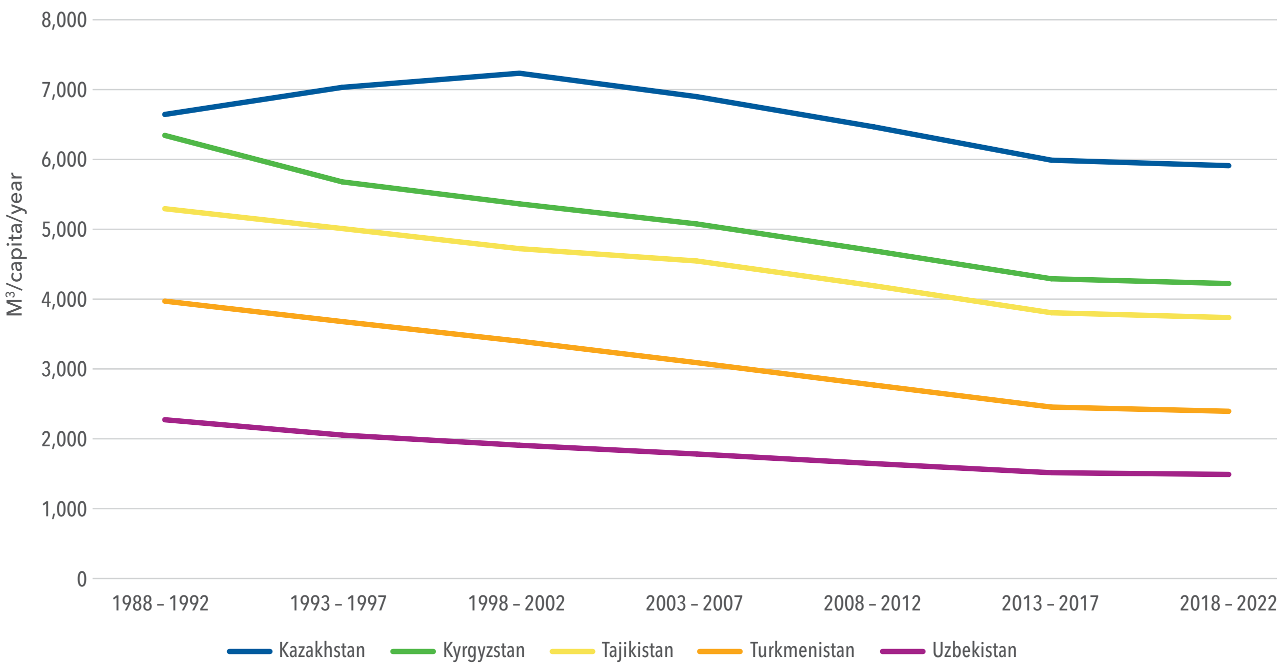
CLIMATE CHANGE IMPACTS ON FOOD SYSTEMS

Climate change is already affecting food systems in Central Asia. Rising temperatures and extreme climate events have contributed to reductions in land and soil quality, availability of water resources for irrigation and human use, and crop yields. Land degradation is a major challenge, resulting from the combination of rising temperatures and aridity, unsustainable agricultural and irrigation practices, and overgrazing of pastureland.[6] About a quarter of the population of both Kazakhstan and Uzbekistan already live on degraded land.[7] Moreover, with increased probability of drought, the region is vulnerable to dryland expansion and desertification. These impacts have high costs. Land degradation reduces agricultural incomes by lowering crop yields and livestock productivity and by necessitating increased input use.[8] The annual cost of land degradation in Central Asia between 2001 and 2009 has been estimated at about US$5.85 billion, equivalent to 3 percent of GDP in Kazakhstan and Uzbekistan, 4 percent of GDP in Turkmenistan, and 10–11 percent of GDP in Kyrgyzstan and Tajikistan.[9]

Renewable water resources in Central Asia are limited. These resources, including critical seasonal runoff (meltwater), will be affected by a combination of changes in precipitation, increasing glacier melt, earlier snowmelt, and higher evapotranspiration that will aggravate regional water shortages and reduce water available for irrigation in the summer months.[10] Already as a result of rising temperatures, nearly a third of the glacial area in the Tien Shan and Pamir mountains has disappeared since 1930.[11]

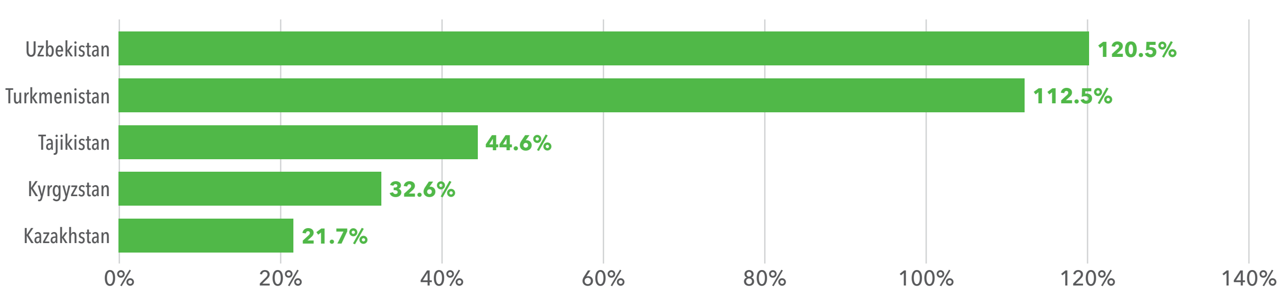
Water scarcity can be physical (lack of water of sufficient quality) or economic (lack of adequate infrastructure plus technological and institutional constraints).[12] Currently, only Uzbekistan is considered physically water-stressed, with water availability averaging just 1,505 m^3 per capita per year.[13] Turkmenistan also has relatively low renewable water resources per capita (2,407 m^3 per year). However, over the past three decades, all Central Asian countries have experienced a steady decrease in the per capita availability of renewable water resources due to the rising population (Figure 1). Turkmenistan and Uzbekistan are severely water-scarce countries in economic terms, with withdrawal levels for available renewable water resources reaching more than 100 percent[14]; Kyrgyzstan and Tajikistan, which withdraw 33 and 45 percent of their renewable water resources, respectively, are considered water-stressed countries (Figure 2). Most of the region is expected to face a significant increase in water stress[15] due to climate change.[16] This is a major concern for the sustainability of Central Asia's agrifood systems, as irrigation is essential for agriculture in most of the region, and

FIGURE 1 Total renewable water resources per capita, Central Asia, 1988–2022



Source: FAO Aquastat 2021.

FIGURE 2 Proportion of renewable water resources withdrawn, Central Asia, 2018–2020



Source: FAO Aquastat 2022.

Note: Abundant water resources = up to 25%; Water stressed = 25% to 60%; Water scarcity = 60% to 75%; Severe water scarcity = above 75%.

competition for water is increasing, leading to intra-regional conflicts.

Increased aridity and water stress levels, together with the greater frequency of extreme weather events, have already caused sizable declines in the region's crop yields. For example, crop yields in Tajikistan dropped by 30–40 percent in 2000/01 and again in 2007/08 as result of droughts. Combined with the global food crisis, this has led to more than 2 million people being undernourished.[17] Nevertheless, Central Asian countries achieved significant progress in reducing child malnutrition during the past two decades. Child stunting rates in Kazakhstan declined from 17.7 percent in 2000 to 6.7 percent in 2020, in Kyrgyzstan from 29.9 percent to 11.4 percent, in Tajikistan from 41.6 percent to 15.3 percent, and in Uzbekistan from 29.5 percent to 9.9 percent.[18] However, the risk of malnutrition in the region is likely to increase, especially among children and other vulnerable groups, as the adverse effects of climate change may become a significant challenge for agriculture, especially for crop yields. In addition to indirect effects related to land degradation, water availability, and extreme weather events, climate change affects crop yields directly through changes in precipitation, temperatures, and carbon dioxide availability. Projections from IFPRI's IMPACT and DSSAT models show that Kazakhstan will experience modest losses in cereal yields but significant losses in potato yields in the period up to 2050, while Tajikistan and Uzbekistan will likely face higher yield losses for major crops.[19] The projections for Tajikistan indicate that adverse effects of climate change may lead to a significantly higher (4.6 percent) number of malnourished children than there would be without climate change.[20]

POLICY RESPONSES

Policy responses to climate change have been limited in Central Asia until recently. Climate policies predominantly aim to reduce the adverse effects of weather extremes and focus on production of staple crops rather than building resilience.[21] However, at least two potential interventions could support adaptation.

CROP DIVERSIFICATION

Agricultural crop diversification is a potentially feasible and cost-effective means to increase the resilience of Central Asia's agricultural systems. Greater crop diversity can improve resilience by reducing threats from pest outbreaks and pathogens (which are expected to worsen under climate change) and buffering crop production from the effects of growing climate variability and extreme weather events. The production structures and economic incentives adopted in the 1990s encouraged the production of just a few crops. Together with the belief that specialized agricultural systems are more productive than diversified systems, these policies have hindered past attempts to promote diversification.[22] As a result, reforms that support agricultural diversification have only recently emerged in Central Asia. The region's governments have now begun to adopt crop diversification policies, with support from major bilateral and multilateral development partners.[23] For example, the governments of Uzbekistan and Tajikistan are encouraging farmers to grow horticultural crops, and the Kazakh government is encouraging farmers to allocate more land to oilseed crops.

Crop diversification can be implemented in various forms and at a variety of scales, allowing farmers to choose a context-appropriate strategy that both increases resilience and provides economic benefits. For example, the cultivation of more winter crops may provide good market opportunities for farmers. However, efforts may be needed to promote the adoption of these crops, including providing information to farmers and ensuring availability and access to seeds, fertilizers, and plant protection products. Another potential opportunity, arising as a result of climate change, is the shift of farming to some areas that were previously too cold for optimal farming of summer crops.[24]

WATER-SAVING TECHNOLOGIES

Implementation of climate-smart agricultural (CSA) technologies — such as conservation technologies, water-saving irrigation technologies, drought-resistant crops, and climate-resilient varieties — remains limited despite their potential benefits. Of these, water-efficient technologies are critical, given the vital role of irrigation for agricultural production in Central

Asia. Such technologies, including drip irrigation, sprinklers, and smartsticks, can support adaptation to climate change and boost productivity, contributing to improvements in farmers' livelihoods and food security.[25] However, high initial and maintenance costs for this equipment and lack of necessary technical capacity are major constraints to large-scale implementation in the region.

In this regard, a significant policy shift recently took place in Uzbekistan, where in 2020 the government adopted a program that redirects subsidies from the energy sector to support water-saving technologies. The evidence suggests that improved irrigation practices, such as drip irrigation, can save approximately 30 percent of the water used compared to traditional irrigation practices.[26] These technologies would also reduce energy use and carbon emissions and improve crop yields in pump irrigated areas. Research by the International Water Management Institute (IWMI) in the Karshi region of Uzbekistan has shown that optimized irrigation could save half a trillion liters of water, spare 259 gigawatt-hours of electricity, and cut 122,000 tons of CO2 emissions.[27] Considering that the irrigation sector accounts for about 21 percent of total electricity use in Uzbekistan, the adoption of water-saving technologies should lead to significant energy and water savings. This could be a promising path forward for other countries in Central Asia, where, overall, 18 percent of irrigated areas are under pump irrigation, covering about 2.84 million hectares.[28]

LOOKING FORWARD: OBSTACLES AND LESSONS

Demand for nutritious food in Central Asia is rising as a result of population and income growth.[29] At the same time, the food supply faces significant constraints due to increasing land degradation and water scarcity. While policies that encourage water-saving technologies and crop diversification can help mitigate these problems in the short and medium term, additional innovations are needed.

First, digital technologies (such as precision agriculture, weather-station-based irrigation advisory systems, and unified digital market platforms) enabled by internet and mobile phone connectivity could help farmers efficiently and sustainably use limited land and water resources, improve decision-making, better manage risks and variability, and enhance efficiency (see Chapter 12).[30] However, Central Asia lacks the necessary infrastructure for a digital transformation of the food system, a problem that has been highlighted by the COVID-19 pandemic.[31] Regional governments need to invest in digital connectivity infrastructure and encourage public–private partnerships to accelerate the digital transformation of the agrifood sector.

Second, regional policy coordination is needed, given that Central Asian countries share common water and other essential resources for agriculture. Poor coordination of policies has been a serious obstacle. For example, during the pandemic, some national governments moved to impose export restrictions, which led to higher food prices and exacerbated food insecurity issues already worsened by the crisis. Moreover, Central Asia historically has a complicated relationship with water, and the "water tensions" between upstream (Kyrgyzstan and Tajikistan) and downstream (Kazakhstan, Turkmenistan, and Uzbekistan) countries are well known.[32] This underscores the importance of policy coordination and transboundary water cooperation across the region to make the agrifood system inclusive and resilient to climate-change-related shocks. In this regard, regional intergovernmental bodies such as the International Fund for Saving the Aral Sea (IFAS) and the Interstate Commission for Water Coordination (ICWC) need to improve their efficiency and promote evidence-based decision-making.

Finally, one of the biggest challenges in Central Asia is the lack of reliable data on climate change and food systems, including land, labor, and water productivity, as well as the costs and benefits of water-saving technologies. This problem is compounded by inadequate analytical capacity in the region. Developing a robust and comprehensive framework on how climate change will impact the region and its consequences for water and food security and nutrition will require innovative data solutions.

SOUTH ASIA

ADITI MUKHERJI, AVINASH KISHORE, AND SHAHIDUR RASHID

Aditi Mukherji is a principal researcher, International Water Management Institute (IWMI), New Delhi. **Avinash Kishore** is a research fellow, South Asia office, International Food Policy Research Institute (IFPRI), New Delhi, and **Shahidur Rashid** is director for South Asia, IFPRI, New Delhi.

South Asia is a climate change hotspot, with many climate-induced risks compounded by significant existing vulnerabilities. All available indicators – glacier melt in the Himalayas, sea-level rise, extreme weather events, precipitation patterns, and the frequency of natural hazards turning into disasters – have worsened since 1950. Rapid economic growth in recent decades, which is expected to continue, will likely exacerbate these alarming trends, and the high economic costs of climate change in the region are projected to increase further.

Policy actions vary across countries, but all governments in the region have signed the Paris Agreement on climate change. However, all South Asian countries are lagging in undertaking some critical actions[1] that would directly contribute to both climate change adaptation and mitigation in the region, and COVID-19 has led to a significant reduction in climate-related investments.[2]

In South Asia, as in much of the developing world, total greenhouse gas (GHG) emissions have been rising since the 1990s.[3] Agriculture is both a major source of emissions and the sector most affected by climate change. Globally, agriculture and associated land use and land-use change activities account for roughly a quarter of all GHG emissions. Three-quarters of these emissions can be attributed to developing countries, and South Asia is a major contributor. With these broad trends in mind, this chapter focuses on 1) observed and projected climate impact drivers (also called climate hazards) that are driving climate change and its societal impacts, 2) observed and projected impacts on agrifood systems, and 3) policy solutions that can be implemented in the near term to adapt to and mitigate climate change in the region.

CLIMATE CHANGE IN SOUTH ASIA

Anthropogenic GHG emissions, including CO_2 and other GHGs, have already caused a temperature rise of about 1.1°C globally.[4] In South Asia, hot extremes (both the frequency and intensity of daily maximum temperatures), heavy precipitation events, and other climate shocks have increased since 1950. These changes are expected to accelerate with every increment of global temperature increase.[5] South Asia's pre-existing vulnerabilities – high levels of poverty, governance challenges, and limited access to basic services and resources – amplify the region's climate risks, with potentially devastating effects if warming continues at this pace.[6]

MEAN AND EXTREME TEMPERATURES HAVE RISEN AND ARE PROJECTED TO RISE FURTHER. The temperature rise in South Asia over the past century is well documented, and the projections are dire. However, temperatures have not risen evenly across the region. For example, while the average temperature rise was 0.7°C between 1901 and 2018, a larger increase was observed over the Himalayas (1.3°C). In Bangladesh, average annual temperatures have increased in the last six decades, with warming accelerating from 2001 onward.[7] South Asia has experienced a lower-than-global-average temperature rise mainly due to the cooling effect of aerosols, including short-lived climate pollutants, which have their own negative health and agricultural consequences.[8] For the region as a whole, annual mean temperatures are projected to increase by between 1.2°C and 4.3°C (under low- and high-emissions scenarios) by the end of the century.[9] The average temperature across India is projected to rise by between 2.4°C and 4.4°C by 2100.[10] Similarly, summer heat waves are projected to triple or quadruple by 2100 in India,[11] and increase at the rate of 0.71 days per decade in Pakistan.[12]

HIMALAYAN GLACIERS ARE MELTING AT UNPRECEDENTED RATES. These glaciers, which are an important source of the region's rivers, have lost more mass since 2000 than in the entire 20th century.[13] With temperature rise over the Hindu Kush Himalayas in the northwestern area of South Asia potentially reaching around 6°C under high emissions scenarios, glaciers could lose up to two-thirds of their volume by 2100, with severe consequences for people living in downstream river basins — including reduced water availability for agriculture, hydropower, and domestic use.[14] Melting of Himalayan glaciers also affects vulnerable mountain populations upstream who directly depend on glacier meltwater for their livelihoods. Projected intensification of monsoon precipitation is expected to increase annual river flows, but seasonal flows reduced by lower baseflow due to early melting will affect both irrigation and hydropower generation, while extreme precipitation events are likely to make flood events more intense and impactful.

WARMING-INDUCED INCREASE IN MONSOON RAINFALL. Mean precipitation in South Asia has increased since the 1950s due to higher GHG emissions, although the cooling effect of aerosols has kept the rate of precipitation increase below the global average.[15] Both low and high extremes have increased, especially since the 1980s, with more frequent dry spells and more intense wet spells.[16] Notably in India, summer monsoon precipitation has shown declining trends over the last few decades, with larger decreases over the main breadbasket region of the Indo-Gangetic belt;[17] and in Bangladesh, a decline in precipitation of about 84 mm per decade was observed from 1981 to 2010.[18] Projections show increases in both mean and extreme precipitation for the entire region by the end of this century, with some variation across countries, ranging from about a 17 percent increase in mean precipitation in Bangladesh to more than 27 percent in India under a high emissions scenario.[19] Studies also project that extreme precipitation events will be 1.7 times more likely in Bangladesh by 2050 than they are now.[20]

CLIMATE HAZARDS ARE PROJECTED TO WORSEN. Over 750 million people in South Asia are currently exposed to climate hazards, primarily floods and droughts.[21] In India, reduced summer monsoon rainfall has increased the frequency and spatial extent of droughts from the 1950s onward.[22] Similarly, in Pakistan, the intensity and severity of droughts have increased over the last century.[23] Greater incidence of localized extreme precipitation events has increased flood risks in India, and projections show increases in flood intensity and occurrence in the Indus, Ganges, and Brahmaputra River basins.[24] On the other hand, the tropical cyclones over the Northern Indian Ocean region have become less common, although very severe cyclonic storms have become more frequent in the post-monsoon season.

Event attribution studies are relatively rare in South Asia and remain an important knowledge gap. The 2017 Bangladesh flood is one rare case. In 2017, flash floods damaged about 220,000 hectares of nearly harvestable *boro* paddy in Bangladesh. Several attribution studies show that anthropogenic climate change increased the likelihood of the extreme rainfall events that led to this flood.[25]

OBSERVED AND PROJECTED IMPACTS ON AGRIFOOD SYSTEMS

The impacts of climate change on South Asia's agrifood systems include decreases in yields, depleted natural resources, and associated income losses. Globally, total factor productivity (TFP, a measure of technological innovation and efficiency in production) in agriculture has fallen by about 21 percent since 1961 due to climate change, and warmer areas like South Asia have seen the largest declines.[26] At the same time, the likelihood of climate shocks affecting crops including wheat, soybeans, and maize increased in most global breadbaskets, and especially in South Asia.[27] Increased water demand for agriculture is draining aquifers and could worsen food and nutrition insecurity in the region. Negative impacts on agricultural GDP and trade outcomes have also been projected at higher levels of warming.

DECLINING YIELDS IN ALL MAJOR AGRICULTURAL SUBSECTORS WILL CONTINUE. The unprecedented suite of climatic changes has caused crop yield declines and production losses in the region, with a few exceptions for certain crops and subregions. For instance, in Bangladesh, temperature and rainfall explain 12 percent of crop production variability,[28] and rising temperatures are linked to decreasing wheat yields.[29] However, productivity of some crops has benefited from temperature and humidity trends, notably rainy season paddy (*aus* and *aman*), though not irrigated *boro* paddy. In Pakistan, declines in rice and wheat yields are observed with climate change, although the use of heat-tolerant varieties has provided some resilience and forestalled greater impacts.[30] In the country's mountainous Khyber Pakhtunkhwa region, however, increased average precipitation improved crop yields between 1985 and 2016.[31]

In India, agricultural production data (1967–2016) for several crops show that average land productivity decreases as average temperatures increase,[32] and this impact accelerates at higher levels of warming. Projections show yields of India's crops falling by 1.8 to 6.6 percent by mid-century (2041–2060) and by 7.2 to 23.6 percent by end-century (2061–2080) under a middle-of-the-road scenario for climate change.[33] Yield losses are projected to be higher in rainfed conditions,[34] and yield losses in wheat and maize are projected to be higher than yield losses in rice. In Nepal, flood-induced damages to the area under paddy are already significant and projected to rise further, reaching 50 percent by the end of the century under a scenario with little emissions mitigation.[35]

In India and Bangladesh, subsistence fisheries provide up to 60 percent of animal protein in people's diets,[36] but increasing salinity intrusions in inland aquaculture ponds have resulted in fish mortalities.[37] Globally, fisheries productivity is projected to fall in tropical and subtropical regions like South Asia.[38]

GROUNDWATER DEPLETION IS ACCELERATING RAPIDLY. South Asia accounts for a quarter of global groundwater use. Groundwater extraction for agriculture contributes to food security, livelihood support, and poverty alleviation.[39] Yet groundwater depletion — at rates exceeding 2 cm per year in the Indo-Gangetic aquifer[40] — is straining the limits of these resources, leading to lower agricultural production and loss of related benefits,[41] including effects on the adaptive capacity of communities.[42] Episodic recharge during extreme rainfall events has been recorded in India's semi-arid tropics,[43] but the future impact of climate change on groundwater recharge is uncertain.

EXISTING VULNERABILITIES TO FOOD AND NUTRITION SECURITY WILL GROW. The impacts of climate change in South Asia, compounded by the impacts of COVID-19, will make it very difficult for the region to achieve the goal of zero hunger (SDG2) by 2030.[44] Climate change shocks have direct and long-term impacts on food and nutrition security. For example, a district-level analysis from India concluded that the odds of children suffering from stunting, wasting, and being underweight or anemic increases by 30 to 60 percent in districts with high climate vulnerability compared to districts with low vulnerability.[45]

A global study that accounts for extreme weather events estimates that, by 2050, the number of people at risk from hunger will increase by 11 to 20 percent, with South Asia (along with sub-Saharan Africa) at greatest risk, and estimates that South Asia will need three times its current food reserves to offset the impacts of such events.[46] Similarly, an earlier study estimated that food shortages caused by climate change could lead to a significant increase in the number of malnourished children in South Asia.[47] In Bangladesh, near-term projections estimate a reduction of up to 17 percent in total calorie consumption by 2030 due to climate change.[48]

NEGATIVE IMPACTS ON AGRICULTURAL GDP AND TRADE ARE PROJECTED. Climate change is projected to reduce agricultural GDP through declining crop yields, and increase consumer prices, with greater losses associated with higher warming levels. For example, the Pakistan floods of 2010 caused economic losses of US$4.5 billion,[49] while the losses caused by the 2014 drought in India are estimated at $30 billion.[50] Floods in Bangladesh in 2017 caused a 30 percent year-on-year rise in paddy prices. Economic projections for Bangladesh for the short term estimate a modest decline of 0.11 percent of GDP by 2030, and a 1.23 percent fall in agricultural GDP.[51] Another study projects loss of ecosystem services as a result of climate change in the range of $18 to 20 million by 2050 in Bangladesh under low- and high-emissions scenarios.[52]

Water scarcity is also projected to worsen with climate change. Of the world's five basins where water scarcity–led GDP losses are projected to be highest, three (Indus, Sabarmati, and Ganges-Brahmaputra) are in South Asia. In the Indus Basin alone, GDP losses are expected to exceed $5,000 billion by 2100.[53]

Negative impacts on agricultural trade are also projected. In Pakistan, empirical results show a decline in agricultural export trade (1975–2017) attributable to climate change.[54] Moreover, recent evidence suggests that the welfare losses caused by decreases in food production, increases in food prices, and decreases in food consumption cannot be adequately compensated through trade and fiscal policies.

AGRICULTURAL GHG EMISSIONS

In South Asia, GHG emissions from agriculture are largely attributable to 1) methane emissions from rice cultivation, 2) application of urea, 3) animal husbandry, 4) burning of crop residues, and 5) use of fossil energy for irrigation.[55] These practices are supported by government policies that promote their continued use. Some of the most productive and intensively cultivated areas, like the Punjab and Haryana regions in the northwest and Bangladesh and West Bengal in the east, are locked into rice–wheat or rice–rice monocropping by policies. Both state and national governments provide incentives for farmers to produce these staples through public procurement, price guarantees, preferential provision of subsidized inputs, and disproportionately large investments in the development of improved varieties of these two crops (see Chapter 2, Box 2). The use of urea, a major emitter of nitrous oxide, is heavily subsidized across the region, especially in irrigated areas, resulting in its widespread overuse. South Asia has the world's largest livestock population, which is another major methane source, particularly the region's large bovine population. India alone is home to 30 percent of the total global bovine population. Moreover, the share of animal products in the total value of regional agricultural output is rising; in fact, the livestock sector is benefiting from its relative resilience to drought. In addition, subsidized or free fossil-fuel-based electricity is used for pumping water in large areas of India and Pakistan and parts of northwest Bangladesh, making groundwater irrigation both unsustainable and carbon intensive (see Chapter 9). Currently, more than 260 km³ of groundwater are extracted every year, largely using fossil fuels.[56]

ADAPTATION AND MITIGATION ACTIONS

Some proven strategies can make agriculture more resilient to climate change *and* mitigate GHG emissions from food production, including changes in practices and crops, and most importantly in South Asia, reforming agricultural policies that promote unsustainable, GHG-intensive practices.

TECHNOLOGIES AND CROP DIVERSIFICATION

IRRIGATION AND SOIL MOISTURE CONSERVATION are perhaps the most widely used and most effective adaptive strategies at the farm level for building resilience to droughts, dry spells, and high degree days. However, increases in water requirements for crops and the demand for irrigation in a warming world may worsen water scarcity.[57] Rationalization of electricity subsidies and use of grid-connected solar pumps can support increased use of irrigation while reducing GHG emissions. In India, for example, solar irrigation pumps could reduce the country's CO_2 emissions from agriculture by 8–11 percent.

DIVERSIFICATION TO CROPS more resilient to higher temperatures (such as maize) and moisture stress (coarse cereals, legumes) and allied activities (animal husbandry, poultry, and fisheries) can also support farm-level adaptation. Switching from rice to other crops in the water-scarce northwest and peninsular India will reduce GHG emissions, save scarce water and energy used for irrigation, and reduce crop residue burning. Moreover, the area under rice could be reduced in the region without threatening food security.[58]

AGRICULTURAL MECHANIZATION is reducing farmers' reliance on cattle for draught power and allowing animal husbandry to specialize in milk and meat production, thus leading to a gradual reduction in the cattle population while increasing its economic value. However, in India, recent changes in government policies may have slowed the reduction of unproductive cattle.

POLICY REFORMS

Rationalizing food, fuel, and fertilizer policies can support both adaptation to climate change and mitigation of GHG emissions. Switching to crop-neutral food policies, including allocation of resources for R&D and other input and output subsidies, can help reduce

GHG emissions from food production and make agriculture more resilient to climate change. Four major reforms are worth considering.

INCREASE INVESTMENT IN R&D. Countries in South Asia underinvest in agricultural R&D. As of 2009, the region invested $0.21 to $0.40 in agricultural research for every $100 of agricultural output, well below the $0.61 invested by sub-Saharan African countries and $1.14 by Latin American and Caribbean countries.[59] Governments in the region should increase budget allocations for agricultural research and direct a larger share of this budget to non-cereal crops and allied sectors (livestock and fisheries), given their rising share in agricultural GDP (see Chapter 4).

REFORM FERTILIZER SUBSIDIES. Lowering the subsidy on urea could help reduce emissions of nitrous oxide. Urea is heavily subsidized in all large South Asian countries, and its excessive application is common. Governments hesitate to decontrol the price of urea, fearing strident opposition from farmers.[60] For example, when implementing its nutrient-based subsidy in 2010, India's government partially decontrolled the prices of other fertilizers but left the subsidy for urea untouched. A sharp increase in the price of urea may be politically unfeasible, but a gradual reduction in the subsidy may be possible. India used this strategy successfully to phase out its diesel fuel subsidy. Switching to non-distortionary direct cash transfers for fertilizer subsidies is another option that South Asian governments have tried or are seriously considering.[61] However, successful implementation of a direct cash transfer system requires significant investments in data and monitoring systems.[62]

REFORM ENERGY POLICIES. Electricity use for irrigation is heavily subsidized or free in India, resulting in wasteful use of energy and water and high GHG emissions. Proposals to raise electricity rates are deemed politically unviable, but governments are exploring other ways to reduce use of grid electricity for irrigation. One such scheme in India, PM-KUSUM, aims to convert a million irrigation pumps to solar power, which will decarbonize groundwater irrigation. Connecting this solar power production to the electricity grid will allow farmers to use the power to irrigate their land and/or sell it to the electricity company at a pre-fixed price. This option may create incentive for farmers to use less water and energy for crops.[63] Pilot tests of business models for implementing direct benefit transfers to subsidize electricity for irrigation — which in essence pay farmers for saving energy — are also being tried in some Indian states, including Gujarat, Karnataka, Punjab, and Rajasthan.[64] India's government proposed switching to a direct transfer subsidy in the 2021 Electricity Amendments Bill, but dropped this option in response to strong objections from farmers and other stakeholders. The rollback suggests that such reforms should be undertaken by the state governments, which are responsible for distribution and supply of power to rural and urban consumers.

REFORM AGRICULTURAL SUPPORT. Guaranteed prices for two main cereals (rice and wheat) in much of South Asia have led to overproduction of these crops and disincentivized crop diversification. Given high methane emissions from paddy, rolling back the output price subsidy could help reduce GHG emissions from agriculture. However, resistance from the special interest groups that benefit from these policies may hamper reform efforts. In one reform effort, the state government in Haryana, India, is offering a cash incentive of INR 7,000 (US$92) per acre to farmers who replace paddy with crops like maize and pulses in water-scarce areas, but the impact of this incentive scheme has not yet been assessed.

Climate change presents immediate and long-term challenges for South Asia. Glacier melt, sea-level rise, groundwater depletion, extreme weather events, and frequency of natural hazards are evident and likely to worsen in the coming decades. Solutions to these challenges are complex, encompassing human activities in all sectors of the economy at the country, regional, and global levels. But policy actions within agriculture can be taken now to support adaptation and mitigation. Governments in the region can undertake several critical actions, including scaling up climate-smart technologies, crop diversification, and elimination of policy incentives that encourage unsustainable use of water, fossil fuels, fertilizers, and land resources. The political economy of such reforms will be difficult, as is evident from recent farmer protests in India, but the cost of inaction for future generations would be too high.

EAST AND SOUTHEAST ASIA

KEVIN CHEN AND YUE ZHAN

Kevin Chen is a senior research fellow, International Food Policy Research Institute (IFPRI), Beijing, and a chair professor, Zhejiang University, Hangzhou, China. **Yue Zhan** is a research analyst, IFPRI, Beijing.

The East and Southeast Asia region is among the most vulnerable to natural hazards and climate change, due to the high concentration of population and economic activity along its extensive coastlines and its heavy reliance on agriculture and other natural resources to providing livelihoods and income.[1] Economies in the region are slowly diversifying away from agriculture and other natural resource-based activities, but most countries still depend substantially on these sectors. Agriculture is the largest economic sector for Cambodia and Lao PDR,[2] and remains one of the top five sectors across the region (with the exceptions of Singapore and Brunei). Thus, East and Southeast Asian countries, and especially the agriculture-dependent communities within them, will suffer climate change impacts, including threats to the region's food security. Moreover, because the region is a major contributor to global grain exports, most notably rice, the impacts of climate change in East and Southeast Asia will also affect food security globally.

CLIMATE CHANGE IMPACTS AND CHALLENGES

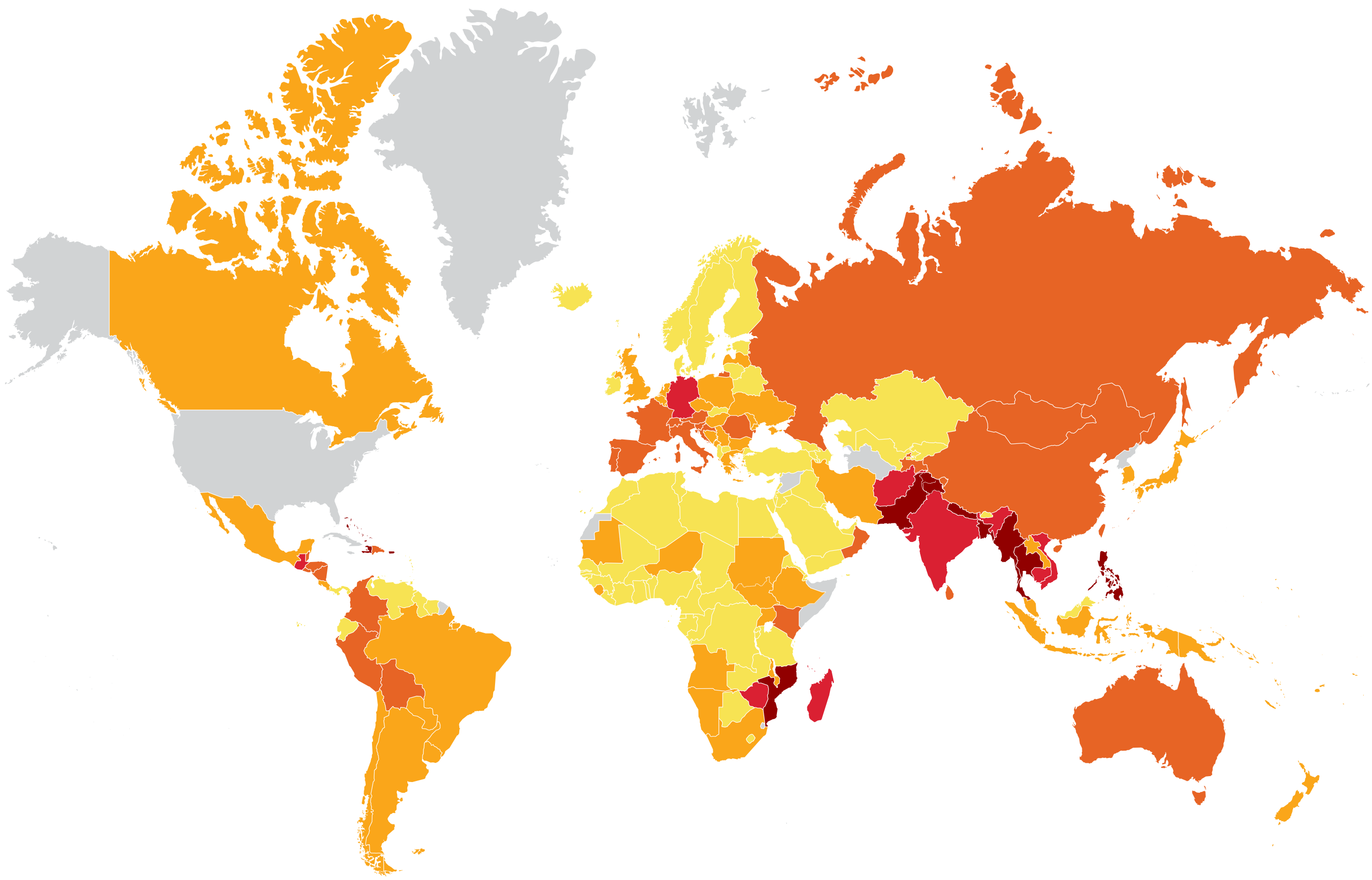
On the production side, East and Southeast Asia are already experiencing growing intensity and frequency of extreme weather events, including droughts, floods, typhoons, and heatwaves, as well as sea level rise, that are causing significant economic, environmental, and social damage.[3] The Global Climate Risk Index ranked Myanmar, Philippines, Bangladesh, and Thailand among the top 10 countries globally most affected by extreme weather events (Figure 1), and overuse of chemical inputs and water also endanger long-term sustainability of agriculture in the region. These impacts threaten the region's role as a major producer of grain and industrial crops (of which the most important are rubber, palm oil, and sugarcane), with many countries projected to experience a relative decline in agricultural productivity as climate change progresses (compared to a scenario with no climate change).[4]

On the consumption side, rising household incomes and urbanization have shifted food preferences from cereals toward animal products. Animal-source foods require more resource-intensive production and produce more greenhouse gas (GHG) emissions than plant-based products. Beef generates the most GHG emissions per kilocalorie consumed and has the largest water footprint. However, high average consumption of rice in the region also leads to significant GHG emissions and water use per capita from rice production.[5] This has important implications for land and water use, as well as for climate change.

Projections from IFPRI's IMPACT model indicate that with climate change, average calorie consumption in the region in 2050, compared with a no–climate change scenario, will be about 3 percent lower and cereal consumption 5 percent lower. In a no–climate change scenario, the number of people at risk of hunger in the region is projected to fall from 268 to 92 million between 2000 and 2050. Climate change will reduce this progress, and the number of people at risk of hunger will only fall to 105 million in 2050 under a middle-of-the-road scenario, leaving 13 million more people at risk of hunger than the no–climate change scenario.

The region's agriculture sector will have to adapt and adjust to climate change impacts over the medium and longer term; it will also have to contribute to climate change mitigation. Globally, agriculture currently generates 19–29 percent of total greenhouse gas (GHG) emissions.[6] Emissions from agriculture

FIGURE 1 Map of the Global Climate Risk Index 2000 – 2019



Source: Germanwatch, *Global Climate Risk Index 2021* (Bonn: Germanwatch, 2021). www.germanwatch.org/en/cri.

have been highest in Asia over the past 30 years. In 2019, the equivalent of 4.1 billion metric tons of CO_2 was produced on agricultural lands in Asia. Among the regions, South Asia and East Asia have the highest agricultural production-related emissions, followed by Southeast Asia.[7] These emissions are mainly from deforestation, livestock production, and soil and nutrient management.[8] Therefore, allied to the pressure created by climate change is the need to better manage the region's natural resources and find ways to produce food sustainably. Curbing emissions in the region is critical to advancing the global climate change agenda, and the agriculture sector must play a role.

POLICIES AND RESPONSES

REGIONAL AND NATIONAL STRATEGIES

Countries in the region have made substantial progress in recognizing climate change issues in their planning processes, either by explicitly mentioning these issues or identifying means to address them in their development plans, as identified in various official communications, including the National Communications, Nationally Determined Contributions, Adaptation Plans, and Adaptation Strategies. The People's Republic of China (PRC), Japan, and the Republic of Korea have announced the ambitious target of carbon neutrality by mid-century. Common climate change priorities for agriculture and natural resources are found in East and Southeast

Asian countries: increasing forest cover is a specified target for Cambodia, Lao PDR, Malaysia, and Myanmar. Sustainable forest management is among commonly prioritized activities in the region, which is a major deforestation hotspot due to logging and clear-cutting for food production, cash crops, and other agriculture.[9] The promotion of climate-resilient agriculture and farming systems (irrigation, cultivation, crop rotation, livestock/pasture management) are also priorities.[10] At the regional level, under the broad umbrella of ASEAN regional cooperation on climate change adaptation, several activities have been implemented, including capacity building workshops, information exchange workshops, forums, and implementation of specific projects. An expansion of regional cooperation from ASEAN countries to countries outside ASEAN will provide opportunities to enhance adaptation actions in the region.

CLIMATE CHANGE ADAPTATION PRACTICES

The region has a demonstrated commitment to climate-smart agriculture (CSA) to support adaptation.[11] The most common adaptation techniques in the region are changes in cropping patterns and cropping calendars and improved farm management, for example, a switch from rice–rice to rice–maize cropping patterns and use of drought-resistant and heat-resilient varieties.[12] Climate-smart technology is also an active area of research and implementation in the region. Countries that have made progress in climate change risk assessments, adaptation planning, and CSA are well placed to share this expertise. For example, the International Rice Research Institute (IRRI) has developed the Rice Crop Manager (RCM), a web-based smartphone application currently deployed in many parts of the Philippines and Viet Nam.[13] The RCM app enables agricultural extension staff to support sustainable productivity gains for poor rice farmers through cost-effective crop management.

Starting in 2015, the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) began scaling up CSA practices using the climate-smart village approach in Southeast Asia, bringing tailored CSA interventions to target communities through continuous participatory research and evaluation. With the efforts of various partners, the initial 7 climate-smart villages have grown to 90. Based on this experience in Cambodia, Lao PDR, Myanmar, the Philippines, and Viet Nam, the pathways for scaling up can be followed through knowledge transfer, policy incidence, and commercialization.[14]

CLIMATE CHANGE MITIGATION PRACTICES

Adaptation can make a substantial contribution to reducing the damages expected from climate change, but would not be sufficient on its own. Mitigation practices can generate significant synergies with adaptation by improving ecosystem functioning, increasing water availability, and improving resilience to drought, pests, and other threats. A range of existing technologies and management actions could be deployed now, including improved crop and grazing land management; site-specific nutrient management based on crop needs; restoration of degraded lands and soils; livestock management; manure and bio-solid management; and sustainable and bio-energy use.[15] Progress in implementing these practices in the region has been slow and efforts are needed to accelerate their adoption. Projections for China suggest that the combination of improving agricultural technologies, reducing food loss and waste, and shifting dietary patterns could reduce GHG emissions from the food system by 47 percent as of 2060.[16] Therefore, to address climate change, a comprehensive emissions reduction strategy should be formulated for the whole agrifood system — from farm to consumer.

FINANCING CLIMATE CHANGE MITIGATION AND ADAPTATION

New ways of financing climate change adaptation and mitigation must be found. Estimates of financing needs for the region vary widely, reflecting the uncertainties associated with potential climate change scenarios and their likely impact. However, emerging estimates of the additional investment needed indicate a financial gap of hundreds of billions of dollars every year for several decades to come (see Chapters 2 and 5).[17]

Financial support to smallholder farmers is required to address the multiyear gap between investments and financial benefits if they are to adopt climate-smart practices. In particular, transition financing involving the use of loans wherein repayment terms are pushed back to accommodate multiyear return gaps should be considered (see Chapter 9). Access to transition funds would help farmers to cover upfront costs for seed and new equipment that farmers face when adopting climate-smart practices.

Where upfront costs are not entailed, farmers can benefit from payment schemes for environmental services. Governments can create incentives through public payments (or charges) to private resource users for the enhancement (or degradation) of ecosystem services.[18] For example, payment for environmental services (PES) can be designed to compensate resource managers for the maintenance or restoration of environmental services such as clean water. China has conducted numerous national, provincial, and local experiments over the past decade with different forms of eco-compensation, focused primarily on water resources management.

LOOKING FORWARD

With climate change expected to put downward pressure on yield growth of many crops, the role of agricultural research and development (R&D) and innovation systems will become increasingly important for agricultural development. For East and Southeast Asian countries, compared with other countries at a similar level of development, there appears to be significant scope to increase investments in R&D and innovation systems to help safeguard future levels of productivity growth and to mitigate some of the expected effects of climate change.[19]

For some countries, reform of distorting trade policies and agricultural input and output price support policies is needed (see Chapters 2 and 3). For example, in the Philippines, support policies for rice work against incentives for adaptation and can increase producers' exposure to climate risks.[20] Similarly, for the region as a whole, current trade distortions and war-fueled reemergence of food inflation have the potential to magnify the global price effects from climate change.

LATIN AMERICA AND THE CARIBBEAN

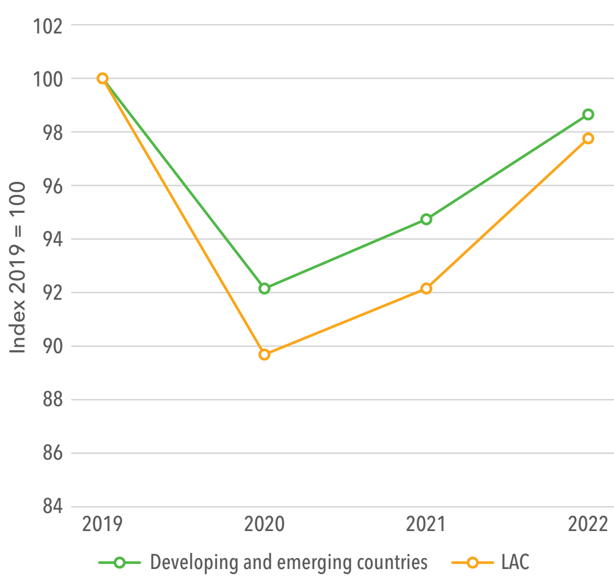
EUGENIO DÍAZ-BONILLA, CAROLINA NAVARRETE-FRIAS, AND VALERIA PIÑEIRO

Eugenio Díaz-Bonilla is a special advisor, Inter-American Institute for Cooperation on Agriculture, and senior visiting research fellow, International Food Policy Research Institute (IFPRI), Washington, DC. **Carolina Navarrete-Frias** is a senior advisor on Environmental Policy and Biodiversity, Alliance of Bioversity and CIAT, Cali. **Valeria Piñeiro** is a senior research coordinator, Markets, Trade, and Institutions Division, IFPRI, Washington, DC.

Food systems in Latin America and the Caribbean (LAC) play a vital role in the region's economies, in global food security, and in the global response to climate change. They operate, however, within a region that has suffered from economic stagnation in recent years. While LAC enjoyed annual growth of 2.1 percent in per capita incomes between 2000 and 2011 as the commodity cycle was trending upward (even with the 2008–2009 global crisis), when the cycle turned downward, per capita growth fell to a meager 0.2 percent per year until 2019. The region's economies experienced the worst eight years since the 1980s, and the stagnation affected political stability in LAC.[1] Then COVID-19 hit. Despite having only about 8 percent of the world's population, the region recorded more than 30 percent of global COVID-related deaths. Several factors have made LAC particularly vulnerable to the pandemic, including its high level of urbanization, significant income inequality (which also limits access to high-quality health services), informality of labor markets, prevalence of obesity, and the ongoing economic stagnation.[2]

In 2020, due to the pandemic, LAC experienced the deepest economic recession among developing regions, and recovery is expected to be slow (Figure 1). Governments in LAC countries reacted to the pandemic with lockdowns and various health initiatives, while also increasing economic and social interventions to mitigate the negative impacts of lost income and employment. Most countries have suffered significant health and economic setbacks, despite implementing diverse policies in regard to movement restrictions and the allocation of public funding.[3] Human capital has been affected by the interruption in education; nutritional problems associated with insufficient and less healthy diets; and the strain on job skills and abilities due to long unemployment periods. Currently, much is still unknown about the dynamics of the pandemic, both in LAC and globally, but COVID-19 appears likely to become an endemic condition with long-term implications for societies, economies, and human health.

FIGURE 1 GDP per capita



Source: Based on data from International Monetary Fund (IMF), *World Economic Outlook*, October 2021.

In the very short term, it is necessary to increase vaccination coverage, reinforce prevention policies, and strengthen access to and provision of health-care in LAC. As of mid-October 2021, large disparities in vaccination rates existed in the region (Figure 2). Vaccination coverage in some countries is above the average for developed nations, while in others, vaccination rates are below those of lower-income developing countries.

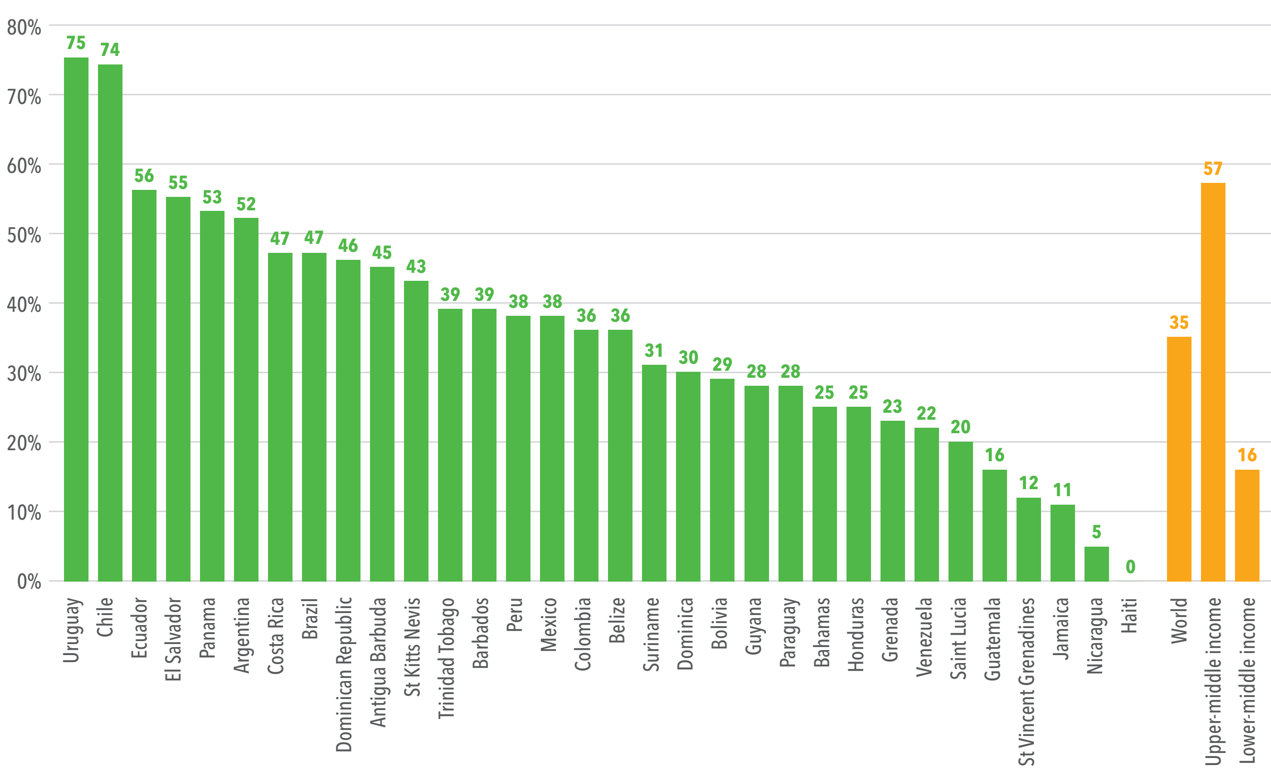
For the longer term, LAC countries, like all developing countries, require integrated recovery programs that are coordinated at the highest governmental level. These are needed to alleviate the economic and human costs of the pandemic and to contend with preexisting economic and social problems, while also tackling the current and future challenges of climate change.

These programs will require strong support from the international community, including debt restructuring and write-offs, and from multilateral development banks operating in the region (see Chapter 5). The Special Drawing Rights (SDRs) recently allocated by the International Monetary Fund will need to be used more creatively to set up a trust fund that guarantees the issuance of bonds to finance pandemic recovery programs and a climate-positive transformation of economies, including food systems.[4]

LAC'S ROLE IN GLOBAL FOOD SECURITY AND SUSTAINABILITY

Agrifood systems in the LAC region are crucial to food security at both the national and global levels. LAC is the world's largest *net* food- and agriculture-exporting region (exceeding the combined value of the United States, Canada, Australia, and New Zealand), making it pivotal to global food security. The region is also critical to global environmental sustainability and biodiversity: it holds about 36 percent of the CO_2eq stock kept in all forests worldwide and more than a third of the total global volume of renewable water resources. Of the world's top ten most biodiverse countries,

FIGURE 2 Population fully vaccinated in LAC countries, compared to global rates of vaccination



Source: Compiled from Our World in Data (https://ourworldindata.org/covid-vaccinations).

six are located in the region, including the two most biodiverse countries.[5] The LAC region also contains about 23 percent of the world's forested areas. Environmental and biodiversity functions are closely interlinked with forest cover and ecosystem integrity. However, deforestation continues to increase, with the region's forested area declining from 1.07 billion hectares in the early 1990s to 932 million hectares in 2020.[6] Deforestation has led to increases in greenhouse gas emissions, and reduced positive contributions to the oxygen and water cycle, carbon sequestration, and the preservation of biodiversity.[7]

Several international agreements and partnerships aim to reduce deforestation and forest degradation. Policy implementation research could inform choices and guide the development of solutions for the underlying problems of forest governance. However, the success of these efforts depends on the integration of lessons learned from implementing previous international conventions, forest laws, and other environmental policies.[8] The Glasgow Leaders' Declaration on Forests and Land Use [9] represents a new opportunity to reverse current trends; this declaration was signed by 141 countries, including Brazil and most LAC countries with large forested areas. Changes in overall incentives (such as through adequate pricing of carbon) and supportive financing will also be necessary (see Chapter 5).

Two key priorities of the 2030 Agenda for Sustainable Development are preserving the planet and providing food that is sufficient, safe, affordable, and nutritious. These priorities are not easily reconciled, however.[10] In addition to the LAC region's dual roles for global food security and environmental sustainability, agrifood systems are very important for individual countries' economic development, poverty alleviation, food security, population retention, and crime reduction, particularly in rural areas. Achieving these multiple goals will require major efforts to scale up innovations and investments in the intensification of sustainable agriculture and to transform food systems to make them carbon neutral.

OVERVIEW OF INNOVATIONS, POLICY OPTIONS, AND OBSTACLES[11]

LAC countries have long been experimenting with different innovations and policy approaches, in many cases with support from CGIAR centers. Here we focus on the most recent ones.

CLIMATE-SMART AGRICULTURE TECHNOLOGIES. The most promising climate-smart agriculture (CSA) technology clusters in the region include intercropping, green manures/cover crops, organic inputs, silvopasture, conservation agriculture, mulching, improved pastures, stress-tolerant crops, and adequate management of grazing, fertilizer, and water use. Local strategies are key to tailoring CSA innovations to farmers' needs, including preserving or improving genetic diversity to strengthen resilience and applying alternate wetting and drying (AWD) for water-use efficiency and emissions reductions. Those innovations generate co-benefits and "multiple wins" that are key to strengthening resilience and attaining global goals such as the Sustainable Development Goals and the Paris Agreement on mitigation and adaptation. As these technology clusters are scaled up, context-specific opportunities and limitations within LAC must be considered.

WATER QUALITY AND EFFICIENCY. The development of water-smart strategies requires addressing information gaps on water quality and sources of contamination, as well as implementing policies to address sources of water pollution in the long term. Innovations in water-efficient irrigation infrastructure, drip irrigation, and supportive policies are crucial, given that agriculture uses 70 percent of water in LAC and many farmers still depend on rainfed systems.

RESTORATION OF DEGRADED LANDSCAPES. LAC has large degraded landscape areas with low agricultural productivity. Restoring these degraded landscapes presents an opportunity to enhance habitat connectivity, protect biodiversity, and increase ecosystem services, while also fostering community-based activities and supporting livelihoods through sustainable business models.

SUSTAINABLE LIVESTOCK SYSTEMS. LAC produces approximately 26 percent of the world's bovine meat and exports nearly 20 percent of its own production, representing about 28 percent of global bovine meat exports (average 2015–2019).[12] The livestock sector is an important source of employment in the region, particularly for small farmers,[13] but it poses environmental challenges. To address these issues, the LAC region is pursuing various innovations to increase profitability, reduce emissions, and limit land degradation and land use conversion, including silvopastoral systems of varying intensity, site-specific agriculture for pastures (which adjusts practices and inputs to specific locations), and plot division and rotational grazing.

BIODIVERSITY IN AGRICULTURAL LANDSCAPES. Agroecological knowledge must be incorporated into agricultural practices to reduce pests and disease, mitigate climate change, promote crop pollination, and restore soils, landscapes, and ecosystem services. These goals align with the priorities set by the UN's Post-2020 Global Biodiversity Framework. Agroecological approaches can be combined with other production applications to advance the technology frontier and offer flexibility in the selection of the appropriate mix of technologies.

ANCESTRAL PRACTICES. LAC benefits from ancestral knowledge that could be combined with CSA practices to strengthen resilience to climate change. This traditional knowledge includes bio-indicators for predicting climate variability, wild genetic diversity (such as potato landraces in Peru), and platforms, terraces, canals, and ponds that can conserve soil and retain water. Furthermore, the strong social base of local communities can support governance mechanisms to reduce land use change.

INSTITUTIONAL INNOVATIONS. The promotion and scaling up of technological solutions will require strong and sound institutions, cross-sector coordination, and appropriate policies. The region's Local Technical Agroclimatic Committees (LTAC) are one example of a relevant institutional innovation in Latin America. These committees, which are set up by governments in close collaboration with local actors, help smallholder farmers to prepare for climate change. LTACs develop local and regional forecasts showing potential effects on crops, and they introduce ways to reduce vulnerability and negative impacts (such as alternative dates for sowing and irrigation). These committees are now present in Chile, Colombia, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, and Peru. LTACs can identify and promote bundles of technologies and services that are appropriate to local conditions and needs, and share these through South–South technical exchanges to strengthen the management of climate risk at a regional level.

DIGITAL AGRICULTURE FOR CLIMATE ACTION. In LAC, investments in digital agricultural technology are still low.[14] CSA strategies should make use of the digitalization of agriculture to innovate with agroclimatic services and virtual roundtables for farmers and entrepreneurs; promote knowledge-sharing, data-driven agronomy, and digital extension through the internet of things; and employ simulation modeling and peer-to-peer learning (see Chapter 12).

BARRIERS TO CSA ADOPTION AND POSSIBLE SOLUTIONS. Common barriers to CSA adoption include limited access to training and information and to credit and markets, limited availability of required inputs (such as improved seeds), and high costs of equipment (such as irrigation facilities). Furthermore, the global crisis driven by the pandemic and, more recently, the conflict in Ukraine is increasing inflation in LAC and causing key agricultural inputs, such as fertilizers, to become scarce and expensive. Measures to counter the effects of these crises include lowering trade tariffs for agricultural inputs and producing alternative inputs on site (such as compost). Other solutions include further expanding LTACs, designing country-based CSA investment plans, and promoting financial alternatives for scaling up CSA best practices. The LAC region has great potential to implement practices that increase carbon sequestration (using appropriate soil and vegetation maps), leverage carbon markets and credits, and take advantage of COP26 agreements on the operationalization of these tools.

BUILDING BACK BETTER

Countries in the LAC region have been experimenting with and scaling up a variety of innovations, in many cases with support from CGIAR centers. These innovations relate to modern crop and livestock production and management techniques, promote low-emissions agricultural practices and technologies, strengthen national research organizations to deliver more nutritious and climate-resilient varieties, use local knowledge and practices, expand climate information services, and experiment with new finance partnerships. The private sector, including small and medium enterprises and entrepreneurs, could play a bigger role in promoting the adoption of environmentally friendly technologies, and private-public partnerships could help support the availability and financing of these technologies as well as the monitoring of policy schemes with environmental objectives (for example, through certification and accountability).

LAC is still suffering from the crisis caused by the pandemic and compounded recently by the war in Ukraine, which may affect its key role for both global food security and environmental sustainability. Countries in the region need to develop and effectively implement comprehensive public programs to "build back better" from the pandemic and transform food systems, with a strong application of science, technology, and innovation, while taking advantage of ancestral knowledge. All this will require significant financing and support from international stakeholders, as well as financial and political commitment from the governments in LAC (see Chapter 5). Failure to do so will not only affect the region, but the whole world.